IFMIF/EVEDA BEAM DUMP SHIELDING: OPTIMIZED DESIGN OF THE FRONT PART

M. García, F. Ogando, D. López, P. Sauvan, A. Mayoral, J. Sanz,
Departamento de Ingeniería Energética, UNED, Madrid, Spain
B. Brañas, J. M. Arroyo, Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain

Abstract

The Beam Dump of the IFMIF/EVEDA accelerator prototype needs to fulfil radioprotection requirements. In order to protect workers and public against radiation arising from the Beam Dump, a shielding for this device has been designed. This radiation is generated due to the stopping of the 125 mA and 9 MeV deuteron beam on the copper cone Beam Stop. The activation of the Beam Dump materials give rise to a residual dose around it but also produce a dose field in the area devoted to the accelerator components maintenance. The purpose of this paper is to present a first design of the front part of the Beam Dump shielding that helps to allow the manual maintenance in the accelerator area.

INTRODUCTION: DEFINITION OF THE PROBLEM

The IFMIF-EVEDA accelerator prototype will be a 9 MeV, 125 mA CW deuteron accelerator [1], identical to the low energy section of one of the IFMIF [2] accelerators, which will be tested in Japan to verify the validity of the design before launching the IFMIF construction. As no target is foreseen for the accelerated deuterons, a Beam Dump (BD) is located at the end of the accelerator to stop the beam. A specific shielding for the BD has been designed demonstrating its capability to fulfil the radioprotection requirements during beam-on and on beam-off phases [3,4]. Figure 1 shows the already defined shielding, where the beam is coming from the left side of the figure.

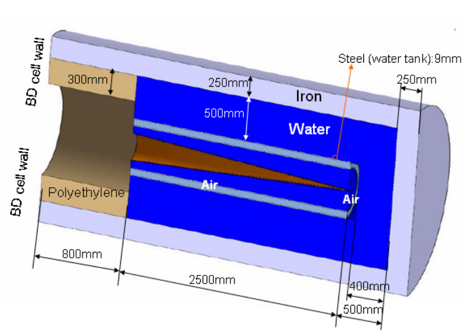

Figure1: Shielding of the Beam Dump.

In the design of the BD two of the key radioprotection requirements to be fulfilled are: i) dose values outside the accelerator vault during accelerator operation must be below the limits for workers and ii) inside the accelerator vault manual maintenance must be allowed during beam-off phases. This paper is focused in the design of the front part of the BD shielding whose main objective is to reduce doses during beam shutdown to fulfil requirement ii).

Figure 2 shows the location of the BD at the end of the accelerator line. The beam line is bent 20º before the BD to protect the accelerator components from the radiations coming from the BD on beam-on phase.

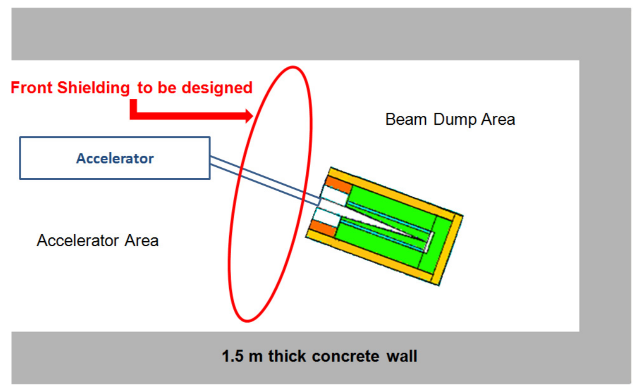

Figure 2: General layout of the accelerator vault. Location of the front BD shielding to be designed is showed.

Radiation Sources to Take Into Account

The radiations to be shielded during beam-off phase are coming to the BD activated components. The main activated materials are: i) the copper-cone Beam Stop; which is mainly activated by the deuteron beam and ii) the external iron layer of the BD shielding, activated by the secondary neutron source generated by the deuteron-copper interaction. It was shown previously [3,4] that outside the BD cell contribution ii) was negligible.

A preliminary analysis showed that residual radiation in the accelerator area due to the BD activation is mainly that coming across the vacuum line of the accelerator due to deuteron activation of the copper cone.

METHODOLOGY

The Monte Carlo codes MCNPX and PHITS, widely used in radioprotection accelerator studies, were initially considered as candidates for this kind of IFMIF/EVEDA applications. These codes use built-in analytical models to deal with deuteron nuclear interactions. In some of the first EVEDA radioprotection studies aimed to the BD design, the applicability of MCNPX to predict neutron production with sufficient accuracy in the particular situation of 9 MeV deuterons impinging on the copper beam stop was found questionable [5]. The traditionally used Monte Carlo codes, as MCNPX and PHITS, have been found as unreliable for transport deuterons. The models used in the mentioned codes such as INCL4/ABLA, ISABEL/Dresner/RAL, CEM03 and LAQGSM give rise to secondary particle production and spectra very different than those obtained by experiments. Thus, it turned out that the present version of the nuclear models included in MCNPX and PHITS are not appropriate for dealing with deuteron-induced reactions in the energy range of IFMIF/EVEDA applications [6] (up to 9 MeV).

Consequently, both generate reliable evaluated data libraries for deuterons and extend MCNPX to handle the nuclear data libraries is needed. The data used to transport deuterons are the TENDL libraries, generated by the nuclear code TALYS. The use of this data instead of semi-empirical models allows changing easily the nuclear data used to transport radiation when they need to be improved. The MCNPX code has been extended by the authors to handle with deuteron libraries, but also protons, triton and alpha particles. This new tool, called MCUNED [7], jointly with the TENDL library, is used to evaluate the secondary particle production and the associated spectra in the transport calculations in the IFMIF/EVEDA BD.

Once obtained the deuteron flux and the secondary particle production (neutron flux), the activation calculations are performed with the ACAB code [8] and the gamma source is transported with the MCNPX code [9]. Photon flux conversion to dose rates is done with the ICRP74 [10] conversion factors for ambient dose equivalent.

FRONT PART SHIELDING OF THE BD: DOSE RATES COMPLIANCE WITH LIMITS FOR WORKERS

A complete analysis of the radiations to be shielded, the space limitations and other considerations, was done in previous work [3,4]. As a result, a conceptual solution was proposed based on:

i) a concrete wall of 60 cm thickness and 4.5 meters high,

ii) additional 20 cm thick and 3 meters high concrete walls. All walls were assumed to be made of the same concrete of the accelerator vault walls (concrete proposed by JAEA with a hydrogen content of 0.56 % wt [3] (density = 2.1 g/cm^3) and

iii) a movable lead plug which is placed inside the beam tube before personnel access to the vault can be allowed.

With this configuration, a small part of the vault (called diagnostics area), that should have restricted access is separated from the rest of it. However, when analyzing the doses in detail using a realistic configuration of the walls with a labyrinth and taking into account also the presence of the accelerator elements, it appeared that there were some regions in the vault outside the diagnostics area in which dose values were too close or even higher than the limits (21 μSv/h).

To try to reduce these dose rate values further analysis have been done in two directions:

a) Explore the possibility of using higher density concrete in the part of the BD cell wall in front of the BD.

b) Optimize the parameters (thickness and radius) of the lead plug.

After this evaluation, a solution with the BD cell wall made of steel-magnetite concrete [11], which is more efficient to attenuate and absorbing the photons (see figure 3) is proposed.

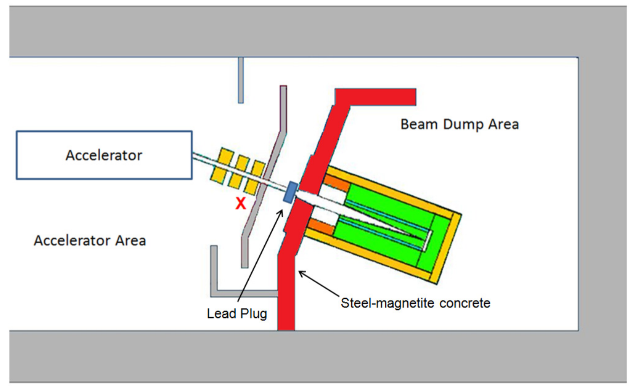

Figure 3: Front part of the Beam Dump shielding.

The shielding proposed consist of the following fixed components: i) a concrete wall of 60 cm thickness and 5 meters high, made of steel-magnetite concrete [11], which is more efficient to attenuate and absorbing the photons and ii) additional concrete walls made of the same concrete of the accelerator vault walls of 20 cm thick and 3 meters high. Also, a movable lead plug is placed on beam-off phase.

The labyrinth configuration is designed to allow manual maintenance at the last part of the accelerator line permitting the entrance to the diagnostic area (area located between concrete walls) when needed.

The composition of the steel-magnetite concrete is showed in Table 1.

Table 1: Steel-Magnetite Concrete Composition (% wt)

Raw materials		Element	
Portland cement	7.55	Hydrogen	0.51
Magnetite	26.19	Oxygen	15.70
Steel scrap	61.73	Magnesium	0.58
Water	4.53	Aluminium	0.60
		Silicon	2.60
		Phosphorus	0.08
		Sulphur	0.06
		Calcium	3.95
		Manganese	0.07
		Iron	75.73

The cross of the Figure 3 shows the place of the accelerator area where maximum residual dose rates are measured. This place is located beside the last quadrupole of the high energy beam transport section of the accelerator. In this place, residual dose is due to: i) photons crossing the hole of the 60 cm-concrete wall and the lead plug and ii) photons crossing the 60 cm-thickness steel-magnetite concrete wall (figure 3).

Different combinations of radius and thickness of the lead plug have been analyzed in order to optimize its size and weight. The requirement to be fulfilled in the accelerator area is the dose rate limit (12.5 μSv/h) for workers according the Japanese law. Table 2 shows residual dose rates at "X" location for different sizes of the lead plug.

Table 2: Residual dose rates at highest exposed location of the accelerator area. 6 months continuous irradiation. 1 day cooling time.

Lead Plug Radius (cm)	**Lead Plug Thickness (cm)**	**Residual Dose Rate (μSv/h)**
14	6	7.1
	9	5.4
	12	5.4
18	6	2.5
	9	1.1
	12	0.7
22	6	2.1
	9	0.4
	12	0.1

All the configurations fulfil the requirement for manual maintenance in the accelerator area without restrictions. The chosen configuration for the lead plug consists of 18 cm radius and 9 cm thickness. The 18 cm radius provides a safety margin for doses in the accelerator area and the 9 cm thickness allows doses bellow the limit for manual maintenance with restrictions (250μSv/h) in the labyrinth.

CONCLUSIONS

This paper is focused on the optimization of the design of the front part of the IFMIF/EVEDA BD shielding. The proposed design fulfils the dose rate limits for workers in the accelerator area without restrictions.

REFERENCES

[1] P. Garin, M. Sugimoto. Main Baseline of IFMIF/EVEDA project. Fusion Engineering and Design. doi:10.1016/j.fusengdes.2008.12.040

[2] A. Mosnier, U. Ratzinger. IFMIF accelerators design. Fusion Engineering and Design. doi:10.1016/j.fusengdes.2008.05.024

[3] M. García, F. Ogando et al. Optimized design of local shielding for the IFMIF/EVEDA beam dump. SATIF 10. Workshop Proceedings, Geneva, Switzerland 2-4 June 2010.

[4] F. Ogando et al. IFMIF-EVEDA Beam Dump Local Shielding: Conceptual Design. CIEMAT Report IN-IF-ACBD-013, LIPAC Report DMS 222329.

[5] J. Sanz, M. García, F. Ogando et al. First IFMIF/EVEDA Radioprotection studies for the preliminary design of the accelerator Beam Dump. Fusion Science and Technology, 56, 1, 273-280 (2009).

[6] V. Blideanu, M. García et al. Deuteron cross section evaluation for safety and radioprotection calculations of IFMF/EVEDA accelerator prototype. Journal of Nuclear Mater. doi:10.1016/j.jnucmat.2010.12.270

[7] P. Sauvan, J. Sanz, F. Ogando. New capabilities for Monte Carlo simulation of deuteron transport and secondary products generation. Nuclear Instruments and Methods. Phys. Res. Sect. A 614, 323 (2010).

[8] J. Sanz. ACAB: Activation Code for Fusion Applications: User's Manual V5.0, Lawrence Livermore National Laboratory, UCRL-MA-143238, February (2000).

[9] D. B. Pelowitz,, ed.: MCNPX User's manual, Version 2.5.0. LA-CP-05-0369 (2005). J. S. Hendricks et al.: 'MCNPX 2.6.0 Extensions' LA-UR-08-2216. http://mcnpx.lanl.gov (2008).

[10] ICRP. 'Conversion Coefficients for Use in Radiological Protection against External Radiation'. International Commission on Radiological Protection, ICRP Publication 74. Tarrytown, NY (1996).

[11] I. Bashter. Calculation of radiation attenuation coefficients for shielding concretes. Annals of nuclear Energy (1997). Volume 24. Issue 17. Pages 1389-1401.