MASTER**NEW NEUTRON CROSS SECTIONS FOR FUSION MATERIALS STUDIES**

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Abstract - Neutron cross sections are being developed for a variety of fusion-related applications including neutron dosimetry, fusion plasma diagnostics, the activation of very long-lived isotopes, and high-energy accelerator neutron sources.

INTRODUCTION

Fusion materials experiments are being conducted in a wide variety of facilities including fission reactors, 14 MeV sources, and higher energy accelerator sources. Our goal is to measure the neutron flux and energy spectra at each facility and to use these data to calculate radiation damage parameters for each materials experiment. These exposure parameters are then used to correlate property changes between facilities and to predict materials performance in fusion reactors. In order to meet these objectives, neutron cross sections are being measured and tested in several different applications.

FUSION REACTOR APPLICATIONS

Cross sections are being measured for neutron dosimetry, plasma diagnostics, and waste generation applications. Activation cross sections for 22 different reactions were measured at the Rotating Target Neutron Source II at Lawrence Livermore National Laboratory in the angular range from 0-60° for neutron energies from 14.5-14.9 MeV at 5, 15, and 30 cm. from the target center¹. Neutron flux spectra were calculated from the beam energy, energy loss in the TiT₂ targets, nuclear data, and relativistic kinematics. Our measurements were then compared with previous data such as ENDF/B-V by averaging the energy-dependent cross sections over the calculated flux spectra at each angle. The largest differences (ENDF/EXP -1) were noted for Ti(n,x)⁴⁷Sc (-22%), ⁵⁹Co(n,p)⁵⁹Fe (+36%), ⁶⁰Ni(n,p)⁶⁰Co (-18%), ⁵⁸Ni(n,p)⁵⁸Co (+14%), and ⁵⁸Ni(n,2n)⁵⁷Ni (-11%). All of the other reactions were in agreement with previous data within 10%. These data are being used for routine dosimetry at RINSII and fusion reactors.

Two reactions which we have measured have been shown to be extremely useful for fusion plasma diagnostics since they both have thresholds near 14 MeV and hence their yields are very sensitive to the plasma ion temperature². These data are shown in Figure 1 along with fusion spectra. The ²⁷Al(n,2n)^{26m}Al³ and

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$^{54}\text{Fe}(n,2n)^{53}\text{Fe}$ (10 m)⁴ cross sections have been measured near 14 MeV in collaboration with Princeton Plasma Physics Laboratory. These reactions are so sensitive that they can be used to measure the ion temperature for a single d-t shot at current reactors such as at the Tokamak Fusion Test Facility at Princeton or the Joint European Torus.

These two (n,2n) reactions on ^{27}Al and ^{54}Fe are also very interesting for another reason since they produce the very long-lived isotopes ^{26}gAl (7.3×10^5 y) and ^{53}Mn (3.7×10^6 y) which are of interest in the disposal of activated waste at fusion reactors. Fortunately, we have shown that both reaction cross sections are significantly lower than expected (about 1/2) and hence they are of less concern than predicted. Measurements of other long-lived radioisotopes such as ^{92}Nb , ^{94}Nb , ^{59}Ni , ^{93}Zr , and ^{93}Mo are now in progress using long irradiations at KINSII followed by gamma counting, liquid scintillation counting, and the relatively new technique of accelerator mass spectrometry.

SPALLATION NEUTRON SOURCES

Spallation neutron sources are being used both in the U.S and Europe for radiation damage studies. These sources present a new challenge for neutron dosimetry and radiation damage calculations since they produce neutrons up to 800 MeV or more in energy. Spallation cross sections themselves are ideally suited for high-energy neutron dosimetry since they have relatively large cross sections and high energy thresholds which vary considerably with the mass of the spallation product. Unfortunately, very few cross sections are well-known in this energy regime. Consequently, we have measured spallation yields from Al and Cu in the energy range from 30-450 MeV at the Intense Pulsed Neutron Source at Argonne⁵. Foil packages were placed directly in the proton beam and activation products were then measured by gamma spectrometry. Some of the measured cross sections are shown in Figure 2. On the assumption that neutron and proton cross sections are about equal at higher energies, we have then integrally tested our data at IPNS and at the Los Alamos Meson Physics Facility⁶. Results show that the Cu data agrees quite well with the calculated neutron spectrum at these facilities and that these data can be used for routine spectral adjustments up to 800 MeV. The cross sections have also been compared to various semi-empirical models. These models only crudely fit the data (within a factor of two) but they are useful for predicting the energy dependence. Radiation damage calculations are also being studied for these higher energy sources⁷. This technique appears to be very promising and further cross section measurements and tests are needed for routine dosimetry at spallation sources.

Fission Reactors and Accelerator Sources

Most fusion materials experiments will actually take place in con-

ventional fission reactors in the foreseeable future due to severe flux and space limitations at available accelerator neutron sources. Cross section measurements are still needed in this energy regime to resolve significant discrepancies between differential and integral experiments and to improve our ability to monitor long irradiations. We are engaged in a program to selectively measure and to integrally test cross sections for a number of activation cross sections. Integral experiments have been conducted at accelerator neutron sources using the Be(d,n) spectrum calibrated by time-of-flight spectroscopy⁸⁻⁹. These data along with the 14 MeV results mentioned previously and with selected low energy measurements at Argonne are being used to adjust many dosimetry reactions which have significant discrepancies between the existing ENDF/B-V evaluations and reactor measurements. As an example, the well-known discrepancies for the Ti(n,x)⁴⁷Sc reaction can be easily explained by a readjustment of the cross section¹⁰. This readjustment is found to agree very well with new data¹¹. By combining selected differential and integral measurements and calculations, many of the cross section needs can be satisfied for the fusion program.

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FIGURE 1. Cross sections for the $^{54}\text{Fe}(n,2n)^{53}\text{Fe}$ reaction near threshold. Neutron energy distributions for a fusion reactor plasma at 1 and 9 keV are superimposed, as is the cross section for the $^{27}\text{Al}(n,p)$ reaction, demonstrating the sensitivity.

FIGURE 2. Spallation cross sections from proton bombardment of Cu are shown to various radionuclides.