Assessment of Personnel Accessibility in the Particle Beam Fusion Accelerator Facility PBFA-II

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Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

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Fusion Technology Institute
University of Wisconsin - Madison
1500 Johnson Dr., Madison, Wisconsin 53706

ABSTRACT

The dose during and after fusion shots around the PBFA-II facility and the line-of-sight (LOS) beam penetration has been calculated. The dose above the 6" thick concrete ceiling of the high bay was found to be excessive and additional shielding is required. On the other hand, the water and oil tanks provide significant radiation attenuation yielding a very low dose level in the screen room. No access during shots should be allowed in the building housing PBFA-II unless 6" thick concrete shield is used around the LOS. In the space between buildings, one should stay at least 2 m away from the LOS axis. In the building housing the neutron measurements laboratory (NML), access during shots should be limited to the area behind the 8" thick wall. A beam dump design with a cylindrical trap having an aspect ratio of 3 significantly reduces the reflected secondary neutrons. Access during shots is allowed anywhere at the back and side of the dump. The total activity in air, glass windows and concrete walls immediately following a DT shot is only 5 Ci and drops by two orders of magnitude in 10 minutes. Access to areas in front of the beam dump should be restricted for at least 15 minutes after shots.

I. INTRODUCTION

The Particle Beam Fusion Accelerator (PBFA-II) facility at Sandia National Laboratory (SNL) is used to perform research on light ion beam driven inertial confinement fusion [1]. Targets at the center of the facility are imploded by 30 MeV Li ions resulting in emission of high energy fusion neutrons. The central cavity is 152 cm in radius and contains the diode and transmission lines. The cavity is surrounded by a water tank and an oil tank that includes the MARX generators. Neutronics calculations have been performed to determine the additional shielding requirements around the facility. The operational schedule for PBFA-II is uncertain and most of the fusion shots are expected to be DD shots. The results presented here are conservative since the calculations assume 10 DT shots per year with a conservative target yield of 3 MJ per shot.

The neutrons emanating from the target travel through a line-of-sight (LOS) pipe that penetrates into the tanks surrounding the central cavity. Upon exiting the facility, the neutron LOS beam travels in the building (building 983), then exits it, entering an adjacent building (building 984) where a neutron measurements laboratory (NML), which is used for neutron diagnostic measurements of ICF target implosion, is located. The neutron LOS beam streaming out of that building is intercepted by a neutron dump at 70 m from the target. An environmental assessment has been performed to evaluate the operation of the NML [2]. As part of this assessment, two-dimensional neutronics calculations have been performed to determine the operational dose during shots in areas around the LOS in both buildings as well as in the space outside the buildings. Different geometrical shapes have been considered for the neutron beam dump to minimize the dose in the surrounding area. In addition, activation analysis has been carried out to calculate the amount of radioactivity produced in air, glass windows, and concrete walls along the LOS and around the neutron beam dump.

II. SHIELDING REQUIREMENTS

Neutronics analysis has been performed for building 983 to determine the biological dose above the high bay ceiling and inside the screen room during the fusion shots. The one-dimensional discrete ordinates code ONEDANT [3] has been used with coupled neutron-gamma cross section data based on the ENDF/B-V evaluation. The cavity has been modeled in spherical geometry with the target representing a point source at the center. The detailed compositions of materials surrounding the target are included. The target is assumed to emit 10^{18} 14.1 MeV neutrons per shot. Based on a maximum allowable occupational dose of 1 rem per year, the dose limit per shot should not exceed 100 mrem for the projected 10 shots per year.

The top cover of the vacuum chamber is considered to be 1 inch thick 304 SS located at 2.4 m from the target. The concrete ceiling is 6 inch thick. The dose above the ceiling amounts to 1.7×10^{6} mrem/shot. Additional shield is needed to reduce the dose below the limit. Four types of shield were analyzed. These are SS/H_2O, W/H_2O, H_2O tank and concrete. The effect of additional thickness of these shielding materials on the dose above the high bay ceiling is shown in Fig. 1. To achieve a dose of 100 mrem/shot above the ceiling, approximately 64, 77, 125, and 145 cm of W, SS, concrete, and H_2O additional shields are needed, respectively. On the other hand, the water and oil tanks provide significant radiation attenuation yielding a very low dose level of 10^{-13} mrem/shot in the screen room.

III. OPERATIONAL DOSE AROUND THE LOS

Two-dimensional coupled neutron-gamma transport calculations have been performed to determine the operational dose along and around the neutron line-of-sight beam in buildings 983 and 984 as well as in the space outside the buildings. The TWODANT discrete ordinates code [4] was used with ENDF/B-V cross section data. An R-Z geometry

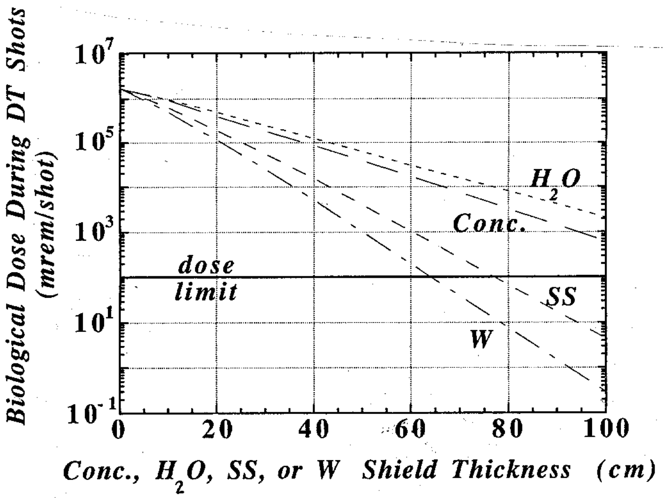

Fig. 1. Dose above ceiling as a function of shield thickness.

was utilized with the target represented by an isotropic point source on the Z-axis. An inherent problem associated with multi-dimensional discrete ordinates calculations with localized sources is referred to as the "ray effect." It is related to the fact that the angular flux is given only in certain discrete directions. It is, therefore, not possible to exactly represent the component in the normal direction ($\mu = 1$) along the beam penetration which can lead to underestimating neutron streaming. We have fully mitigated the ray effect by using the first collision method [5]. In this method, the uncollided flux is determined analytically and the volumetrically distributed first collision source is used in the calculations.

The option of plugging the LOS pipe with lead at the exit from the oil tank to reduce streaming radiation from the central cavity has been considered. Hence, calculations have been performed for two cases with and without a 30 cm thick lead plug at the outlet of the LOS pipe. Attenuation in the air, lead and 1/4 inch glass windows is taken into account. The mean free path values for 14 MeV neutrons are 146 m, 5.6 cm, and 10 cm in air, lead and glass, respectively.

Fig. 2 shows the two-dimensional model used in the calculations. The size of the direct neutron beam streaming from the chamber is determined by the diameter of the LOS pipe at the outer wall of the oil tank. The direct neutron beam is in a cone with a half angle of 0.25 degrees. The fraction of source neutrons streaming out of the chamber is 4.8×10^{-6}. The direct neutron beam will go through the windows without interacting with the concrete frames. The radius of the direct neutron beam at the beam dump is 30 cm.

Figures 3 and 4 show the operational dose in buildings 983 and 984, respectively, as a function of distance from the LOS axis for the case without a lead plug. Based on these results, it is concluded that for the case without a lead plug, no access should be allowed inside building 983 during shots. Otherwise, a 6 inch thick concrete shield is needed around the LOS. In the space between buildings, one should stay at least 2 m away from the LOS axis during shots. In building 984, which houses the neutron measurements laboratory (NML), access should be limited to the area behind the 8 inch thick wall during shots.

If the lead plug is used, the direct beam is attenuated by about two orders of magnitude in the 30 cm thick lead plug with the resulting secondary neutrons yielding a higher dose near the plug but a lower dose farther along the LOS. In this case, no access during DT shots should be allowed to areas in building 983 outside the PBFA tank up to ~30 m from target. If access is required in these areas during shots, a foot thick concrete shield should be used around the LOS. Areas at distances larger than 30 m from the target can be accessed during shots provided that one stays at least 30 cm away from the axis of the LOS.

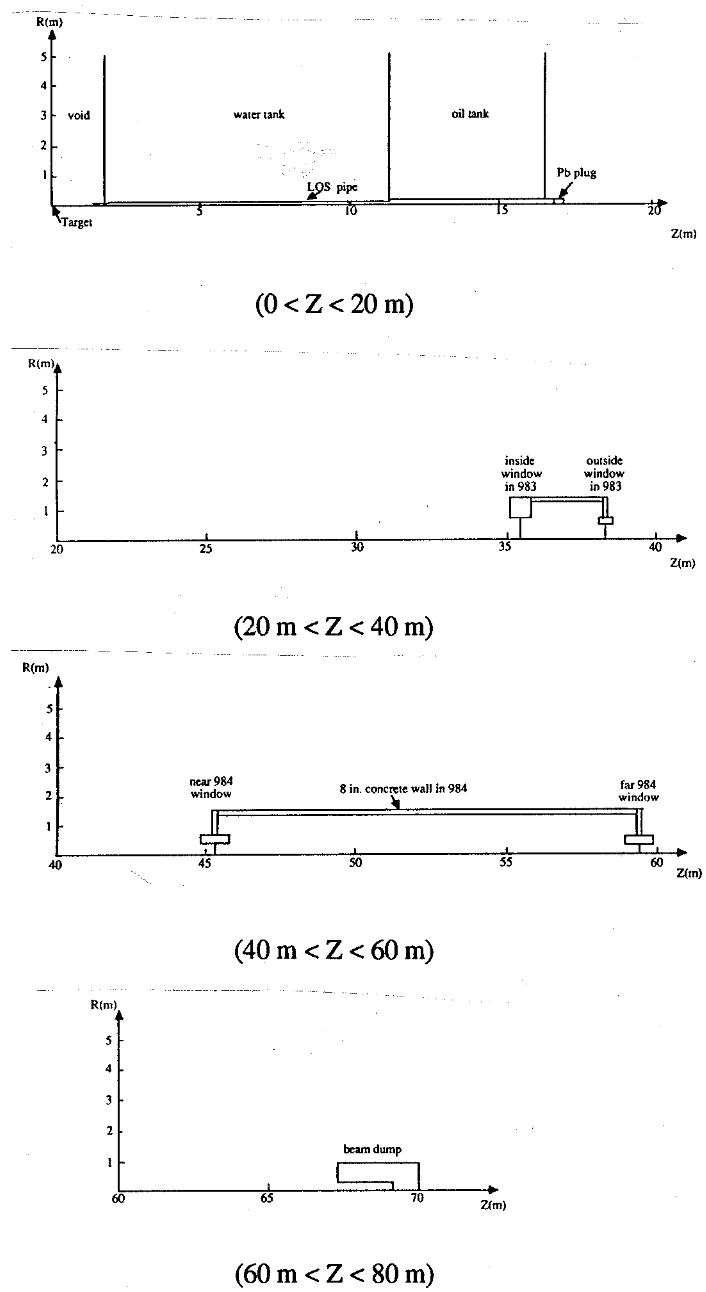

Fig. 2 Two-dimensional model for LOS calculations.

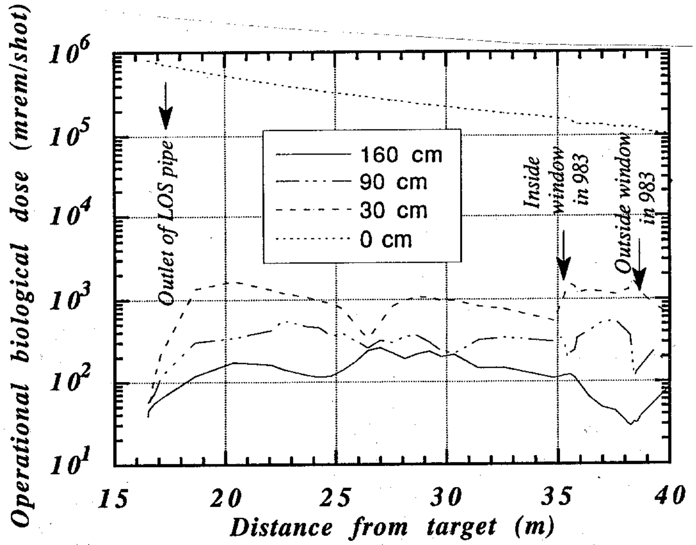

Fig. 3. Dose around the LOS in building 983.

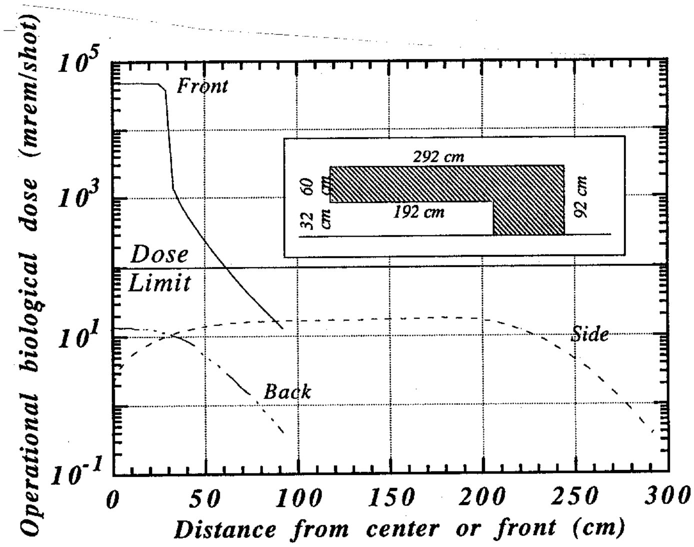

Fig. 5. Dose around the beam dump.

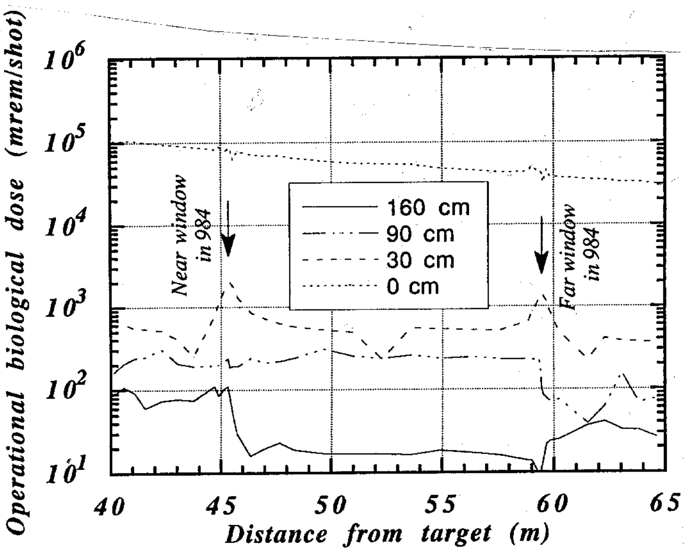

Fig. 4. Dose around the LOS in building 984.

IV. NEUTRON BEAM DUMP DESIGN

Two-dimensional coupled neutron-gamma transport calculations have been performed for different geometrical shapes of the neutron beam dump. The neutron beam dump was modeled using R-Z geometry. A 30 cm radius surface source is used at the front of the dump. The surface source emits 14 MeV neutrons in the perpendicular direction to represent the direct source neutrons incident on the dump. The calculations are conservative since no attenuation for the primary source neutrons in air, glass and lead is considered. Air and glass attenuate the direct source neutrons by a factor of 0.54 as they travel from the target to the dump. A beam dump design with a cylindrical trap having an aspect ratio of 3 (depth to diameter ratio) was found to significantly reduce the reflected secondary neutrons. The operational dose around that beam dump is shown in Fig. 5. Access during shots is allowed anywhere at the back and side of the dump. Access at the front is limited to locations at least 65 cm away from the LOS axis.

V. ACTIVATION ANALYSIS

Activation analysis has been performed to determine the amount of radioactivity produced in air, lead, glass, and concrete along the neutron LOS and to calculate the biological dose rate following the DT shots around the neutron beam dump. The activation calculations have been performed using the DKR-ICF code [6] with the ACTL activation cross section library [7] utilizing the flux determined in the two-dimensional neutronics calculations. The pulsing sequence was modeled with 10 shots and one month period between subsequent pulses. The decay gamma source and adjoint flux were used to calculate the biological dose rate around the beam dump after the final shot. Accessibility following shots is based on an allowable dose rate of 0.5 mrem/hr for full time workers.

The activity generated in air, lead, glass, and concrete along the LOS as a function of time after the final shot has been calculated. The air activity values immediately following a shot are 0.3, 0.05 and 0.07 Ci in building 983, building 984 and the space outside buildings, respectively, for the case without a lead plug. This activity is dominated by ^{16}N and drops by 5 orders of magnitude in an hour when ^{41}Ar becomes the dominant contributor. Air activity at a time greater than a day after a shot is dominated by ^{14}C and is about 8 orders of magnitude lower than that at shutdown. The activity in the concrete walls and glass windows is about a factor of 4 higher than the air activity immediately following the shot and is about 3 orders of magnitude higher after a day. The short term activity is dominated by ^{16}N while the long term activity is dominated by ^{55}Fe for the concrete and ^{39}Ar for the glass.

The short term activity is determined mainly by activation during the final pulse due to decay in the relatively long time between shots. Hence, short term activity (t << 1 month) results are applicable following any shot. Long term activity resulting from isotopes with half-lives longer than a month is influenced by activation in several pulses. Hence, long term activity results give a conservative estimate for activity following fewer than 10 consecutive shots.

If a lead plug is used, the radioactivity produced along the LOS is reduced by about two orders of magnitude due to attenuation of the direct neutron beam in the 30 cm lead plug. The total activity immediately following a DT shot is quite low; 4.9 Ci without Pb and 0.07 Ci with Pb and drops by two orders of magnitude in 10 minutes. The lead activity is only 3×10^{-5} Ci at shutdown and drops by two orders of magnitude in a week.

The total activity generated in the concrete beam dump as a function of time after the final shot has been calculated. It is 0.38 Ci at shutdown and drops to 10^{-4} Ci after 1 hour and 8×10^{-7} Ci after 1 week. The dose rate as a function of location around the beam dump and time after the final shot has been determined. The results are given in Table I. The highest dose rate occurs in front of the dump opening due to contribution from activated material at the inner surface of the dump where the direct neutron beam impinges. The dose rate immediately after the shot is dominated by ^{16}N with 7.13 s half-life and drops by more than two orders of magnitude in 10 minutes. The dose rate results in a week following the final shot are dominated by short lived nuclides that fully decay in the month period between shots. Hence, the results are applicable following any shot. It is recommended that access to the area around the beam dump be restricted for at least 15 minutes after each DT shot.

Table I
Dose Rate (mrem/hr) Around Neutron Dump

Time After Shot	Dose at the Front R= 0 cm	Dose at the Front R= 92 cm	Dose at the Back R= 0 cm	Dose at the Back R= 92 cm
0	284.4	1.83	2.17	0.193
10 min	1.22	1.1×10^{-3}	3.2×10^{-3}	1.0×10^{-4}
1 hour	5.9×10^{-2}	6.2×10^{-5}	1.8×10^{-4}	5.7×10^{-6}
1 day	2.9×10^{-3}	$3.9x\times10^{-6}$	8.0×10^{-6}	3.1×10^{-7}
1 week	3.6×10^{-5}	3.3×10^{-8}	1.1×10^{-7}	3.2×10^{-9}

VI. SUMMARY AND CONCLUSIONS

The dose above the 6" thick concrete ceiling of the high bay area of PBFA-II was found to be excessive and additional shielding requirements were determined. On the other hand, the water and oil tanks provide significant radiation attenuation yielding a very low dose level in the screen room.

Two-dimensional calculations were used to determine the dose during shots in areas around the LOS. It is concluded that no access should be allowed in the building housing PBFA-II unless 6" thick concrete shield is used around the LOS. In the space between buildings, one should stay at least 2 m away from the LOS axis. In the building housing the NML, access during shots should be limited to the area behind the 8" thick wall. If a lead plug is used at the outlet of the LOS pipe, the direct beam is attenuated by about two orders of magnitude in the 30 cm thick lead plug with the resulting secondary neutrons yielding a higher dose near the plug but a lower dose farther along the LOS particularly in the building housing the NML.

Different geometrical shapes have been considered for the neutron beam dump to minimize the dose in the surrounding area. A beam dump design with a cylindrical trap having an aspect ratio of 3 was found to significantly reduce the reflected secondary neutrons. Access during shots is allowed anywhere at the back and side of the dump.

Activation analysis has been carried out to calculate the amount of radioactivity produced in air, glass windows, and concrete walls along the LOS. The total activity immediately following a DT shot is quite low; 4.9 Ci without Pb and 0.07 Ci with Pb and drops by two orders of magnitude in 10 minutes. The dose rate, calculated around the neutron beam dump following pulses, indicates that access to areas in front of the beam dump should be restricted for at least 15 minutes after shots.

ACKNOWLEDGMENT

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