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Measurement of the $^{33}S(n,\alpha)$ cross-section at n_TOF(CERN): Applications to BNCT

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ABSTRACT

Aim: The main purpose of this work is to present a new (n,α) cross-section measurement for a stable isotope of sulfur, ^{33}S, in order to solve existing discrepancies.

Background: ^{33}S has been studied as a cooperating target for Boron Neutron Capture Therapy (BNCT) because of its large (n,α) cross-section in the epithermal neutron energy range, the most suitable one for BNCT. Although the most important evaluated databases, such as ENDF, do not show any resonances in the cross-section, experimental measurements which provided data from 10 keV to 1 MeV showed that the lowest-lying and strongest resonance of $^{33}S(n,\alpha)$ cross-section occurs at 13.5 keV. Nevertheless, the set of resonance parameters that describe such resonance shows important discrepancies (more than a factor of 2) between them.

Materials and methods: A new measurement of the $^{33}S(n,\alpha)^{30}Si$ reaction cross-section was proposed to the ISOLDE and Neutron Time-of-Flight Experiments Committee of CERN. It was performed at n_TOF(CERN) in 2012 using MicroMegas detectors.

Results: In this work, we will present a brief overview of the experiment as well as preliminary results of the data analysis in the neutron energy range from thermal to 100 keV. These results will be taken into account to calculate the kerma-fluence factors corresponding to ^{33}S in addition to ^{10}B and those of a standard four-component ICRU tissue.

Conclusions: MCNP simulations of the deposited dose, including our experimental data, shows an important kerma rate enhancement at the surface of the tissue, mainly due to the presence of ^{33}S.

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1. Background

The most recent reactors and the proposed accelerator-based neutron sources produce epithermal neutron beams, in the keV range, which are considered the most suitable ones for Boron Neutron Capture Therapy (BNCT). A cooperative target to ^{10}B showing resonant capture in this range may enhance the dose for superficial tumors. For this purpose, ^{33}S, a stable isotope of sulfur which represents 0.75% of ^{nat}S, has been studied by Porras[1] because of its large (n,α) cross-section in the keV range, much greater than the (n,γ) one. Porras already showed an enhancement of absorbed dose due to the cooperating effect of ^{33}S and ^{10}B by means of Monte Carlo simulations.[2]

There are some discrepancies, more than a factor of 2, between experimental $^{33}S(n,\alpha)^{30}Si$ cross-section measurements with respect to the resonance parameters available in the evaluated nuclear data files.[7] Only one dedicated measurement of $^{33}S(n,\alpha)$ cross-section can be found in the literature[3] since the other measurements do not provide new specific data for BNCT.[4,5] Such measurement provided data from 10 keV to 1 MeV, thus the cross-section is unknown for neutron energies below 10 keV, the most important range for BNCT since neutrons are moderated by the tissue. Furthermore, there is only one measurement of the (n,tot) cross-section.[6] Both experiments showed that the lowest-lying and strongest resonance of $^{33}S(n,\alpha)$ cross-section occurs at a neutron energy near 13.5 keV. The discrepancies between the resonance parameters obtained[3,5,6] amounted to a factor of 2, being the results of Wagemans et al.[3] the lowest ones. Moreover, the main evaluated nuclear data libraries,[7] such as ENDF/B-VII.1, JEFF-3.1.2, JENDL-4.0, ROSFOND-2010 and JEF-2.2, do not even describe the experimentally found resonant structure. Only EAF-2010 shows the resonances but the values are smaller than those reported by Wagemans et al.[3] Within this framework, a new measurement at the n_TOF facility at CERN was proposed to clarify the existing discrepancies.

2. Aim

Since Monte Carlo (MC) simulation is a standard tool employed to describe neutron transport and to study the dose delivered to tissue, preliminary results of the ongoing $^{33}S(n,\alpha)$ cross-section data analysis from the last measurement at n_TOF (CERN) will be shown and taken into account to calculate the kerma-fluence factors as well as the kerma rate corresponding to ^{33}S in addition to ^{10}B for a standard four-component ICRU tissue.

3. Materials and methods

3.1. $^{33}S(n,\alpha)^{30}Si$ measurement at n_TOF(CERN)

The neutron time-of-flight facility (n_TOF) at CERN, based on a spallation neutron source, is mainly dedicated to measure neutron-induced cross sections, (n,γ) and (n,f), for nuclear technology, astrophysics and basic nuclear physics applying the time of flight technique.[8] In November 2011, a test of the set-up to measure (n,α) cross-section with MicroMegas detectors at n_TOF was carried out.[9] The success of the test led to the first (n,α) cross-section measurement, not related to monitoring purposes, at n_TOF[10] in 2012, preliminary results of which will be presented in this paper.

n_TOF is a neutron facility which provides a neutron beam of energy from thermal to 1 GeV and the energy resolution at 10–100 keV is $\Delta E/E \sim 10^{-3}$. These features let experimental data to be extended below 10 keV. On the other hand, a high energy resolution is required to solve the discrepancies in resonance parameters among evaluations and EXFOR[3,5] data. A fast ionization chamber based on 10 MicroMegas detectors[11] was used to collect the energy deposited by the emitted alpha particles from six ^{33}S samples, two blank samples to characterize the background and two $^{10}B_4C$ samples. The use of the $^{10}B(n,\alpha)^7Li$ cross-section, a standard in the neutron energy range of interest, as a reference allows to extract the relative cross-section and avoid systematic uncertainties specific to

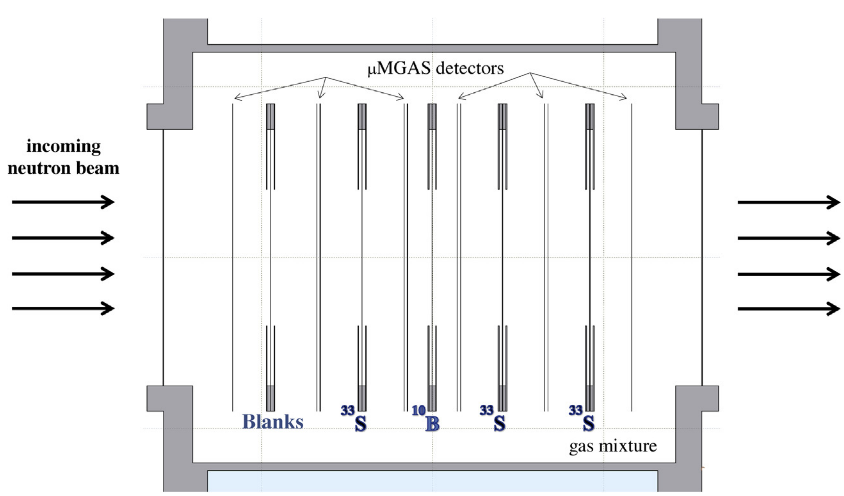

Fig. 1 – Experimental set-up used to measure the $^{33}S(n,\alpha)$ cross-section at n_TOF(CERN). Several MicroMegas detectors can run in parallel intercepting the beam because they are transparent to neutrons.