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NEUTRON MEASUREMENTS AND RADIATION DAMAGE CALCULATIONS FOR FUSION MATERIALS STUDIES

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Fusion reactors will generate intense neutron fields, especially at the inner surfaces of containment vessels. With a typical wall loading of 1 MW/m^2, the yearly neutron fluence will be about 10^{26} n/m^2. In a material like stainless steel this irradiation will produce about 10 atomic displacements-per-atom (DPA), 100 appm helium, 500 appm hydrogen, and various other transmutations. The gas-to-DPA ratios are very high compared to fission reactors due to the 14 MeV neutrons from the d-t fusion reaction. No existing neutron source can produce both the high fluence and high gas rates needed to simulate fusion damage. Consequently, fusion material studies are underway in a variety of facilities including fission reactors and accelerator-based neutron sources. A Subtask Group has been created by DOE to characterize these diverse facilities in terms of neutron flux and energy spectrum and to calculate DPA and transmutation for specific irradiations. Material property changes can then be correlated between facilities and extrapolated to fusion reactor conditions.

Most materials research is currently conducted in fission reactors due to the high flux and large volumes available. Mixed spectrum reactors such as the Oak Ridge Research Reactor (ORNL) and the High Flux Isotopes Reactor (ORNL) are used to study nickel-bearing alloys since the thermal neutrons can be used to produce high helium concentrations from the $^{58}Ni(n,\gamma)^{59}Ni(n,\alpha)^{56}Fe$ reaction.[1] Fast reactors such as the Experimental Breeder Reactor II (ANL-W) are also used to produce high DPA rates with relatively large volumes.

Accelerator-based neutron sources fall into three categories, namely the 14 MeV (d-t) Rotating Target Neutron Source II (RTNSII) (LLNL), the broadspectrum (0-50 MeV) Be or Li(d,n) cyclotron source at the University of California at Davis, and the high energy proton spallation Intense Pulsed Neutron Source (ANL-E). Although the RTNSII source produces 14 MeV neutrons similar to a fusion device, the flux is rather low. Neverthless, with suitable moderators a fusion-like spectrum can be achieved with fluxes comparable to new fusion devices (e.g., TFTR, JET).[2] For the higher energy (>14 MeV) neutron sources cross sections have been developed and tested. Experiments[3] have demonstrated the applicability of these activation techniques to the Fusion Materials Irradiation Test Facility (FMIT) now under construction at HEDL. Spallation cross sections are now being measured and tested to extend dosimetry techniques to 500 MeV or more for spallation sources and, possibly, to measure the very high energy tail of neutrons at FMIT. Insulator and magnet materials are currently being studied at IPNS, due to the availability of a cryogenic (4°K) irradiation facility.

Helium production rates are being measured by Rockwell International at all existing fusion materials facilities. Helium rates are measured simultaneously with radiometric dosimetry to determine production cross sections.[4] Other transmutation rates to stable or very long-lived products are also being measured using a newly developed technique, accelerator mass spectrometry.[5]

Eventually, as fusion engineering test reactors are built, materials research will focus on these devices. Work is now planned to simulate these neutron fields at RTNSII. Experiments are also in progress to measure very short-lived reactions for plasma diagnostics and very long-lived products of concern in waste-handling operations.

Displacement damage is calculated from fundamental nuclear cross sections. Recent developments have included the (n,γ) capture reaction and subsequent beta decays.[6] Work is now in progress to provide uncertainties for displacement cross sections. Such uncertainty analyses are now routinely available for neutron flux and spectral measurements.

Two computer packages have been made available to the fusion community via the National Magnetic Fusion Energy Computer Center at LLNL. DOSFILE reports all dosimetry and damage data for fusion materials irradiations. Users can readily determine fluence and damage rates for a specific irradiation and data is well-documented for future retreival and reanalysis as needed. SPECTER contains displacement damage, gas production, total dose, and recoil atom distributions for elements of interest to fusion experimenters. Users can supply a neutron spectrum with uncertainties, if available, and the program will respond with spectrum-averaged parameters and uncertainties.

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