MASTER

HEDL-SA-2426

CONF-811040--115

RADIATION SHIELDING ISSUES ON THE FMIT

R. J. Burke, A. A. Davis,
S. Huang, R. J. Morford

May 1981

Ninth Symposium on Engineering Problems
of Fusion Research, Chicago, Illinois,
October 26-29, 1981.

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company, a subsidiary of
Westinghouse Electric Corporation, under the Department of
Energy Contract No. DE-AC14-76FF02170
P.O. Box 1970, Richland, Washington 99352

MGW

DISCLAIMER

RADIATION SHIELDING ISSUES ON THE FMIT

R. J. Burke, A. A. Davis, R. J. Morford
Hanford Engineering Development Laboratory
P.O. Box 1970
Richland, WA 99352

S. T. Huang
Ralph M. Parsons Co.,
100 W. Walnut St.
Pasadena, CA 91124

Summary

The Fusion Materials Irradiation Test Facility (FMIT) is being built to study neutron radiation effects in candidate fusion reactor materials. The FMIT will yield high fluence data in a fusion-like neutron radiation environment produced by the interaction of a 0.1A, 35 MeV deuteron beam with a flowing lithium target. The design of the facility as a whole is driven by a high availability requirement. The variety of radiation environments in the facility requires the use of diverse and extensive shielding. Shielding design throughout the FMIT must accommodate the need for maintenance and operations access while providing adequate personnel and equipment protection.

Introduction

The FMIT will provide the first opportunity to investigate the effect of fusion reactor-like neutron bombardment on material properties. To perform the desired accelerated testing of materials, both high neutron flux and high fluence must be provided. A high flux of $\geq 1.4 \times 10^{15}$ n/cm^2-sec will be available in at least 10 cm^3, with $\geq 2.2 \times 10^{14}$ n/cm^2-sec in at least 500 cm^3. High fluence will only be achieved if facility availability is kept as high as possible. Availability of the FMIT will be at least 65% over a design service life of 20 years.

Because of this availability goal, reliability and maintainability of equipment are major considerations. Radiation tolerance or ease of relacement are criteria governing equipment selection. A facility design goal is the performance of hands-on maintenance wherever possible to minimize the need for costly, time-consuming remote maintenance. Radiation shielding on the FMIT must both protect personnel and equipment operations and facilitate hands-on and remote maintenance and operations.

Experimental System

The experimental system consists of the test cell that will contain the neutron flux and the test assemblies, and the service cell where remote assembly and disassembly of test assemblies and other test cell equipment will be carried out.

Test Cell

The most extreme radiation environment in the FMIT will be the neutron environment in the test cell. The deuteron-lithium interaction will produce a neutron flux with an energy spectrum broadly peaked at 14 MeV, the energy of neutrons from the D-T fusion reaction. However, the spectrum also includes a significant number of neutrons with energies up to 30 MeV, and a high energy tail extending up to 50 MeV.

The higher energy neutrons from 30 to 50 MeV significantly impact the test cell shielding design due to their penetrating properties. Extensive shielding calculations, using primarily Monte Carlo techniques, have been made to ensure adequate shield design.[1] The neutron flux will be highly anisotropic, with a rapid spectral variation with angle. The neutron flux at the test cell backwall opposite the neutron source will be as high as 1.7×10^{12} n/cm^2-sec, with a maximum neutron energy of $\sim$ 50 MeV. The flux at the sidewalls will be as high as 1.4×10^{11} n/cm^2-sec with a maximum neutron energy of $\sim$ 45 MeV. In contrast, the maximum neutron flux at the front wall, through which the deuteron beam will be transported to the target, will be on the order of 10^{11} n/cm^2-sec but with a maximum energy of $\sim$ 30 MeV.

Because of the anisotropy of the neutron source, the bulk shielding of the test cell will be asymmetric. The backwall will be constructed of approximately 20 ft. of ordinary concrete. Approximately 11 ft. of ordinary concrete suffices for the sidewalls. The front wall thickness is restricted by the need for crane access on the accelerator side of the wall to service accelerator components. Therefore, high density concrete will be used in that region to reduce front wall thickness to less than 4 ft. The use of large thicknesses of relatively inexpensive ordinary concrete for most of the test cell shielding is made possible by the absence of space limitations except in the front wall area.

Thermal shielding will line the interior of the test cell to prevent over-heating of the concrete bulk shielding. Heat deposition in the bulk walls by the neutron flux would result in damage to the concrete which could impair its performance as shielding and structural support. The thermal shield panels will be composed of steel and graphite, with channels for the flow of gaseous nitrogen coolant. The shield panels lining the back wall will be the thickest due to the high neutron flux there. Interfaces between the test cell and the accelerator vault, lithium equipment vault, and service cell are designed to minimize neutron streaming into areas adjacent to the test cell. The interfacing components will provide shielding equivalent to the test cell bulk walls.

All access to the test cell will be remote due to the high activation level in the cell. Access will be by means of a pair of master-slave manipulators operated from the test cell support area outside the south sidewall and by the service cell crane. Both these methods will require that the test cell sliding top plug be open for access since the manipulators enter the test cell through the edge of the top plug cavity.

Service Cell

The service cell interfaces with the test cell through the sliding top plug. The vast majority of service cell operations are carried out remotely with master-slave manipulators and the service cell crane. However, triennial manned access to the cell is planned in order to perform hands-on preventive maintenance. Therefore, activation levels in the service cell must be kept low and remote decontamination capabilities must be provided to permit this infrequent personnel entry.

Numerous penetrations are required through the test cell top plug for test assemblies and instrumentation. To limit neutron streaming from the test cell into the service cell; the plugs will be doubly stepped; service channels through the assemblies will be packed with low-Z shielding material; and neutron shield collars will be placed around the top of each assembly to block the gap between the assembly and the penetration liner.

The service cell will be a unique hot cell in that it will have a neutron, as well as a gamma, environment. Neutrons which enter the service cell during beam-on periods will activate service cell equipment. Equipment thus activated and activated test cell equipment present in the service cell will be sources of gamma radiation. Shielded storage areas will be provided in the service cell for storage of activated equipment prior to manned entry.

The dual radiation environment of the service cell requires that service cell windows, service penetrations, and doors be constructed to prevent both neutron and gamma streaming. Steel window frames will be designed to stop the low energy neutrons that can stream through steel. The windows themselves will have sufficient hydrogen content to provide adequate shielding against low energy neutrons. The relatively rare high energy neutrons will be attenuated by heavier elements in the glass.

The bulk shielding of the service cell will consist primarily of 4 ft. thick walls of high density concrete, with limited use of 6 ft. thick walls of ordinary concrete. The service cell support area, where the manipulators are located, is separated from the cell by a high density concrete wall to provide adequate protection for personnel at the manipulator stations.

Accelerator System

The 0.1A, 35 MeV deuteron beam will be produced by a linear accelerator and transported to the test cell by a high energy beam transport system (HEBT). The accelerator and HEBT structures, the accelerator vault walls, and the vault air will become activated as a result of direct deuteron beam loss, neutrons produced by the beam loss, and neutrons backstreaming from the target.

Manned access to the accelerator and HEBT areas during beam-off periods is planned. It is desirable to minimize the decay time necessary before entry as well as the radiation level in the vault during maintenance periods. To achieve these goals, a variety of design features will be provided to reduce and mitigate deuteron beam losses, expedite maintenance procedures, and maintain personnel exposure levels consistent with hands-on maintenance where practicable. The accelerator design also provides for the use of retrofittable, local shielding if necessary due to excessive beam spill.

Features which will reduce and mitigate beam losses include: large drift tube bores to allow for more beam spread than is typical, gold plating on the inner diameters of the drift tubes, and the use of low manganese steel for the linac tank to reduce the amount of activation due to beam spill[2]. ^{197}Au has been selected as a plating material on the basis of its relatively low activation by deuterons. That is, the gamma radiation produced after activation is low in energy and easily shielded. Lead collars will be included in the drift tube bodies to shield the activated material

Features incorporated to expedite maintenance include: modularized components, quick-disconnect flanges, an alignment cart which allows accelerator components to be aligned while separated from the accelerator itself, and a rapid and reproducible alignment system[3].

The HEBT will be highly activated due to beam losses as the 35 MeV deuterons produced by the linac are transported to the target, as well as by neutrons backstreaming from the target. Local shielding consisting of 3 ft. thick borated limestone concrete walls will be provided around and above the HEBT beam tube. Electrical, water, and instrumentation fittings to service the HEBT will be terminated at panels external to the local shielding to allow hands-on maintenance to these components. Features such as specially designed quadrupole magnets and a modularized beam tube are provided to expedite maintenance activities.

Certain incidents could require closer access to the HEBT beam tube. The beam tube will therefore be constructed of aluminum due to aluminum's relatively rapid (∿ 1 week) cooldown rate. Because of the susceptibility of aluminum to chemical attack by lithium, the segment of beam tube closest to the lithium target will be made of stainless steel with a 0.070 in. inner liner of aluminum.

For design purposes, radiation resulting from beam loss is based on the maximum estimated deuteron beam loss values: a 3 μA/m continuous loss throughout the accelerator and HEBT, and a 10 μA loss at each of certain HEBT bending and focusing magnets.[3] On the basis of these beam loss values, provisions are being made for future shield walls between the HEBT and the linac, and between the linac and the injector vault. The wall between the linac and the injector vault would provide shielding from neutrons backstreaming from the high energy end of the linac. The wall separating the linac from the HEBT would shadow shield HEBT structural components from activation by linac neutrons and shield against gamma radiation from activation of the high energy linac tank during beam-off access to the HEBT area. The design of the bulk shield walls takes no credit for these future walls. Actual beam loss values will determine whether the walls are necessary or not. Providing for, but not taking credit for, future walls is an example of design flexibility which meets shielding needs while permitting costs to be minimized.

With the exception of the accelerator vault crane, no remote handling equipment is planned for the accelerator. The design features previously described will enable the accelerator system to meet the goal of hands-on maintenance to minimize downtime.

Lithium System

The circulating lithium inventory of approximately 1100 gallons will become activated as it passes through the deuteron beam, along with the impurities and corrosion products in the lithium stream.

^{7}Be is the activation product of most significance with respect to facility design. An equilibrium ^{7}Be activity of 4.54×10^4 Ci in the lithium loop has been calculated, corresponding to ∿ 10mCi/cm^3. Tritium will also be generated in the lithium system, but does not represent a direct radiation hazard due to its low energy β decay.

The large lithium system components and most of the lithium piping are located in the lithium equipment vault which is shielded by 4 ft. thick walls of ordinary concrete. Because of the short-lived high level activity induced in the lithium stream, the areas adjacent to the lithium vault are normally inaccessible to personnel during beam-on periods. For beam-off, the gamma radiation produced by activated corrosion products and lithium impurities such as sodium, drives shield design, whereas the relatively soft gammas produced by ^{7}Be are attenuated rapidly by the bulk shielding. However, the unshielded beam-off dose rate is governed by the ^{7}Be inventory.

The original design of the lithium system called for hands-on maintenance to all components if possible. As the design progressed, examination of failure rate data, maintenance scenarios, radiation levels, especially the large contribution of ^{7}Be, and access requirements indicated that shield design and personnel exposure criteria could not be met for hands-on maintenance. As a result, the present compartmented design was chosen, where the electromagnetic pump and the large valve are enclosed in shielded cubicles in the vault.[4]

Remote maintenance capability to each cubicle will be available,[5] including:

- Provisions for installation of dual heavy duty master-slave manipulators,
- Crane access from the lithium vault,
- Appropriate lighting, and
- Provisions for installation of full cell TV viewing capability.

Personnel access to a cubicle will be necessary if a failure requires the removal and replacement of the pump or valve. Component removal and cubicle decontamination as necessary can be performed remotely but manned access is necessary to perform welding on the new component. Manned access will be possible only after the component has been removed and the pipe stubs plugged and remotely decontaminated. These restrictions are due to the plated-out layer of ^{7}Be and corrosion products that will remain after the lithium system is drained for repair. The ∿ 2 1/2 ft. thick ordinary concrete walls of the cubicles are designed to shield entering personnel from the lithium vault radiation environment due to plate-out in other components and piping.

Totally remote maintenance is planned for the lithium heat exchanger, which, because of its large surface area, will contain large quantities of plated-out ^{7}Be and corrosion products after system drain. Manipulators, closed circuit TV, equipment for the remote removal of the heat exchanger head, and remote tube leak testing and plugging equipment will be provided.

CONCLUSION

The competition between the extensive, varied shielding needs and the need for maintenance and operations access has required the use of system-specific design solutions in the FMIT. The high radiation environment of the experimental system requires that a vast majority of work be done remotely through bulk shielding. In the accelerator system, the use of design features to reduce beam loss and expedite maintenance, along with local shielding of lead and concrete, permits hands-on maintenance to most components. The need to do hands-on maintenance on certain lithium system components has resulted in a lithium system design which combines remote maintenance capabilities with the ability to perform some tasks hands-on. Thus a system-specific shielding approach allows both shielding and maintenance needs to be met.

References

1. L. L. Carter, R. J. Morford, and A. D. Wilcox, "Nuclear Data Relevant to Shield Design of FMIT Facility," Proc. of a Symposium on Neutron Cross Sections from 10-50 MeV, Brookhaven National Laboratory, Upton, NY, May 1980. (BNL-NCS-51245).

2. D. J. Liska, et. al., "Modular Design Aspects of the FMIT Drift-Tube Linac," in Proc. of the 10th Linear Accelerator Conference, Montauk, NY, Sept. 1979. (BNL-51134)

3. D. J. Liska, et. al., "High Radiation-Zone Design of the FMIT High Energy Beam Transport," Proc. of the 1981 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-28(3).

4. S. T. Huang, A. M. Shapiro, W. C. Miller, and J. B. Lee, "Shielding Consideration for a Deuteron Activated Liquid Lithium System," Proc. of the 8th Symposium on Engineering Problems of Fusion Research, San Francisco, CA, Nov. 1979, Vol. 2, pp 642-644.

5. V. P. Kelly, "Remote Maintenance Features of the FMIT Lithium System," Transactions of the American Nuclear Society, Vol. 38, June 1981, pp. 698-699.