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Radiation Shielding for a Nuclear Fusion Device with Inertial Electrostatic Confinement

S. M. Lee[1], H. Yoriyaz, and E. L. L. Cabral[2]

[1]smlee@ipen.br, [2]elcabral@ipen.br

[1,2]Instituto de Pesquisas Energéticas e Nucleares
Av. Prof. Lineu Prestes, 2242, 05508-000, São Paulo, SP, Brazil

1. Introduction

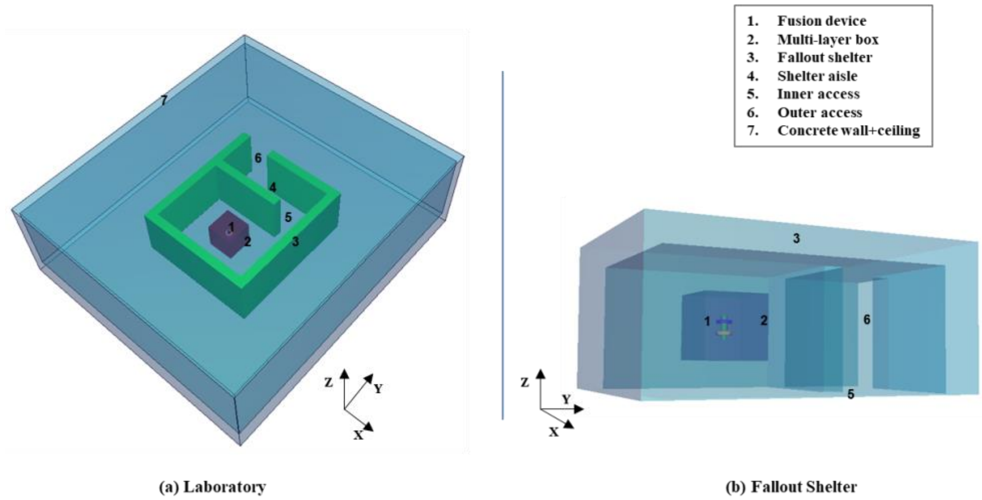
This work is part of the development of a new type of Inertial Electrostatic Confinement Nuclear Fusion device (IECF) [1-4] and aims to develop a radiation shielding for neutrons and gamma rays generated as result of the fusion reactions and neutron interaction with matters, respectively. This work will be used for developing a neutron detection system for the IECF device, because neutron detection is essential for the development of this kind of device, due to the fact that obtaining experimental data of the device in operation is necessary to enable its efficiency analysis and model validation. The first step for detection of those neutrons is to moderate them down to the thermal state; therefore, the radiation shielding for the device must have a layer of moderator, thick enough to assure the thermalization of the neutrons. For these purposes, a transport model is elaborated using the Monte Carlo N-Particle Code (MCNP) [5-7]; this model is applied to design the required radiation shield for the safe operation of the device, and further, will enable the determination of the proportionality between the detected thermal neutrons and the fast neutrons which are generated in the device. In this context, this work is carried out in two stages: (1) development of a neutron transport model using the MCNP code to simulate the interaction of the neutrons generated inside the IECF device with the surrounding materials; and (2) determination of suitable dimensions and materials of the radiation shielding for the device.

2. Methodology

The detailed features of IECF device model for simulation on MCNP are found in S. M. Lee, *et al.* [8], as well as the initial model of neutron shielding. For the purpose of the present work, however, the fusion device can be consider as a source of fast neutrons whose production is proportional to fusion reactions inside the device. Since the IECF device is modeled as a simple cylindrical shell containing deuterium at low pressure, it is assumed to be a homogeneous, isotropic and mono-energetic source of fast neutrons of 2.5 MeV, whose intensity is chosen by the user. Here, the intensity of the source is assumed to be 10^{12} neutrons/sec.

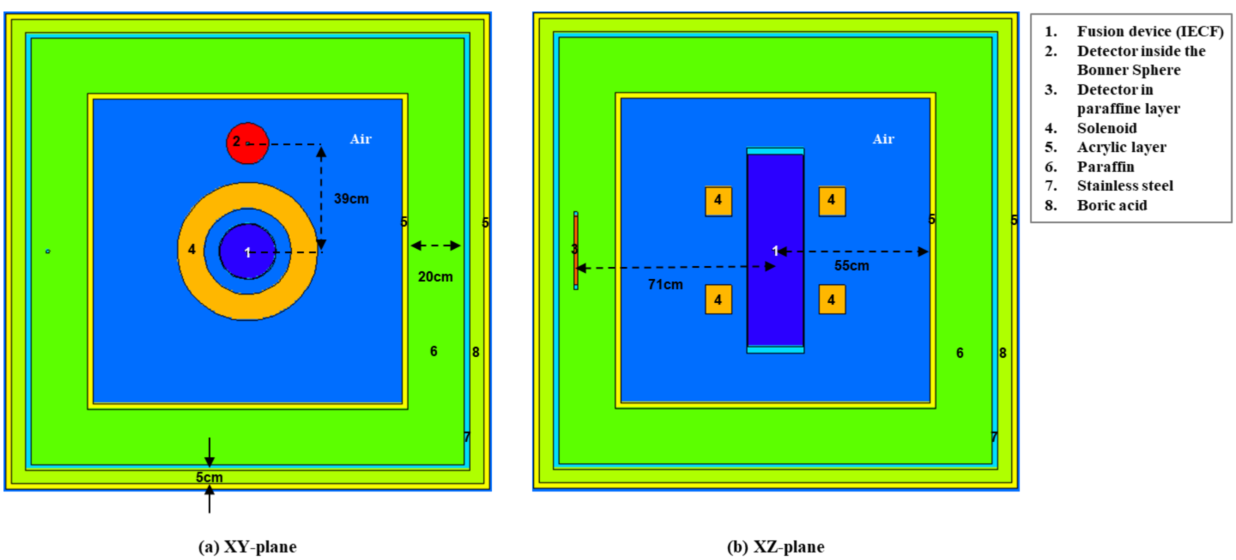
Figure 1 illustrates model of the laboratory for MCNP simulation, where two radiation barriers inside the room can be observed: multi-layer box and fallout shelter. The multi-layer box is the first barrier surrounding the fusion device and consists of three types of materials: 1) fast neutron moderator; 2) thermal neutron absorber; and 3) structural materials. As neutrons main moderator, paraffin $C_{31}H_{64}$ (ρ=0,9g/cm^3) is chosen; and as thermal neutron absorber, boric acid, H_3BO_3 (ρ=1,435g/cm3). The density of the main structural material, stainless steel, is assumed to be 7,86g/cm^3. Now, the fallout shelter is the second barrier mainly for gamma ray shielding and consists of a concrete building with density of 2.35 g/cm^3, although simulations were carried out also with the shelter of lead (Pb) and stainless steel.

Figure 1: Layout of the laboratory for MCNP calculation.



Three configurations of multi-layer box were analyzed and the layout of the thinnest one is shown in Figure 2. The first model has 20cm of paraffin and 5cm of boric acid; these measures are increased by 20 and 50 percent, in the second and in the third, respectively.

Figure 2: Layout of the medium sized multi-layer box for MCNP calculation



The calculation of radiation doses is performed using the model of an imaginary 850cm radius ring detector, with the origin in the center of the IECF and the conversion factors of the National Council on Radiation Protection and Measurements, NCRP-38 [7].

3. Results and Discussion

The doses equivalent rates calculated using the medium sized multi-layer box, namely, with paraffin and boric acid layers of 24.0 cm and 6.0 cm thick respectively, and the fallout shelter of three different materials (concrete, stainless steel and Pb) are listed in Table I.

Table I: Doses Equivalent Rates calculated using medium sized multi-layer box.

Material	**Concrete**		**Stainless Steel**		**Pb**	
Thickness (cm)	**DE(n)** (rem/h)	**DE(γ)** (rem/h)	**DE(n)** (rem/h)	**DE(γ)** (rem/h)	**DE(n)** (rem/h)	**DE(γ)** (rem/h)
1.0	1.610E-02	5.730E-02	1.561E-02	4.661E-02	1.695E-02	3.317E-02
2.0	1.468E-02	5.314E-02	1.446E-02	3.535E-02	1.587E-02	2.012E-02
3.0	1.375E-02	4.912E-02	1.353E-02	2.696E-02	1.546E-02	1.264E-02
4.0	1.234E-02	4.544E-02	1.303E-02	2.055E-02	1.502E-02	8.122E-03
5.0	1.134E-02	4.204E-02	1.272E-02	1.575E-02	1.483E-02	5.207E-03
6.0	1.029E-02	3.861E-02	1.137E-02	1.051E-02	1.335E-02	3.130E-03
7.0	9.784E-03	3.549E-02	1.048E-02	9.137E-03	1.272E-02	1.976E-03
8.0	8.569E-03	3.267E-02				
9.0	7.976E-03	3.012E-02				
10.0	7.298E-03	2.769E-02				
11.0	6.742E-03	2.553E-02				
12.0	6.193E-03	2.347E-02				
12.5	6.233E-03	2.261E-02				

According to the norm of *Comissão Nacional de Energia Nuclear* (CNEN), the limit of the radiation dose for an individual working in environment with risk of ionizing radiation is 2 rems per year, considering that an operator works 2000 hours during this period. Thus, assuming that the IECF device is operated for 10 minutes a day, 5 times a week, for 48 weeks; then, the dose rate limit would be 0.05 rems per hour. Therefore, from Table I it can be inferred that the minimum shelter thickness to reduce the total equivalent dose below 0.05 rems per hour are: 6 cm for concrete and 2 cm for steel and 1 cm for lead. The minimum shelter thicknesses for the other two sizes of multi-layer boxes are: 13 cm (concrete), 7 cm (steel and Pb) for the smallest box; and 0 cm (concrete, steel and Pb) for the biggest one. Obviously, a readjustment in the thickness of the shields is necessary whenever there is an increase in the neutron generation rate or in the time and frequency of operation of the fusion device.

4. Conclusions

It was verified that the model for the fallout shelter as a second radiation barrier is efficient for its purpose and plays an important role in the whole radiation shielding system for the IECF. The previous study focused in neutron shielding has contributed significantly to the development of the model of the entire shielding system, since the subject of gamma-ray shielding is relatively straightforward. Concrete proved to be the most feasible material for shelter, as long as space is not a concern, not to mention that there are advantages in several aspects associated with the use of this material for the structure. The data obtained in this work serve as a reference even when there is a need to change the neutron generation rate inside the IECF device, since the results are proportional to the neutron generation rate. Therefore, the model can be considered definitive without needing significant changes in the future.

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References

[1] R. W. Brussard, "Some Physics considerations of magnetic inertial electrostatic confinement: a new concept for spherical converging-flow fusion," Fusion Technology, Vol. 19, No. 273. (1991).

[2] W. M. Nevis, "Can inertial electrostatic confinement work beyond the ion-ion collisional time scale?", Physics of Plasma, Vol. 2, pp. 1853 (1995).

[3] T. H. Rider, "A general critique of inertial confinement fusion systems," Physics of Plasmas, Vol.2 (6) (1995).

[4] M. Rosenberg and N. A. Krall, "The effect of collisions in maintaining a non-Maxwellian plasma distribution in a spherically convergent ion focuses" Physics of Fluids B, Vol. 4 (1992).

[5] C.J. Werner, *et al*., "MCNP6.2 Release Notes", Los Alamos National Laboratory, Report LA-UR-18-20808 (2018).

[6] C.J. Werner, "MCNP User's Manual - Code Version 6.2", Los Alamos National Laboratory, report LA-UR-17-29981 (2017).

[7] Pelowitzh, Denise B., *et al*., MCNP6TM User's Manual. Version 1.0, Los Alamos National Security, LLC. (2013).

[8] S. M. Lee, *et al*., "Development of Neutron Shielding for an Inertial Electrostatic Confinement Nuclear Fusion Device", 2019 International Nuclear Atlantic Conference – INAC2019, pp. 5088-5095. (2019)