ACTIVATION CALCULATIONS FOR THE TARGET OF THE ULTRACOLD NEUTRON SOURCE

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In order to operate safely and dispose of the target of the planned Ultracold Neutron Source at PSI after its lifetime, it is necessary to have detailed knowledge of the induced activation in the target system. The following article deals with the calculation of the induced activation of the target assembly of the UCN.

INTRODUCTION

The **U**ltra**c**old **N**eutron Source - UCN-source - is scheduled to start operation at PSI in 2006 using an up to 2 mA proton beam from the ring cyclotron. It will be operated in a pulsed mode - beam on target for 8 s and off for 792 s - resulting in an average current of 20 μA. Detailed knowledge about the activation of all components of this facility is required to ensure safe maintenance.

However, special attention has to be payed to the target assembly of the UCN as it is the most highly activated component. The target assembly will be mounted horizontally in the proton beam line and consists of the following components: the Aluminium beam window, the container of the Zircaloy target, the Zircaloy target (Zy), a Lead shielding block and a steel shield towards the handling zone - see Figure 1. The neutron production will mainly take place in the Zircaloy rods (Zy) at the front end of the target right behind the proton beam window. The fast neutrons are thermalized in D_2O and then converted into ultracold neutrons in the D_2-moderator at 8 K. Since the first 4 components of the target assembly lie under the moderator they have to be made from materials with low absorption cross sections to minimise neutron flux depression. Finally about two meters of steel are added to shield the handling zone from the target front end. The target head as well as the target container and the beam window will be cooled with heavy water.

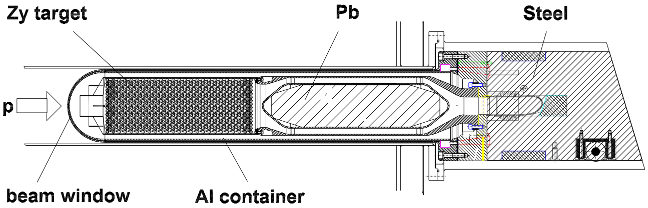

Fig. 1: Schematic drawing of the UCN target assembly.

One of the main requirements for safe operation and disposal of the target after its lifetime is to have detailed knowledge about the activation induced in the various components mentioned above.

CALCULATION METHOD

The target assembly of the UCN will be activated by a mixed radiation field consisting of the primary 590 MeV protons, secondary high energy collision products (E $>$ 20 MeV) and low energy neutrons (E $<$ 20 MeV). To account for these different "sources" of activation the calculation is split into two parts. In a first step, the Monte-Carlo particle transport code MCNPX [1] is used to determine the nuclide inventory produced by the primary protons as well as the high energy (E $>$ 20 MeV) secondary particles created in spallation reactions within the target assembly. Moreover, low energy neutron spectra (E $<$ 20 MeV) are calculated for the regions of interest. In the second step, the neutron spectra calculated in MCNPX serve as an input for calculations with the **E**uropean **A**ctivation **Sy**stem - EASY [2]. This package consist of a code - FISPACT - which solves the Bateman equations and several decay as well as neutron activation cross section libraries (E $<$ 20 MeV) for 766 target isotopes. In order to take into account the residual nuclide production of the high energy part of the calculation, a modified version of FISPACT - SP-FISPACT [3]- is used. Thus SP-FISPACT is able to calculate isotope production rates spanning the whole energy regime. As a result one obtains a complete nuclide inventory for different regions in the UCN target assembly after specific irradiation scenarios.

RESULTS

Calculations as described in the previous section have been performed for each of the components of the UCN target assembly. However, in this report only an overview of the results can be given. The nuclide inventory of each component of the UCN target cannot be listed because the information would be too extensive (up to 600 isotopes). Therefore, only total activities and leading isotopes will be discussed for the major parts of the target assembly.

The component with the highest induced activation is the Zircaloy target since the primary proton beam is fully stopped within this module. The primary protons induce spallation reactions which form an internuclear cascade consisting of high energy nucleons, clusters and pions as well as an evaporation spectrum. The high energy particles undergo further spallation reactions within the various regions of the target assembly while the low energy neutrons will produce residual nuclei through reaction channels like (n,α), (n,γ), (n,2n), etc. with masses close to the nuclei hit.

In Figure 2 one can see the total activity (solid line) and the activity induced by high energy particles (E $>$ 20 MeV) (dotted line) as a function of time. It is assumed that the target is irradiated with an average current of 20 μA for 1 year, after which the beam is

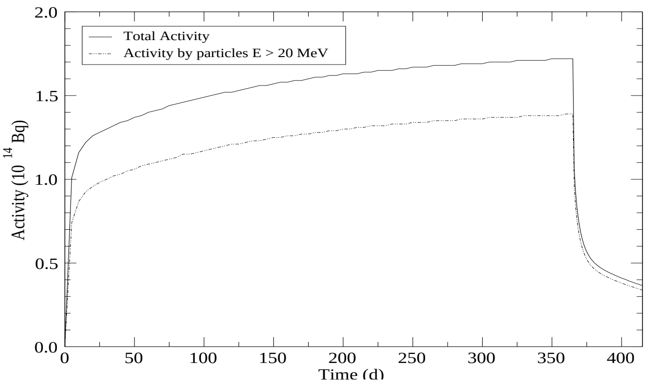

Fig. 2: Total induced activation (solid line) and activation due to high energy particle (E $>$ 20 MeV) interactions (dotted line) in the Zircaloy target block as a function of time. An average proton current of 20 μA is assumed to hit the target for 1 year. Thereafter the behavior of the activity during 50 days is shown.

switched off and the activity decay is observed. One can see that the total activity of the Zircaloy rods is dominated by that from high energy particles; about 80 $\%$ is due to residuals produced in high energy reactions. Moreover, the lifetimes of the isotopes produced in low energy neutron reactions are short, since after 50 days cooling the total activity has nearly dropped to the level of the high energy activity.

The values for the total activation of the Zircaloy have been compared to values computed for the SINQ [4] using HETC + O5R_PSI in combination with ORIHET. Agreement within a factor of 1.5 was found.

Component	1 day	10 days	30 days
Zr rods	1.06×10^{14}	5.67×10^{13}	4.28×10^{13}
Al Cont.	1.20×10^{11}	3.16×10^{10}	3.04×10^{10}
Al BW	7.24×10^{10}	4.03×10^{10}	3.75×10^{10}
Pb block	4.11×10^{11}	9.23×10^{10}	4.74×10^{10}
Steel	2.68×10^{11}	2.27×10^{11}	1.93×10^{11}

Tab. 1: Total activities (Bq) after 1 year irradiation with an average proton current of 20 μA within different regions of the UCN target assembly for cooling times of 1, 10 and 30 days.

The nuclides dominating the activity in the Zircaloy rods after a cooling time of 30 days are ^{88}Y, ^{88}Zr and ^{85}Sr, which together contribute more than 60 $\%$ to the total activity. For the other components of the target assembly the following leading isotopes can be identified; Aluminium beam window and container ^{22}Na (80 $\%$); Pb ^{195}Au (37 $\%$); first 50 cm of Steel ^{54}Mn (45 $\%$) and ^{55}Fe (31 $\%$).

Several of the isotopes produced during the irradiation will decay by emitting gammas of a specific energy. The resulting gamma spectra for the Aluminium beam window are shown in Figure 3 for cooling times of 1 and 30 days.

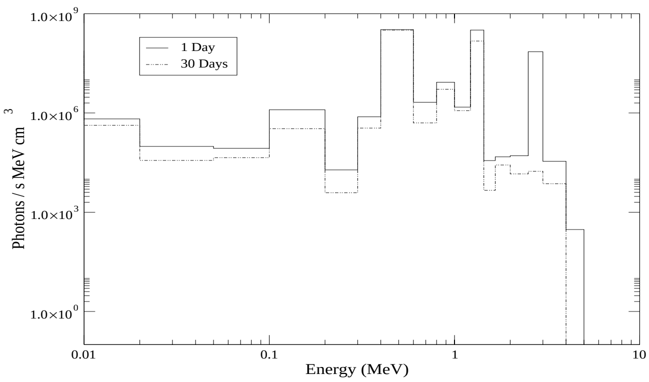

Fig. 3: Calculated decay gamma spectra for the Aluminium beam window after 1 year irradiation with 20 μA proton beam and cooling 1 day (solid line) and 30 days (dotted line).

One can clearly see that after 30 days decay the high energy part of the spectrum has changed. The gamma lines due to ^{24}Na in the interval between 2.5 and 3.0 MeV have disappeared, because the half-life of the isotope is 14.96 hours.

CONCLUSION

Nuclide inventories have been calculated for the different components of the UCN target complex using a combination of the Monte-Carlo transport code MCNPX and the European Activation System.

With the knowledge of the isotopic composition for the different parts of the UCN target complex after an irradiation of 1 year with an average proton current of 20 μA one can design the exchange flask to safely remove the target after its lifespan and transport it into the ATEC area where further processing can be done. The layout of the exchange flask is calculated using the MICROSHIELD program [5].

REFERENCES

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