Production of ^{53}Mn in a Fusion Environment

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Improved and highly accurate nuclear data are urgently required for the design of advanced reactor concepts, like the design of nuclear fusion devices (e.g. ITER), or next generation nuclear power plants. In a fusion environment particularly long-lived activation products may lead to significant long-term waste disposals and radiation damage. Many of these production cross sections are not well-known, making it difficult to calculate concentration limits [1]. With the high neutron flux, also impurities in structure materials may lead to significant or dominating activations. For such nuclides production cross-sections and induced activities are key parameters for safety and design analysis.

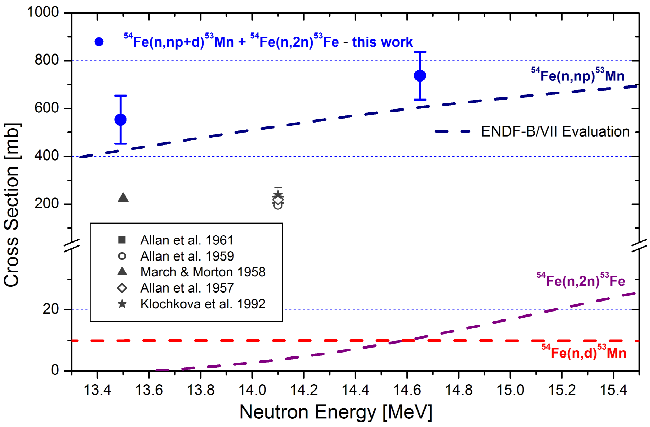

Fig. 1: Excitation function for the production of ^{53}Mn around 14 MeV. Experimental data are shown as symbols. A recent evaluation [7] disentangles the contribution of the three different reaction channels producing the long-lived ^{53}Mn (dashed lines).

The high production rate of ^{53}Mn ($t_{1/2}$ = 3.7 Myr) is of some concern as an activation product since this activity will increase steadily during the lifetime of an operating reactor. In particular, Fe-containing material are candidate materials for fusion reactor systems: ^{53}Mn can be produced directly via ^{54}Fe(n,np) and ^{54}Fe(n,d). The respective neutron threshold energies are 9 and 6.8 MeV. ^{53}Mn can also be produced via the ^{54}Fe(n,2n)^{53}Fe reaction, and decay of ^{53}Fe ($t_{1/2}$ = 8.5 min). The latter reaction has its threshold at 13.6 MeV neutron energy. This high threshold makes it a very sensitive measure for fusion temperature changes, similar to ^{27}Al(n,2n)^{26}Al [2]. Experimental information for the production of ^{53}Mn is scarce and discordant to calculations. Recent activation experiments in a fusion peak neutron field showed, that for materials like the favoured Eurofer, production of ^{26}Al and ^{53}Mn are the dominant long-term activities, with estimated contributions of 70% and 27% to the total dose rate, respectively, however, for ^{53}Mn with an uncertainty of 60% [3,4].

Fe metal samples, highly enriched in ^{54}Fe, have been irradiated with quasi-monoenergetic neutrons for about 22 hours at TU Dresden's 14-MeV neutron generator [5]. Via the T(d,n)^{4}He reaction, neutrons with energies between 13.4 and 14.9 MeV were produced. Several Fe samples were exposed to neutrons with a total fluence of a few 10^{13} n cm^{-2}. In addition, short-term irradiations were performed to measure the production of short-lived ^{53}Fe.

After the neutron activations the Fe samples were dissolved in hydrochloric acid and a known amount of stable ^{55}Mn was added. Manganese was separated from the Fe bulk material through exposure to diisopropylether. The remaining fraction was further used for ionchromatography, mainly to remove the stable isobar of ^{53}Mn, ^{53}Cr. Finally, Mn was converted to oxide form and pressed into Ag sample holders.

^{53}Mn was measured via accelerator mass spectrometry (AMS) utilizing the 14-MV tandem accelerator of the MLL. In combination with a dedicated particle detection system featuring a time-of-flight system, a gas-filled magnet and a multi-anode ionization chamber, a detection limit lower than 10^{-14} for ^{53}Mn/^{55}Mn isotope ratios was achieved [6]. Assuming a cross-section value of 600 mbarn [7], with the well-known neutron fluence (> 10^{13} n cm^{-2}), we calculate an isotope ratio ^{53}Mn/^{55}Mn of at least $6{\cdot}10^{-12}$ - well above background.

Previous measurements for the ^{54}Fe(n,np+d)^{53}Mn reaction [8] have been performed in the neutron energy range between 13.5 and 14.1 MeV. These measurements are based on the detection of emitted protons and are sensitive to the np-channel only. Their results indicate a constant cross section of about 200 mbarn. However, they disagree by a factor of 2–3 with recent evaluations (see e.g. [7]). These evaluations indicate an increasing excitation function with cross-section values between 400 and 650 mbarn between 13.4 and 15 MeV.

Preliminary experimental data obtained in this work are plotted in Fig. 1. Our data, for the first time based on AMS measurements, are sensitive to the total production of ^{53}Mn in such a neutron environment. However, these preliminary data indicate that previous data seem to strongly underestimate the production of ^{53}Mn in this energy range. The new data are also slightly higher than the ENDF evaluation.

References

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