BEAM STOP OF SPIRAL2 FACILITY: ACTIVATION AND RESIDUAL DOSE RATE CALCULATIONS

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Abstract

SPIRAL2 facility will produce 5mA of deuterons at 40 MeV. A beam dump device has been designed to stop the beam.

The residual dose rates in the beam dump room during beam-off phases at cooling times up to one year have been computed using the following methodology: i) ISABEL built-in MCNPX nuclear model to deal with deuterons transport and production and transport of secondary neutrons, ii) deuteron and neutron induced activation were simulated using ACAB code and EAF2007 library, iii) decay gammas were transported using MCNPX to compute residual dose rate.

The ambient dose equivalent rate is mainly due to the activated copper pieces of the beam stop. Uncertainties in the results are mainly due to d-Cu activation cross sections and due to the determination of the neutron source. Correction factors to improve the activation cross section are proposed and residual dose rate range depending nuclear data used to compute the neutron source (nuclear model or library) will be evaluated.

INTRODUCTION

The SPIRAL2 facility at GANIL-Caen is now in its construction phase. It has been design to produce various accelerated beams at high intensities. As no target is foreseen for the accelerated beam, a beam dump (BD) is required to stop it. The BD device is located in a dedicated room. The knowledge of the decay dose rate during beam-off phases is an important safety issue for dismantling tasks.

The residual dose rate evolution of the Spiral2 accelerator working with deuteron beam have been computed for cooling times up to one year. The origin of the residual dose rates are on one hand the deuteron induced activation of the BD materials and on the other hand the secondary neutron interaction with all the materials of the BD room (cartridge, concrete walls, supports and other accessories). Methodology, results and their uncertainties are presented in following sections.

METHODOLOGY

The simulation has been done using the specifications provided in the facility plan [1]. The deuteron beam (40 MeV and 5 mA) is coaxial with the beam stop and has a radial gaussian intensity distribution. The irradiation scheme for simulation is 20 years of pulsed operation, defining each pulse as 3 months of irradiation (417 W continuous) followed by 1 month of cooling.

The simulations have been performed in three steps. In the first step, main items are the transport of deuterons, production and transport of secondary neutrons. The deuteron and neutron fluxes obtained in this step are used to compute the activation of the materials and to get the residual gamma sources. The last computational step is the transport of all these residual photon sources to calculate the dose rate.

Neutron fluxes (first step) are computed using ISABEL/DRESNER/RAL built-in MCNPX nuclear model. Additional approaches have been used to compute the neutron fluxes: INCL4 from MCNPX2.6f code [2] and TENDL2009 libraries [3] with MCUNED code [4]. Neutron and photons transport simulations have been done using Monte Carlo code and ENDF/b-vi and MCLIB04p nuclear data library [5]. The activation is computed using the ACAB code [6] and EAF2007 nuclear data libraries [7].

The dose rate is presented through the magnitude ambient dose equivalent (ADE), as defined in ICRP103 [8]. The conversion factors from fluency to dose rates come from ICRP74 [9].

RESULTS

Dose Rate Due to BD Cartridge Activation

The BD cartridge is made of copper and steel 304L pieces (figure 1). In this section the BD is located out of the niche (hole in the concrete wall of the BD room) for dismantling analysis purpose.

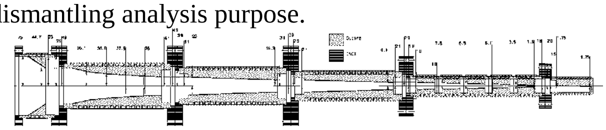

Figure 1: SPIRAL2 beam-stop sketch [1].

The figure 2 shows the ADE maps and the cartography for locations parallels to beam axis at radial distances of 20 cm (yellow lines) and 1 m (blue lines) at times up to 1 year after shutdown. The ADE rate has radial symmetry, but in the inlet of the BD (x=0) it is approximately to one order of magnitude higher than that at the apex (x=166 cm). The maximum value at 1 day after shutdown is 21 mSv/h. This level decreases to 16 and 9 mSv/h at 90 and 365 days, respectively.

The total ADE rate is due mainly to copper activation (at 1 and 365 days after shutdown, contributions from d-Cu are 69% and 52%; and from n-Cu 23% and 40%,). The steel pieces are only activated by neutrons. The main radionuclides contributing for cooling times up to one year from d-Cu are Zn65 and Co60 and from n-Cu it is Co60.

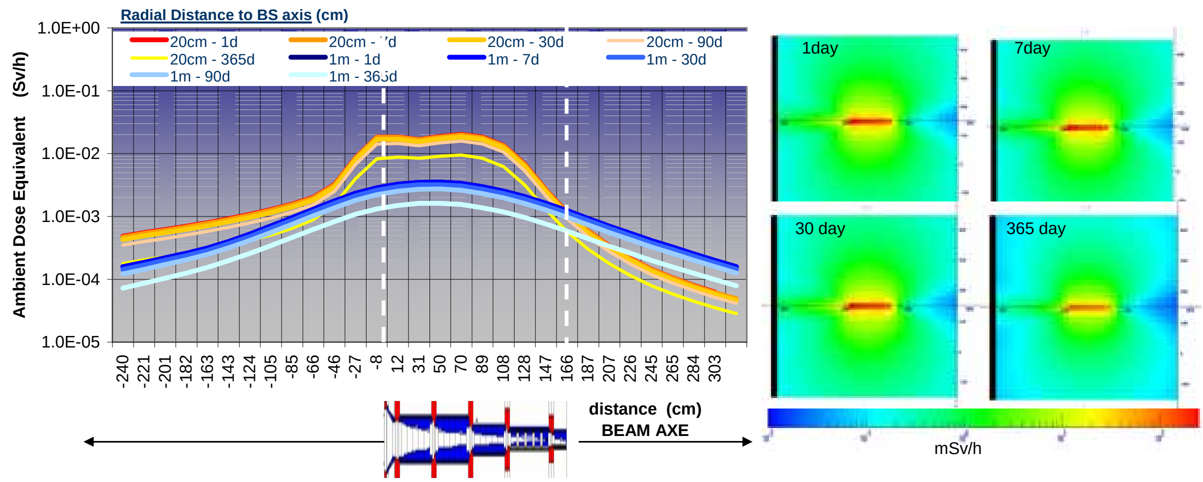

Figure 2: ADE rates at cooling time up to 1 year. Cartography and dose maps for radial distances of 20cm and for 1m from BD axis (cylinder mesh. Origin axis at the inlet of the BD. BD length 166 cm)

Residual Dose Rate in the Beam Dump Room

The BD room is a dedicated room for this device. The entrance to this area is mainly expected for dismantling task but some maintenance operations can be realized also. The BD is located at 150 cm from the floor inside a niche (hole in the east wall). All the walls are made of concrete. Marble and lead are additional shielding to reduce the dose in the room [1].

The maximum dose is located close to the BD niche. At 1 day after the shutdown the maximum ADE is 12 mSv/h. It decreases to 78% and to 34% at 30 and 365 days of cooling time, respectively. ADE has not radial symmetry with the beam axis for cooling times shorter than 7 days, due to the photons coming from activated walls and accessories.

The ADE decreases with the distance to the BD niche along a location parallel to the beam axis (3 and 1 order of magnitude for 20cm and for 60cm, respectively). Finally, the main contributor to the ADE in the BD room is the BD cartridge activation. Therefore, only the transport and activation of the BD will be assessed regarding uncertainties.

UNCERTAINTIES ASSESSMENT

Former studies about the residual dose rate due to deuteron induced activation in copper showed significant uncertainties due to activation cross section and the nuclear data used to compute the neutron source (built-in nuclear models or libraries) [10,11]. This section includes the assessment of these uncertainties regarding the results presented in this paper.

d-Cu Activation Cross Section Uncertainties

The figure 3 shows the comparison between the activation cross sections (XS) used in this work (EAF-2007) and available experimental data [12,13,14] for the main radionuclides contributing to residual dose (Zn65, Co58 and Co60).

The radionuclide Zn65 (contribution to ADE from 40% to 44% at 1 and 365 days) mainly comes from Cu65(d,2n) reaction. The XS used shows a reasonable fit to experimental data for energy up to 11 MeV and lightly underestimation for higher energy [12]. For Co58 and Co60 radionuclide the fit with experimental data is not so good (fig.3). For Co58 (contribution to ADE at 1 and 365 days: 38% and 3% respectively) the results are an overestimation [13] and for Co60 (at 1 and 365 days: 19% and 52% respectively) above results are an underestimation [14].

In order to solve the disagreement with the experimental data for Co58 and Co60, it is proposed to modify the ADE with a correction factor for each reaction based on the ratio between the corresponding collapsed cross section obtained using the experimental data and using EAF2007. The modified ADE rates using this procedure (table 1) leads to a reduction at 1 day of cooling time from 21.6 to 18.8 mSv/h. At 365 days it will be increased from 9.5 to 10 mSv/h.

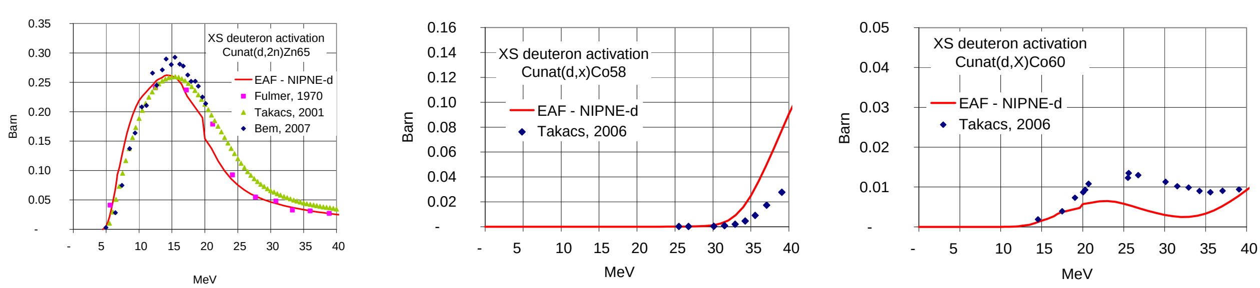

Fig.3 EAF2007 activation data base and available experimental data [12, 13, 14]

Neutron Source Computational Approach

The neutron source needed to calculate the neutron induced activation in the previous sections were computed using ISABEL nuclear model (default model MCNPX). In this section two additional approaches have been used to compute the neutron source: i) INCL4 built-in nuclear model MCNPX ii) TENDL2010 library with MCUNED code.

At one day after shutdown the maximum ADE rate computed with ISABEL, INCL4 and TENDL2010 are 21, 18 and 17 mSv/h, respectively. The ADE contribution due to neutron induced activation calculated with ISABEL model along BD zones is up to two times higher than that for INCL4 option and up to 7 times higher than that for TENDL2010. The difference in the results from these approaches is due to the amount of produced Co60. The half life of the isotope Co60 (1925 days) allows to suppose that differences at 1 day will be similar for cooling times up to 1 year (table 1).

The combined effect of the total neutron flux and its energy spectrum allows to explain the differences in the dose rate by each approach. The effect of the neutron spectrum regarding Co60 formation for the different approaches can be summarized through the collapsed cross sections (CXS) along the BD zones (ISABEL CXS is in range 0.9 to 1.15 compared with INCL4; and in range 2 to 3.4 compared with TENDL2010).

Also, it has been observed that ISABEL computes unphysical high energy neutrons above 45 MeV.

Table 1: Summary: ADE rates and proposed corrections

mSv/h	MCNPX ISABEL	XS d-Cu activation	Neutron source INCL4	TENDL10
1d	**21.6**	-2.8	-3.4	-4.4
365 d	**9.5**	+0.5	-3.4	-4.4

CONCLUSIONS

The work presented here is focused on the assessment of the residual dose rates that can be expected in the BD room of Spiral2 facility during beam-off phases as consequence of the deuteron beam stopping.

The maximum dose rates due to BD cartridge activation 1 day after shutdown is 21 mSv/h. This level decreases to 16 and 9 mSv/h at 90 and 365 days respectively. It is due mainly to copper pieces activation (+90%).

The BD is located inside a hole in the concrete wall. Marble and lead plug are additional shielding. The dose in the room is mainly due to BD cartridge activation. The maximum dose rate is 12 mSv/h at one day after shutdown (it decreases to 9 and 4 mSv/h at cooling times of 30 and 365 days respectively).

The uncertainties due to the methodology used to compute the residual doses were assessed. Significant differences in the ADE rate calculated are due to the not good fit of the activation data library used (EAF2007) with the experimental data for d-Cu reactions. A correction factor for each reaction has been proposed to improve the fit: "the ratio between the corresponding collapsed cross section experimental data and for EAF2007". The maximum dose rate due to BD cartridge at 1 day after shutdown will be modified from 21.6 mSv/h to 18.8 mSv/h and at 365 days from 9 mSv/h to 9.5 mSv/h.

The differences over the ADE due to neutron flux computational approach used are relevant. The ISABEL option (default MCNPX nuclear model) is the most conservative, but it shows an unrealistic neutron spectrum. INCL4 and TENDL2010 approaches will decrease the resulted ADE rate in 3.4 mSv/h and 4.4 mSv/h, respectively.

Summarizing, the ADE due to BD cartridge activation will be in range of 21.6 to 14.4 mSv/h at 1 day of cooling time; and in range of 9.5 to 5.6 mSv/h at 365 days.

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