INDIRECT MEASUREMENT OF POWER DEPOSITION ON THE IFMIF/EVEDA BEAM DUMP BY MEANS OF RADIATION CHAMBERS*

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Abstract

The beam stop of the IFMIF/EVEDA accelerator will be a copper cone receiving a total power of ~1 MW, coming from 9 MeV D^+ at 125 mA. The mechanical stresses in this beam dump (BD) come mainly from the thermal gradients generated in the cone, being related with the power deposition profile. Anomalous situations can lead to variations in this profile outside the normal operation range, which must be detected and corrected for BD protection. Due to the interaction between D^+ and the Cu cone, important neutron and gamma fluxes are generated around the BD, with a spatial profile which is directly linked to the power deposition. A diagnostic based on a set of fission chambers is proposed to measure this radiation field, giving indirect information about the power deposition on the BD.

INTRODUCTION

Since the deuteron interaction with the copper cone will produce an intense neutron and gamma field, radiation monitors have been proposed for indirect measurement of the power deposition profile on the BD [1].

A first search has showed a variety of detectors susceptible of being used: self-powered neutron detectors (SPND), boron proportional counters, fission and ionization chambers. However, the response time of SPND is extremely high and cannot be used as safety interlock. Concerning the boron lined proportional counters, their typical size is too large for the available space in the BD, and the neutron flux range which they can cover is not enough. Fission or ionization chambers seem to be adequate sensors to be installed in the BD.

Since the gamma fluxes in the BD are not excessively large compared to neutron fluxes, the work has been concentrated on exploring the feasibility of using fission chambers (FC) to detect variations on the neutron flux.

STARTING POINT FOR FC DESIGN

The main objective of the FCs is to follow the correct operation of the BD in terms of the expected radiation fields. Thus, the chambers detect possible misalignments or defocusing of the beam through the neutron flux measurement.

For this application, the chosen FCs should fulfil the following requirements:

- Adequate neutron sensitivity for the expected fluence rates. Additionally, the operational range should allow measuring the radiation field at different beam powers.
- Reduced burn-up at the end of the operation period, to assure a constant sensitivity.
- High availability is one of the main requirements of IFMIF/EVEDA accelerator. Therefore, it also demands a high reliability in the instrumentation, which should be as standard as possible.
- Proper dimensions in order to have the best spatial resolution. If not, changes in the spatial distribution of the radiation field could be not properly distinguished.
- Linked to the previous point the impact on the design of the BD should be minimal.
- Small response time.

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DESIGN CALCULATIONS

Setup

The detectors will be installed in the free space between the cartridge and the shielding tank (approximately 10 cm of free space) to avoid penetrations for cables inside the cartridge, see Fig. 1. In order to detect possible asymmetries in the neutron and gamma fluxes, the FCs must be placed at symmetrical and opposite places.

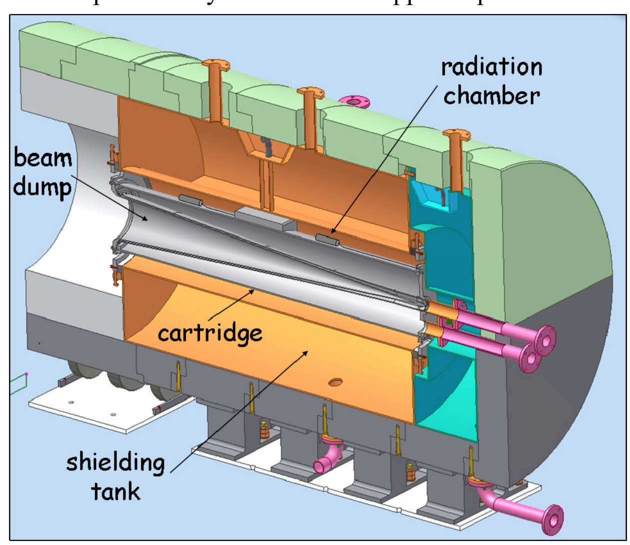

Figure 1: Detector positions inside the beam dump.

The foreseen setup consists of a set of six detectors grouped in two rings along the axis of the cone (250 cm). The three detectors of each ring will be distributed azimuthally at 120º (Fig. 2), being azimuthal detector positions equal in both rings.

Neutronics Calculations

MCUNED code [2] with TENDL09 nuclear data has been used to calculate fluence rates and spectra. MCUNED retains MCNPX transport capabilities and allows using external libraries for light ion reactions. The calculated neutron fluence rates are in the range $10^9 – 10^{11}$ n/cm^2/s, which after one year of full power operation would lead to a total neutron fluence of 10^{18} n/cm^2.

To check the feasibility of the FCs for detecting abnormal operations of the beam two scenarios have been studied: a) beam divergence at the last quadrupole 10% smaller than nominal, which will cause a longitudinal (along the BD axis) shift of the source intensity distribution; b) beam misaligned by 10 mm, which will result in non axisymmetric radiation field.

In this last case the beam has been shifted by 10 mm in the direction towards one of the detectors (NEAR detector, see Fig. 2). In the most general case beam can be misaligned to an arbitrary direction, but simple mathematics and thorough consideration of system symmetries allow determining the displacement direction.

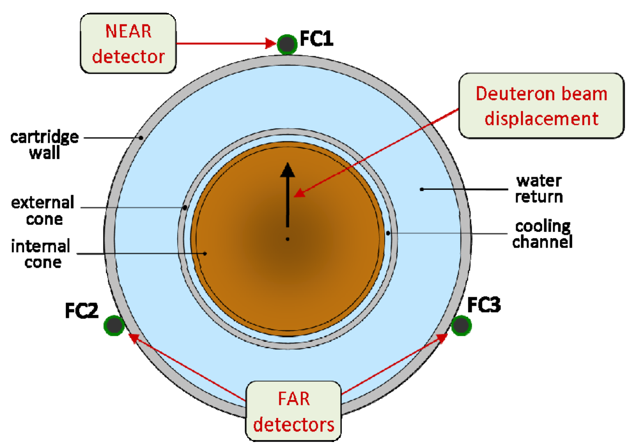

Figure 2: Cross section of a detector ring with misaligned beam.

Two longitudinal positions have been selected for the study, corresponding to x_{RING1} =60 cm, x_{RING2} =165 cm, with x measured from the cone base.

Table 1 shows the variation percentage of the neutron fluence rate with respect to the nominal case for both rings. As can be seen, the neutron and gamma responses to beam perturbations are similar.

Table 1: Neutronics for RING1 and RING2 Positions

	RING1 neut	RING1 gamma	RING2 neut	RING2 gamma
Nominal (1/cm^2/s)	$5.16 \cdot 10^9$	$2.94 \cdot 10^{10}$	$4.53 \cdot 10^9$	$3.92 \cdot 10^{10}$
Narr	-46%	-34%	+19%	+17%
Misal: NEAR	+24%	+20%	0%	+5%
Misal: FAR	-5%	+2%	0%	+6%

Fissile Material Selection

The fissile material which covers the electrode of the FC has been chosen to obtain the maximum sensitivity (which is proportional to the fission rate) for the representative neutron energies. As seen in Fig. 3, in both ring positions the thermal part of the neutron spectrum is dominant compared to high energy neutrons (E > 1 MeV). Therefore it seems advisable the use ^{235}U as fissile deposit, being commercially available.

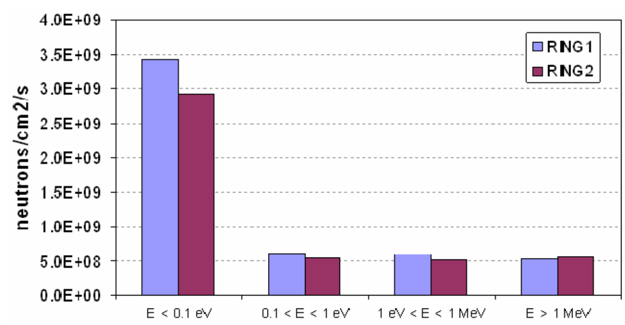

Figure 3: neutron fluence rates for x_{RING1} and x_{RING2} positions, per energy group.

On the other hand, the signal level from the chamber is strongly linked to the burn-up of the fissile material. A simple calculation has been performed taking into account the main reaction responsible of the loss of the deposit, i.e. radiative capture, (n,γ). The total 'burning' rate is 3.55 x 10^{-13} s^{-1}, which corresponds to a burn-up after 1 year of operation < 0.01%.

Technical Characteristics of the FC

The most general expression for the FC sensitivity, which only assumes isotropic emission of the fission fragments and straight fission fragment paths with a constant energy loss per unit length, is given in [3]. Considering neutron fluxes ~5 x 10^9 n/cm^2/s (RING1, RING2 positions), and desired signals of the order of several μA (since the beam will work at different powers from 0.1 to 100%), a neutron sensitivity value of S_n ~ 2 x 10^{-15} A/(n/cm^2/s) is required.

Concerning the operation regime, it is assumed that the FC will work within the saturation zone, i.e. where all the primary charges created when a fission product crosses the gas are collected. This zone is independent of the applied voltage, between a minimum value V_{min} and a maximum of V_{max}. Their expressions can be found in [4]. A numerical code, based on [4,5], was developed and presented in a previous work, [6]. The procedure calculates the intensity delivered by the chamber and the limits of its saturation plateau.

A study for obtaining the maximum S_n value, attending to size constraints and the operational regime of the detector, has been performed. As a result, the technical characteristics for a FC operating in the BD have been obtained (Table 2). In this table, r_c is the cathode radius, r_a the anode radius, h the length of the fissile deposit and μ_s the surfacic mass of the fissile material.

This chamber has the following values of sensitivity to neutrons and gammas, with the saturation plateau limits:

$$S_n = 1.7 \times 10^{-15}\ \mathrm{A/(n/cm^2/s)};\ S_\gamma = 2.37 \times 10^{-10}\ \mathrm{A/(Gy/h)}$$
$$V_{min} = 88\ \mathrm{V};\ V_{max} = 1400\ \mathrm{V}$$

Table 2: Technical Parameters of the Proposed FC

Geometrical characteristics		
	Nominal diameter	20 mm
	r_c	10 mm
	r_a	8 mm
	h	60 mm
Filling gas		
	gas	argon
	pressure	2 bar
Fissile deposit		
	material	^{235}U
	μ_s	2 µg/mm^2

FC SIGNALS DURING BD OPERATION

The saturation current of a fission chamber with the technical parameters of Table 2 has been calculated according to [6]. Two different positions in the BD, corresponding to three fission chambers located in RING1 and RING2, have been evaluated during normal operation and perturbed scenarios: a narrower beam and a misaligned beam. Fig. 4 shows the total current ($I_n + I_\gamma$) calculated for the six chambers. Note that the gamma contribution is less than 1% for all the cases studied. FC1 corresponds to the NEAR detector (see NEUTRONICS). Results show that, during normal operation, signals of the order of 7 - 8 µA are expected.

When abnormal situations are presented, changes in the absolute signals as well as in the relative values between the chambers are found:

a) beam divergence reduction of a 10% produces opposite effects in the two rings, keeping the axial symmetry in both.

b) misalignment by 1 cm produces a smaller but detectable response on most of the chambers. For the NEAR detector, the effect is quite strong.

RING2 of detectors is hardly sensitive to misalignments; RING1 shows noticeable anisotropy in results.

Therefore, out of nominal conditions the set of FCs produces a response that can be used to detect the kind and magnitude of the beam perturbation. Moreover, with the appropriate electronics a FC chamber can easily measure signals of the order of nA, so the corresponding minimum neutron flux that can be measured is ~10^6 n/cm^2/s. Therefore, the proposed FC can operate even when the beam has 0.1% of its total power (assuming that the response is lineal within all the range).

CONCLUSIONS

In this work, a diagnostic based on a set of FCs for measuring the radiation field around the BD has been explained. Its main objective is to relate changes in the neutron flux with changes in the beam power deposition on the BD. The main strategy has been explained, establishing the main specifications and requirements of the detectors.

Neutronics calculations have been performed with MCUNED code. Both neutron and gamma fluxes are similarly sensitive to beam perturbations, with variations due to the test cases in the order of 20%, which is higher than typical detector accuracy. Fission chambers are therefore suitable detectors to get information about beam perturbations and changes in its intensity.

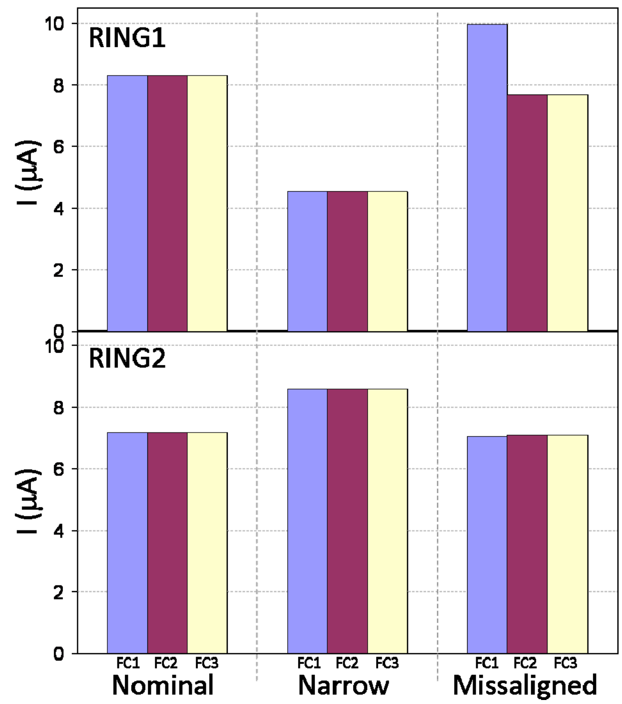

Figure 4: Total current delivered by the FCs for three different scenarios.

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