INFLUENCE OF SUBCASCADE FORMATION ON DISPLACEMENT DAMAGE AT HIGH PKA ENERGIES — R. E. Stoller (Oak Ridge National Laboratory) and L. R. Greenwood (Pacific Northwest National Laboratory)

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Extended Abstract

The design of first generation fusion reactors will have to be rely on radiation effects data obtained from experiments conducted in fission reactors. Two issues must be addressed to use this data with confidence. The first is differences in the neutron energy spectrum, and the second is differences in nuclear transmutation rates. Differences in the neutron energy spectra are reflected in the energy spectra of the primary knockon atoms (PKA). The issue of PKA energy effects has been addressed through the use of displacement cascade simulations using the method of molecular dynamics (MD). Although MD simulations can provide a detailed picture of the formation and evolution of displacement cascades, they impose a substantial computational burden. However, recent advances in computing equipment permit the simulation of high energy displacement events involving more than one-million atoms [1-3]; the results presented here encompass MD cascade simulation energies from near the displacement threshold to as high as 40 keV. Two parameters have been extracted from the MD simulations: the number of point defects that remain after the displacement event is completed and the fraction of the surviving interstitials that are contained in clusters. The MD values have been normalized to the number of atomic displacements calculated with the secondary displacement model by Norgett, Robinson, and Torrens (NRT) [4].

The energy dependence of the two MD defect parameters was used to evaluate the effects of neutron energy spectrum. Simple, energy-dependent functional fits to the MD results were obtained, and the SPECOMP and SPECTER codes [5,6] were used to compute effective cross sections for point defect survival and point defect clustering. PKA spectra for iron obtained from SPECTER were then used to weight these effective cross sections in order to calculate spectrum-averaged values. In order to provide a broad comparison, values were obtained for several irradiation sites. These include: the 1/4-thickness position in the pressure vessel of a typical commercial pressurized water reactor (PWR), the peripheral target position (PTP) and a removable beryllium reflector position (RB*) of the HFIR, a midcore and below-core position (BC) in the FFTF, the first wall spectrum of Starfire [7], and the radiation effects facility in the intense pulsed neutron source (IPNS REF) in the Argonne National Laboratory [8,9]. Since the IPNS is a spallation neutron source with neutron energies up to the proton beam energy of 450 MeV, it produces PKA with even higher energies than does DT fusion.

The primary results of these calculations are summarized in Fig. 1. The PKA-spectrum-averaged defect survival fraction is shown in Fig. 1a, and the interstitial clustering fraction in Fig. 1b. In both cases, the effective production cross section has been divided by the NRT dpa cross section. The lowest point defect survival fraction is obtained in the Starfire FW as a result of the 14.1 MeV source term. However, the defect survival fractions shown in Fig. 1a are not simply determined by how hard the initial neutron energy spectrum is. For example, the survival fractions for IPNS and both FFTF sites are greater than any of the water moderated fission reactor spectra. An examination of the PKA spectra indicates that the results shown in Fig. 1a and 1b are generally dominated by PKA below 100 keV. Thus, average behavior is controlled by the details of the spectra in the low to intermediate energy region. Here the differences between the fission and Starfire PKA spectra are greater than those between fission and IPNS. Similarly, the average interstitial clustering fraction shown in Fig. 1b is only weakly dependent on the initial neutron energy spectrum. The average clustering fraction tracks the defect survival fraction (since only defects that survive can cluster), but the differences among the various environments are reduced because the energy dependence of interstitial clustering is opposite to that of defect survival [1-3].

Although the values shown in Fig. 1a and 1b for the Starfire first wall lie at the lower limit of all the sites illustrated, these results suggest that the nature of the displacement damage formed in a DT fusion reactor first wall should not be significantly different from that obtained in fission reactors. The average defect survival fraction is about 0.20 to 0.30 and the interstitial clustering fraction is about 0.10 to 0.15 for all the cases shown. In this case, the primary uncertainty regarding the use of such data is the impact of differences in transmutation production rates between the two environments.

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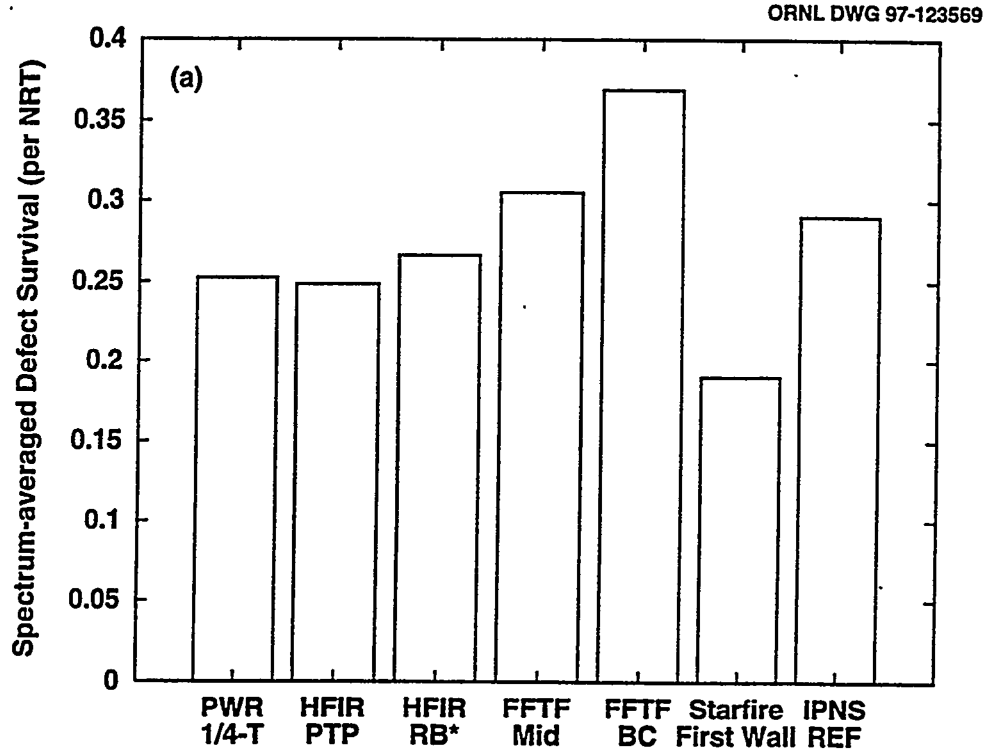

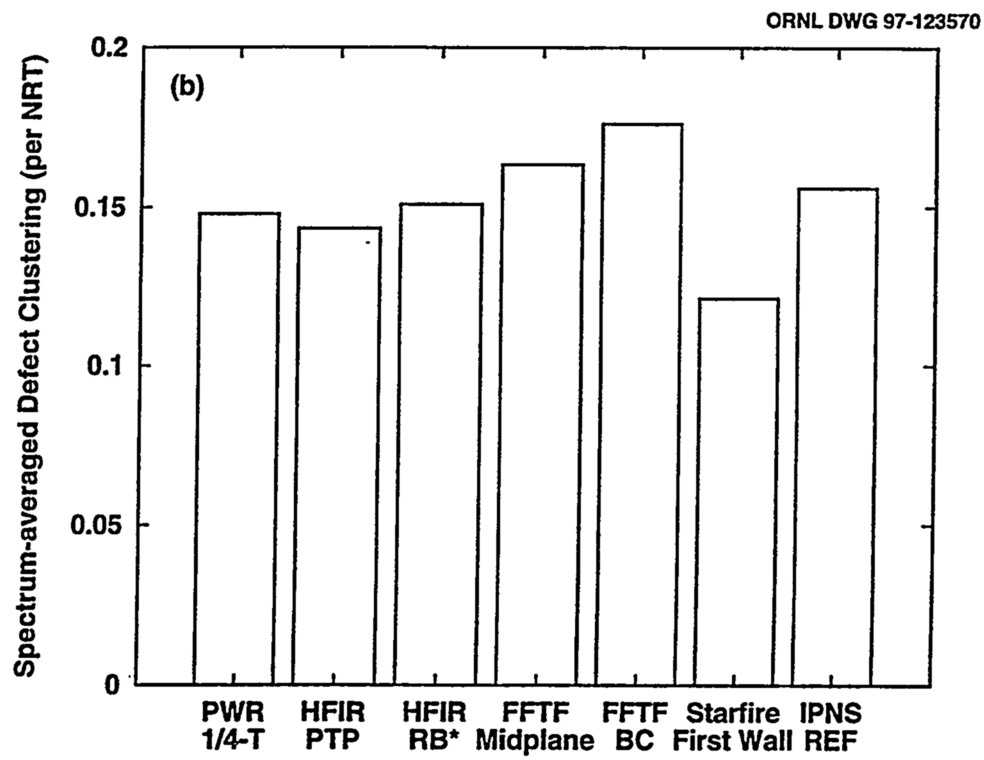

Figure 1. Comparison of spectrally-averaged damage production cross sections (per NRT dpa) for various irradiation environments; defect survival ratio is shown in (a) and the interstitial clustering fraction is shown in (b).