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Chamber and Diode Region of the Light Ion
Fusion Target Development Facility**

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RADIOLOGICAL DOSE CALCULATIONS FOR THE CHAMBER AND DIODE REGION
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Abstract

Biological dose rate calculations are performed for two preliminary designs of the Light Ion Fusion Target Development Facility (TDF) for times following an operational period of one month. The primary wall material considered is aluminum Al-6061-T6 with an alternative material being 2-1/4 Cr-1 Mo steel. The diode material considered is SS304LN stainless steel and the penetration in the chamber wall is 10 cm in radius. As an alternative to the base case 3 m radius chamber design, a 1 m radius chamber is analyzed with various shield materials -- borated water, concrete and graphite between the chamber wall and the diode. The dose rate behind the Al first wall for the 3 m chamber design is 34.5 mrem/hr at 1 week after shutdown. For the 1 m chamber design this number is 8.4 rem/hr with an aluminum first wall, and 5 rem/hr with a steel first wall.

For the diode region calculations, the first wall is taken as Al-6061-T6 for both the 1 m and 3 m cases. The dose rate at a point external to the diode vacuum casing, one week after shutdown, is 24 mrem/hr for the 3 m case. For the 1 m case, the dose rates at one week after shutdown are 3.7, 3.8 and 5.8 mrem/hr with shield materials of borated water, concrete and graphite, respectively.

Introduction

The Light Ion Beam Target Development Facility (TDF) is a proposed experimental facility intended to test 50-800 MJ fusion targets at the rate of 10 to 12 per day, accumulating approximately 15,000 shots over a five year time period. Activation of the target debris, target chamber and surrounding components occurs as the high energy neutrons released by the burn of the DT fuel interact with the materials. Being an experimental device, the level of radioactivity induced by this number of high yield shots is of concern as access to the target chamber, the ion diodes and a target diagnostic package may be required relatively soon after a shot or a number of shots.

Two different preliminary designs of the TDF target chamber have been undertaken with the goal of reducing exposure dose at the chamber wall and diode. The first design uses aluminum 6061-T6 as the chamber

wall material and has the target chamber submerged in a borated water pool as portrayed in Fig. 1. The radius of this cylindrical chamber is 3 m and the wall thickness is 5 cm. There are 50 cm thick graphite blocks inside the chamber to moderate the 14 MeV neutrons before they reach the first wall. The softer neutron spectrum reduces the number of (n, charged particle) reactions in aluminum, thus reducing the activation and dose. The diodes are positioned at 4 m from the chamber center with 10 cm radius penetrations through the chamber wall and graphite blocks to allow passage of the ion beams. This design has two changes from a previously reported design [1]. The boron in the borated water pool surrounding the chamber is enriched to 90% boron-10 for neutron absorbing purposes. Also the 100 cm thick graphite moderator (40% void fraction) in the previous design is replaced by 50 cm of graphite (no void).

As an alternative, a 1 m radius chamber and two different first wall materials, Al-6061-T6 and 2-1/4 Cr-1 Mo steel, are examined. This is shown in Fig. 2. The chamber is spherical and has a wall thickness of 5 cm. A 1 cm thick woven graphite liner serves as a heat shield to protect the metallic wall from the microfireball but offers little moderating effect on the neutrons. The diodes remain at 4 m because this distance is required for time-of-flight compression of the ion pulse. A 10 cm radius pipe extends from the diode vacuum casing to the wall of the chamber. This leaves room for neutron shielding. Three materials were examined: borated water, graphite, and concrete.

Neutron Transport Calculations

A consistent neutronics analysis must account for neutron target interactions which result in considerable spectrum softening of the fusion neutrons. The target DT fuel is assumed to be compressed to a density times radius product (ρR value) of 2 g/cm^2 . The spectrum of neutrons escaping from the compressed target is given in Fig. 3. For each DT fusion, 1.046 neutrons leak from the target. A 200 MJ target DT yield corresponds to 7.09×10^{19} DT fusions per shot and 7.42×10^{19} neutrons emanating from the target per shot. The neutron spectrum obtained from the target

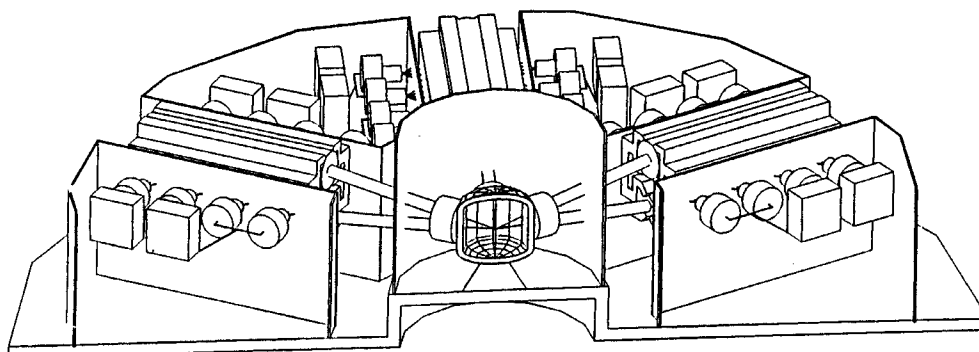


Fig. 1. Preliminary design of the Light Ion Fusion Target Development Facility.

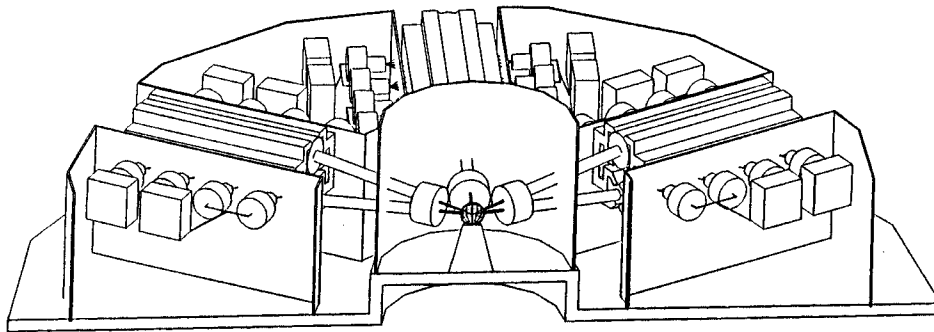


Fig. 2. TDF Chamber design with 1 m radius chamber.

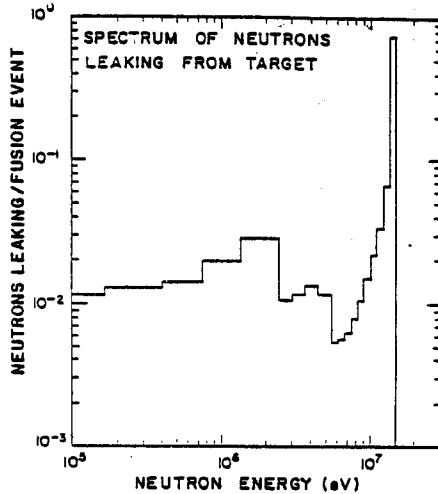


Fig. 3. Spectrum of neutrons emerging from the target.

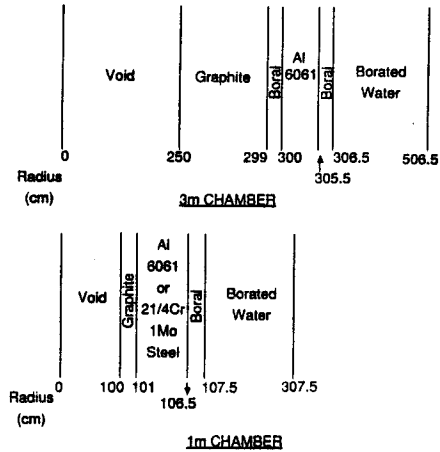


Fig. 4. One-dimensional schematic of the Target Development Facility chamber designs used for the neutronic and activation calculations.

neutronics calculation is used to represent the source for the chamber neutronics.

The neutron flux in the diode is computed in two steps. The cylindrically shaped target chamber is approximated by spherical geometry for a one-dimensional calculation. The TDF target chamber models used in the one-dimensional calculations are given in Fig. 4 for the 3 m and 1 m chamber designs. The first wall thickness is increased by 0.5 cm in the calculation model to account for the chamber structural support. The boral layers have boron enriched to 90% B-10. The source is considered to be a point isotropic source at the center of the cavity. The one-dimensional discrete ordinates code ONEDANT is used together with the LANL MATXS5 cross section data library. The standard LANL 30 neutron-12 gamma group structure is used. The calculations are performed using the P_3 - S_{16} approximation. The neutron flux obtained from the one-dimensional calculations is used to determine the wall activation and dose at the outer surface of the chamber wall.

The one-dimensional calculation is also used to obtain the energy and angular distribution of neutrons incident on the inner surface of the chamber wall. These represent a surface source in the second step of the calculation where the detailed geometrical configuration of the diode is modeled using the two dimensional discrete ordinates code TWODANT along with the same cross section data. Since the beam ports occupy less than 2% of the inner surface area, the one-dimensional calculation in which the penetrations are not modeled gives a fairly accurate estimate of

the nuclear radiation incident on the inner surface of the chamber and the beam penetration opening. In addition, since the diodes are located in the facility midplane, using spherical geometry in the one-dimensional calculation yields reasonably accurate results for nuclear radiation incident on the area around the beam ports. A relatively large S_N order of 16 is used in the calculations for proper representation of the angular distribution of neutrons incident on the inner surface of the chamber.

Figures 5 and 6 represent the r - z geometry used to model the diode regions for the 3 m and 1 m designs. The diode is considered to be stainless steel 304 LN. A spatially uniform surface source is used at the bottom boundary represented by the energy dependent angular flux at the inner surface of the chamber as obtained from the appropriate one-dimensional calculation. The source is given in the eight discrete ordinates directions going into the graphite region. The source is assumed to be uniform in the azimuthal direction. A vacuum boundary condition is used at the bottom boundary since the contribution from neutrons reentering the cavity from the surrounding materials is already taken into account in the surface source. A vacuum boundary is also used at the top. A right reflecting boundary is used in the calculational model to account for the interaction between adjacent penetrations. This boundary should be located at half the distance between the adjacent penetrations. In the actual geometry this distance increases as one moves from the inner surface of the chamber to the diode. However, the two-dimensional r - z geometry allows only for a cylindrical reflecting

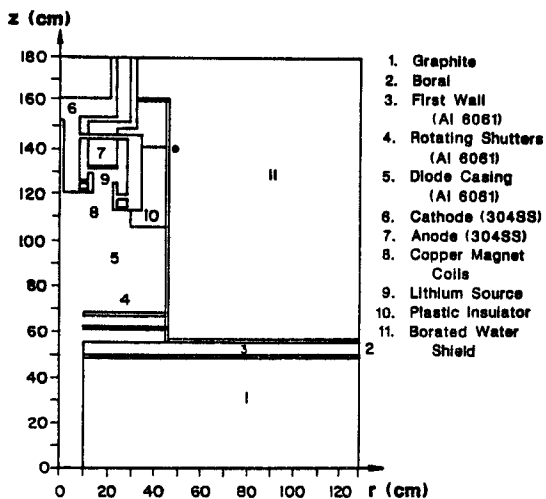


Fig. 5. The r-z geometrical model used in the two-dimensional neutronics and activation calculations for the 3 m chamber design.

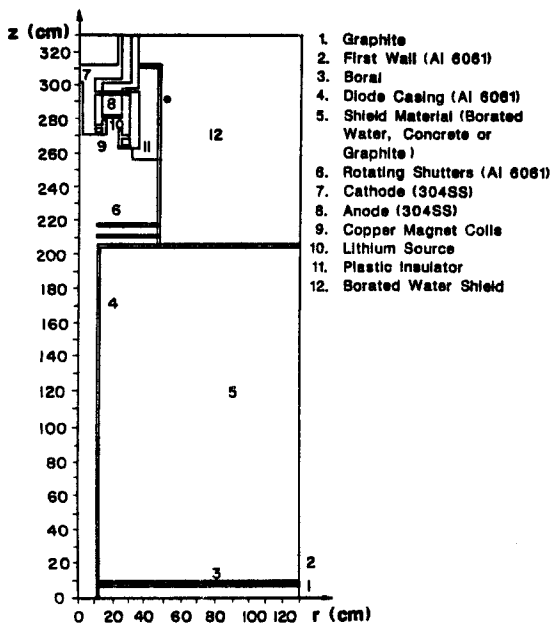


Fig. 6. The r-z geometrical model used in the two-dimensional neutronics and activation calculations for the 1 m chamber design.

boundary as shown in Figs. 5 and 6. Furthermore, while the spacing is smaller at the inner surface of the 1 m chamber than that in the 3 m chamber, it is identical at the diodes which are located at the same distance from the target in both cases. In the 3 m chamber case the reflecting boundary is taken at a radius of 125 cm which is the distance between the penetration centerline and the plane of symmetry between adjacent penetrations at the inner surface of the graphite region. This is expected to give conservative estimates for the flux in the diode due to the larger shielding space between adjacent diodes. In the 1 m chamber case the distance between the penetration centerline and the plane of symmetry between adjacent penetrations is 50 cm at the inner surface of the graphite liner and increases rapidly to values larger than 125 cm in the diode region. The sensitivity of the flux to the location of the reflecting boundary is determined by performing

calculations for reflecting boundaries at radii of 50 and 125 cm. The flux in the 10 cm radius beam duct is found to be insensitive to the location of the reflecting boundary due to the large shielding space between adjacent penetrations. On the other hand, the 50 cm radius reflecting boundary results in over-estimates of the flux in the diode by up to 60% since only 8 cm shielding space is provided between adjacent diodes in this case. Since the spacing between diode centerlines is larger than 250 cm in the actual design, a reflecting boundary radius of 125 cm is used also for the 1 m chamber calculational model. Using an r-z model with a planar disc source at the bottom boundary does not take into account the geometrical divergence of the flux which can be significant for uncollided target neutrons. The $1/R^2$ geometrical attenuation factor is ~ 12 as one goes from the front of the graphite liner to the front of the diode for the 1 m chamber. It is clear that the geometrical approximations introduced by the two-dimensional model tend to give conservative estimates for the flux and dose in the diode region.

In addition to the forward neutron transport calculations, adjoint gamma transport calculations are performed with an adjoint source on the outer surface of the diode casing where the dose after shutdown is calculated. These calculations are used to determine the adjoint dose field distribution that is coupled with the decay gamma source to yield the dose at this position for various times after shutdown.

Dose Rate Calculations

The dose rate calculations are performed using the DKR-ICF code package. The spatial models used for radioactivity and dose calculations are identical to the model used for the TWODANT neutronic calculations. The large dot drawn in the figures designates the point at which the dose rate is calculated. ACTLLIB, a decay and neutron transmutation data library based on the evaluated neutron activation cross section library ACTL, is used as the primary database for the activation calculations. The neutron transmutation data is given in a 46 group structure format. The decay and gamma source data is taken from the Table of Isotopes with the gamma source data being in a 21 group structure format.

The dose rates behind the chamber wall due only to the chamber and borated water are given in Fig. 7. The initial shape of both curves up to

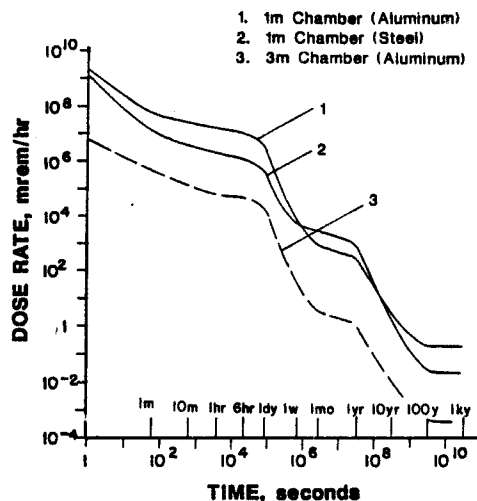


Fig. 7. Dose rates behind the first wall.

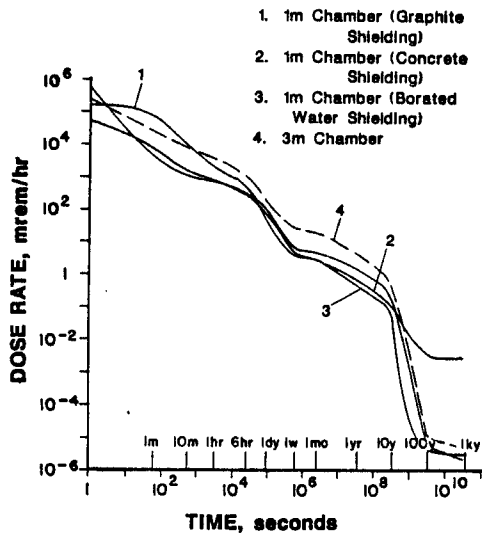


Fig. 8. Dose rates at the diode region for both 1 m and 3 m designs with Al first wall.

approximately 1 day after shutdown shows the same behavior and is determined by the decay of short-lived isotopes Al-28, Mg-27 and Na-26 in aluminum and Al-28 and Mn-56 in stainless steel. The large drop in the aluminum dose rate after one week following shutdown is the result of the decay of Na-24 which has a half-life of 15 hours. The 3 m chamber with an aluminum first wall has a similar curve to the 1 m case, except the level for the 3 m case is more than two orders of magnitude lower. The high energy flux is reduced by the inclusion of the 50 cm of graphite within the target chamber. The dose rate at 1 week after shutdown is 8.4 rem/hr for the 1 m aluminum chamber wall and is 34 mrem/hr for the 3 m chamber wall.

Figure 8 shows the dose rate results at a position near the diode for different shielding materials. Among the different shield materials, borated water (with boron enriched to 90% B-10) is the best for almost all times after shutdown. The lower the level of neutron flux in the diode region, the fewer neutron transmutations that there will be and thus the lower the decay gamma dose level will be in the system. The dose rate at 1 week after shutdown is 3.7 mrem/hr for the borated water shielding case. The corresponding values for the concrete and graphite shielding cases are 3.8 and 5.8 mrem/hr, respectively.

All shielding materials considered in the 1 m case, yield dose rates in the range 3-6 mrem/hr at 1 week after shutdown, whereas it is 25 mrem/hr for the 3 m case. The dose contribution from each component of the system is also of interest. Figure 9 shows the contribution of each component to the dose rate at the point in the diode region for the 1 m chamber. The main contribution several days after shutdown comes from just the diode material SS304LN. This is due to the long-lived elements Cr-51, Mn-54, Co-57, Co-58. The plastic and borated water, that produce the short-lived element N-16, contribute nothing after 4-5 minutes following the shutdown. All the components containing a high percent of aluminum (boral, aluminum first wall and casing) all follow the same behavior. The drop after 1 week is due to the decay of Na-24.

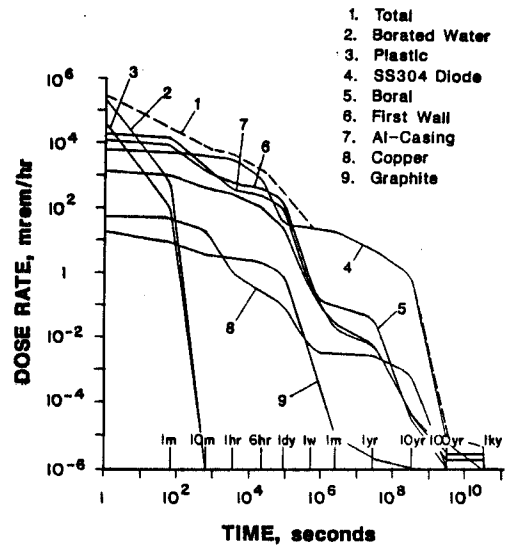


Fig. 9. Contributions from each component to the dose at the diode region for the 3 m chamber design.

Conclusions

Low activation designs of the TDF offer the opportunity to access the target chamber and diodes after a 1 week cooling down period following a month of operation, while keeping occupational dose levels to personnel within accepted limits.

Acknowledgement

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References

[1] D.L. Henderson, G.A. Moses, R.R. Peterson, "Activation and Radiological Dose Calculations for the Light Ion Fusion Target Development Facility," *J. Nucl. Mat.*, vol. 141-143, pp. 49-54, 1986.