RADIOLOGICAL HAZARD ASSESSMENT FOR THE BEAM DUMP OF HIGH INTENSITY DEUTERON ACCELERATORS

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Abstract

The Engineering Validation and Engineering Design Activities (EVEDA) phase accelerator prototype of the International Fusion Materials Irradiation Facility (IFMIF) project will require a Beam Dump (BD). Low activation and low neutron production are some desirable properties that beam facing stopping material (BFSM) should possess. In order to compare the behaviour of candidate materials in a preliminary design of BFSM, Aluminium, Copper, Nickel and Tungsten are studied according to neutron production, generation of troublesome isotopes of concern for gamma dose rates evaluations and its final management options as radioactive waste. A relevant objective in this process is the identification of the main reactions on neutron production and activation behaviour, which can be helpful for further improvements of deuteron cross section.

INTRODUCTION

The irradiation scenario expected in the EVEDA BD is 125 mA current of charged particles with 9 MeV energy. Charged particles are deuterons (D^+) for normal operation. The BFSM (preliminary design considered is a cone of inner dimension: 20 cm diameter, 250 cm length and 0.3 cm thickness) will be activated by both primary charged particles and secondary generated neutrons. These neutrons are also responsible of activation in other components of the BD due to its high penetration. Flux level considered for D^+ induced activation is 10^{15} d/cm^{2}s, which is obtained considering the geometry mentioned above. Neutron induced activation is calculated using the flux obtained multiplying deuteron flux by the corresponding neutron per deuteron value evaluated for each material in the next section. In the activation assessment, ACAB code [1] was used considering 1 month of continuous irradiation. For the candidate materials, neutron production per incident deuteron is computed and reactions resulting on troublesome isotopes in gamma dose rates evaluations are identified. Also, unconditional clearance and near surface disposal as radioactive waste management options are discussed.

NEUTRON PRODUCTION

In the evaluation of neutron produced by incident deuteron only the contribution coming from d-material reactions has been considered. Three methods for this computation have been used: MCNPX [2] and PHITS [3] transport codes and an own procedure [4] that, after characterization of deuteron flux, uses neutron production cross section obtained by EAF-2007 deuteron data library [5] processing. Results are shown in Figure 1, noting significant differences in the case of Tungsten.

These differences between methods can be attributed to two causes: the first one are the nuclear models contained in each transport code, and the other one is the fact that MCNPX transport code do not produce secondary neutrons up to 6 MeV approximately. This last aspect is the reason why PHITS and the own procedure were employed. This last method was also used in the neutron flux computation in order to take into account recent nuclear data contained in EAF-2007 library.

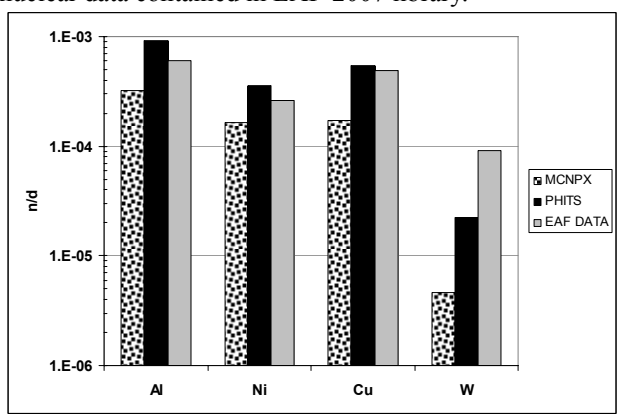

Figure 1: Neutrons produced per 9 MeV incident D^+.

The most important reactions contributing to neutron production up to 9 MeV deuteron energy are given in Table 1 for the natural isotopes of the candidate materials.

Table 1: Reactions contributing to neutron production

Natural Isotopes	Reaction
Al27 (100%)	(d,n), (d,na)
Cu63 (69.17%)	(d,n), (d,2n), (d,na)
Cu65 (30.83%)	(d,n), (d,2n), (d,na)
Ni58 (68.077%)	(d,n)
Ni60 (26.223%)	(d,n)
Ni61 (1.14%)	(d,n), (d,2n)
Ni62 (3.634%)	(d,n), (d,2n)
Ni64 (0.926%)	(d,n), (d,2n)
W180 (0.12%)	(d,n), (d,2n)
W182 (26.5%)	(d,n), (d,2n), (d,2n)-m
W183 (14.31%)	(d,n), (d,2n), (d,n)-m
W184 (30.64%)	(d,n), (d,2n), (d,2n)-m
W186 (28.43%)	(d,n), (d,2n), (d,2n)-m

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GAMMA DOSE RATES STUDIES

This study is focused to assess the contribution of both deuteron and neutron induced activation to contact dose rates in the BFSM preliminary model. For this evaluation, isotopes contributing to dose rates and their production reactions were identified. This list of reactions can be useful on future quality checking of deuteron cross sections and its possible improvement if necessary. Reasonable cooling times considered here for these purposes are up to one week.

Deuteron

ACAB code and EAF-2007 deuteron cross section data library were used in the determination of the radioisotopes contributors to dose rates due to deuteron irradiation.

The greater contributors up to one week of cooling time come from direct reactions (in the case of Aluminium this affirmation is valid since Na24m is a very short-lived radionuclide). In Table 2 can be seen these isotopes with their contribution percentage and production reaction at one week of cooling time.

Table 2: Dose rates isotopes contributors by D^+

Material	Isotope	%	Reaction
Aluminium	Na24	96.85	Al27(D,PA)Na24m [a]
	Na22	3.15	Mg24(D,A)Na22 [b]
Nickel	Co56	83.12	Ni58(D,A)Co56
	Co58	16.88	Ni58(D,2P)Co58 (g+m)
			Ni60(D,A)Co58 (g+m)
Copper	Zn65	99.95	Cu65(D,2N)Zn65
Tungsten	Re184	96.85	W182(D,G)Re184
			W183(D,N)Re184
			W184(D,2N)Re184
	Re182	1.85	W182(D,2N)Re182
	Re183	1.02	W182(D,N)Re183
			W183(D,2N)Re183

[a]Na24m→Na24 (20ms)
[b]Na24→Mg24 (15h)

Figure 2 shows an example of evolution of contact dose rates from the surface for Nickel, separated in isotopes in order to note the contribution of each one up to one week of cooling time.

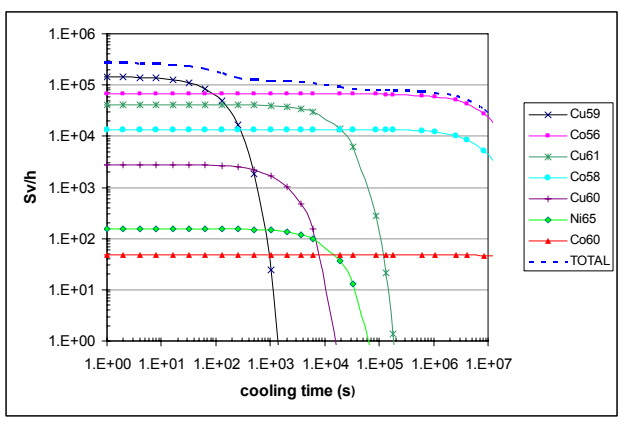

Figure 2: Contact dose rate evolution by D^+ in Nickel.

Neutron

ACAB code and EAF-2007 neutron cross section data library [6] were used in the determination of radioisotope contributors to dose rates due to neutron irradiation.

As in this case of deuterons, main contributor isotopes to dose rates come from direct reactions. In Table 3 present these isotopes with contribution percentage and their production reaction at one week of cooling time.

Table 3: Dose rates isotopes contributors by n

Material	Isotope	%	Reaction
Aluminium	Na24	100.00	Al27(N,A)Na24
Nickel	Co58	98.65	Ni58(N,P)Co58
			Ni60(N,T)Co58
Copper	Co60	99.63	Cu63(N,A)Co60 (g+m)
Tungsten	W187	70.03	W186(N,G)W187
	Ta182	26.01	W182(N,P)Ta182
			W183(N,NP)Ta182
	Ta183	1.87	W183(N,P)Ta183
			W184(N,NP)Ta183
	Hf181	1.68	W184(N,A)HF181

Figure 3 shows an example of evolution of contact dose rates from the surface for Nickel, separated in isotopes and emphasizing the main contribution of Co58 up to one week of cooling time.

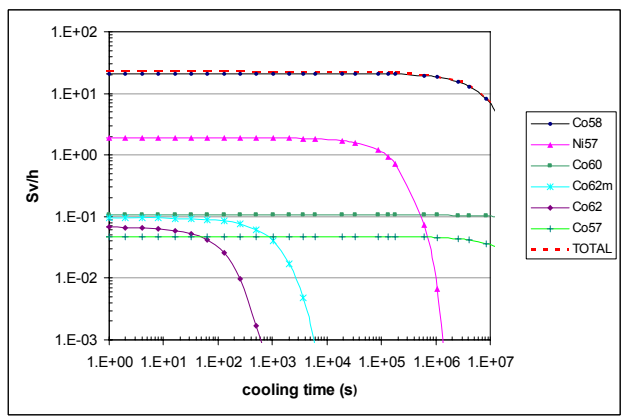

Figure 3: Contact dose rate evolution by n in Nickel.

Comparison

We have computed surface gamma dose rates for a thin infinite slab source of 3 mm thickness due to deuteron and neutron induced activation on BFSM resulting from incident deuteron.

In the preliminary model considered here, deuterons impinge on the BFSM with around two degree angle respect to its surface. This supposes a penetration range of a few micrometers (calculated with SRIM code [7]) and small activated volume. On the other hand, due to its high penetration, neutrons activate whole BFSM. However, deuteron contact dose rate level is higher than that by neutrons for all the studied materials.

Photons emitted by each material by both by deuteron and neutron irradiation have mean free path significantly higher than the thickness of each activation zone and the model for thin infinite slab source can be applied.

Table 4 shows the contributions from deuterons and neutrons at one week of cooling time to total contact dose rate, including ratios of dose rates and activated volumes.

Table 4: Neutron contribution to contact dose rate

Material	Dose ratio	Volume ratio	Neutron contribution
Aluminium	$4.57 \cdot 10^2$	243	34.60 %
Nickel	$3.81 \cdot 10^3$	477	11.11 %
Copper	$7.85 \cdot 10^4$	456	0.57 %
Tungsten	$1.14 \cdot 10^6$	360	0.03 %

WASTE MANAGEMENT

Management options for the activated BFSM as radioactive waste are studied by means of two aspects: clearance levels [8] based on IAEA recommendations and waste disposal ratings (WDR) [9]. Corresponding values were calculated with ACAB code.

Clearance levels give radioisotope concentration limits to use, in this case, in unconditional declassification of activated materials as radioactive waste in order to minimize quantity of matter that requires long-term storage. It can be cleared if the corresponding clearance index (CI) is below unit. For any of the studied elements, the deuteron activated material can not be unconditional clearance at a hundred years of cooling time (Tungsten is the nearest material to the limit and the CI at 100 years of cooling is as high as 70).

WDR is an index used to assess the possibility to place the activated materials after irradiation at a shallow land burial according to American radioactive waste legislation. Irradiated materials with values of WDR below unit can be placed in this type of waste storage. For all the candidate materials, WDR is below allowable limit by both deuteron and neutron induced activation, especially for neutrons. Nickel is the nearest material to this limit (WDR=0.873).

CONCLUSIONS

Several materials have been studied as candidates for a preliminary BFSM model for the EVEDA phase accelerator prototype.

Neutron production was assessed using three methods and noting differences between them. The last one was selected in the determination of neutron flux levels used in activation calculations in order to take into account recent cross section data contained in EAF-2007 data library.

For the assessment of deuteron and neutron contribution to dose rates useful for maintenance works, one week was selected as reasonable waiting time. Radionuclide contributors to contact dose rate by both deuteron and neutron irradiation at this cooling time were identified and checked that comes from direct reactions with the natural isotopes of the candidate materials. Neutron contribution to total contact dose rate was also evaluated, showing in the Aluminium case to be appreciable.

Final waste management comments through clearance levels and WDR index were presented, noting the possibility to place BFSM in a shallow land burial (according to American legislation).

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