NUCLEAR SHIELDING ANALYSES FOR AN INTENSE NEUTRON SOURCE FACILITY

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1. INTRODUCTION

This paper summarizes nuclear shielding analyses applicable to fusion, and fusion related, facilities. The analyses were performed during the design of an Intense Neutron Source Facility, to provide an experimental neutron irradiation facility yielding a neutronic environment similar to that encountered in a fusion power reactor.

The analyses included:

- bulk shield
- skyshine
- various generic and specific penetrations, single and multi-legged
- source cell door design.

All results are based on a neutronic environment generated by a D-T source yielding 3×10^{15} -14 MeV neutrons/second. Analyses included the effect of secondary gamma rays produced by the interaction of primary and scattered neutrons with air and the proposed shielding materials.

2. BULK SHIELD ANALYSIS

The adequacy of an eleven-foot concrete wall, composed of an inner layer of one-foot borated gypsum and ten feet of ordinary concrete to meet the design dose rate criteria was calculated using ANISN. The ANISN computer program calculates radiation transport in a one-dimensional geometry via the discrete ordinates method. This computational technique is commonly used for the solution of deep penetration problems.

To evaluate the computational uncertainty the results were compared using:

- different cross section data sets
- increasing the order of the Legendre expansion of the scattering cross section with a comparable increase in the angular quadrature representation.

Some highlights of the analyses are:

a) An outer wall of one-foot borated gypsum (to minimize activation) followed by ten feet of concrete yields a dose rate of 135 mRem/occupational year.

b) The total dose rate drops rapidly when the detector is placed off the source axis.

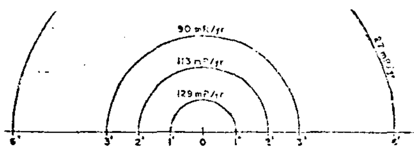

FIG. 1: TOTAL DOSE RATE ON EXTERIOR OF SOURCE CELL WALL AS A FUNCTION OF OFF-AXIS POSITION

c) Use of the CASK 22 neutron-18 gamma ray coupled cross section data set underestimates the neutron leakage by a factor of about three and the total dose rate by more than a factor of two, as shown in Table 1.

TABLE 1: Dose Rates Outside 1' Borated Gypsum and 10' Concrete Wall

Cross Section Data Set	Dose Rate (mRem/hr) Neutron	Gamma Ray	Total
CASK (22N + 18G)	5.25-3	3.63-2	4.16-2
DLC-31 (37N + 21G)	1.55-2	7.30-2	8.85-2

d) Table 2 shows the effect of using a more detailed description of the anisotropic scattering, for an eleven foot concrete shield wall.

TABLE 2: Dose Rate Outside 11' Concrete Wall

Cross Section Data Set	Dose Rate (mRem/hr) Neutron	Gamma Ray	Total
P_3S_8 - DLC 31	1.31-2	7.80-2	9.11-2
P_5S_{12} - DLC 27	6.44-3	6.11-2	6.76-2

3. SKYSHINE ANALYSIS

Some highlights of the analysis include:

a) A source cell roof of eight feet concrete is required to reduce the skyshine dose rate contribution to acceptable levels.

b) For proper skyshine evaluation, the leakage spectrum on top of the source cell roof should be calculated using a two-dimensional discrete-ordinates code. A one-dimensional code will under-estimate the leakage and hence the skyshine contribution by about a factor of ten.

c) The 2-D leakage results can be used as the source for the full 3-D Monte Carlo analysis of the skyshine contribution.

4. PENETRATION ANALYSES

An investigation was done to estimate radiation streaming effects for a variety of penetration configurations. The results may be used to design general penetration layouts, which could then be analyzed in greater detail and accuracy. All analyses were performed with the Monte Carlo method. Preliminary analyses were done with MORSE CG program using the CASK cross section data set, with more detailed results obtained with the LASL MCNP program using the LASL recommended cross section data.

All penetrations analyzed were for a ten foot ordinary concrete wall. Some of the general conclusions are:

a) The line-of-sight uncollided dose rate dominates for penetrations directly facing the source;

b) The scattered dose rate is large (> 1 Rem/hour for a source of 10^{15}-14 MeV neutrons/second) even for a 12 cm penetration angled 45^{o} through a 10 foot wall;

c) Placement of large (two foot diameter) penetrations in an extreme corner of a 12 foot X 12 foot cell is not adequate to reduce streaming to acceptable levels;

d) Use of a multi-legged, non-coplanar design can reduce the exit dose rate, for a large diameter penetration, by several orders of magnitude;

e) Decreasing the penetration size from 2' X 2' to a 1' X 1' opening will decrease the dose rate at the end of the first leg by about a factor of 2, and decreases it by a factor of about 100 at the exit of the four-legged non-coplanar penetration;

f) The above comparison is also valid when an 18 inch (45.7 cm) radiation flux trap is included at the end of the first leg;

g) For some configurations, use of a flux trap will increase the total attenuation by about a factor of two;

h) When using a flux trap, the dose rate at a point on the outer wall surface opposite the first leg may be significantly higher than the dose rate at the exit face of the last leg. A magnetite concrete plug may be used to match the dose rate through the first leg with the dose rate at the penetration exit.

i) The dose rate at the penetration exit, for the multi-legged penetrations analyzed in this study, is due primary to secondary gamma ray leakage. Inclusion of an 8% borated polyethylene liner will decrease gamma ray leakage by a factor of about 100 and the total dose rate by a factor of about 15.

5. SOURCE CELL DOOR DESIGN

Access to the source cell is provided by a system of hydraulic doors. The inner door, adjacent to the cell, is composed of a one-foot liner of borated gypsum followed by 3'-3" of magnetite concrete. The outer door, consisting of 3' of magnetite concrete, contains a lead glass viewing window. The doors are stepped to minimize streaming between the doors and the wall in which they are located. In addition, a steel plate is placed in the cavity beneath the door to eliminate the potential for radiation scattering into the cavity and then re-emerging in front of the door.

TABLE 3: Results of Source Cell Door Analysis

Shield Configuration*	Total Dose Rate (mRem/hr)
Bulk wall (6'-6" mag. concrete)	0.8
Through both doors (6'-3" mag. concrete)	1.4
Through window (3'-3" mag. concrete + 3' Pb-glass)	9.0
Through alternate window design	5.5
Through window lining (3'-3" mag. concrete + 3' Fe)	18.5
Window lining shielded by oil layer	3.6

*All shield configurations included a liner of one foot of borated gypsum.

The results indicate that the dose rate behind the wall and behind the doors meet the dose rate criterion of 10 Rem/occupational year (equivalent to 5 mRem/hr). However, use of a "standard" lead glass configuration will lead to a significant hot spot. Use of an alternate lead glass window composition can reduce the radiation streaming to acceptable levels.

In addition, design of the window frame should include provision for inclusion of a one-foot oil layer in front of the frame to reduce neutron streaming.

6. CONCLUSIONS

This paper presents highlights of nuclear shielding analyses performed during the design of an intense neutron source facility. It is expected that the results, though preliminary in some areas, would be useful in the design of similar fusion-related facilities as well as in the conceptual design of a fusion power reactor complex.

7. REFERENCES

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