SPATIAL VARIATIONS OF DAMAGE PARAMETERS IN FMIT AND THEIR IMPLICATIONS

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December 1978

Paper to be presented at Topical Meeting on Fusion Reactor Materials to be held in Miami Beach, Florida, January 29-31, 1979.
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The major conclusion is that the variation in damage rates in FMIT will be dominated by changes in flux, not spectrum. Throughout the test region where the flux is greater than $10^{14}$ n/cm²-s, the flux varies by a factor of about 20, while the spectral-averaged displacement and helium production cross sections for copper vary by less than factors of two and four, respectively. The corresponding helium-to-dpa ratios bracket a fusion reactor first wall value for copper (i.e., 7.7 appm He/dpa). With the Li(d, n) yields and copper damage energy and helium production cross sections used in this study, the test volumes for which the displacement and total helium production rates are greater than those at a D-T fusion reactor first wall, with a loading of 1.25 MW/m², are about 100 and 130 cm³, respectively.

2. RESULTS

FMIT preliminary design calls for a 0.1 amp beam of 35 MeV deuterons to strike the surface...
of a stream of flowing lithium 2 cm thick. The deuteron ion density is to peak at the center of the target area and be gaussian in the vertical and horizontal directions with full-widths-at-half maximum (FWHM) of 1 cm and 3 cm, respectively. Calculations of the spatial variations of damage parameters have been made for the pristine neutron field as well as for the field perturbed by a representative irradiation test module. The materials in regions A and B, as shown in Figure 3, have densities which are 50 and 25 percent that of stainless steel.

2.1 Pristine neutron field

Contour maps for copper dpa rate and total helium production rate in the pristine neutron field are plotted in Figures 4 and 5. Note that the volumes for which the dpa and the total helium production rates are greater than those in a D-T fusion reactor first wall with a wall loading of 1.25 MW/m² are about 100 and 130 cm³, respectively. Current fusion reactor design studies envision wall loadings up to 3-5 MW/m². Note that the smallest contours in Figures 4 and 5, enclosing 4-5 cm³, have displacement and helium production rates in excess of those corresponding to first wall loadings of 6-7 MW/m². The rates at which these volumes shrink with increasing damage rate is further demonstrated in Figures 6 and 7. These figures show plots of dpa rate and helium production rate versus distance (x) normal to the flowing lithium surface for various y-z coordinates. The damage rate in the y-direction changes fastest near the beam axis where the damage rate is highest.

While test volumes in FNIT are small compared with those available in fission reactors, damage rates are expected to be much higher. Figure 5
shows a bar chart comparing the neutron flux and damage rate in MIT to that in other neutron irradiation facilities, namely HFIR, EBR-II, FTR, and RTNS-II. The data are presented as the natural logarithms of the ratio of the neutron flux, the dpa rate, and the helium production rate in the given facility to the corresponding quantity at the first wall of a 1.25 MW/m² D-T fusion reactor. The MIT source [5] and fission reactors produce displacements at an accelerated rate relative to the first wall, but, unlike MIT, fission reactors produce transmutants at a far lower rate (except for helium production in nickel). RTNS-II, like MIT, will produce helium-to-dpa ratios comparable to a first wall, however, low fluxes in RTNS-II prohibit producing damage rates close to those produced at a first wall. Note that with the damage energy cross sections used in this study (see Figure 2) the displacement rate in copper at the first wall is 16.7 dpa/yr while that in stainless steel is 12.5 dpa/yr.

2.2 Test module perturbed neutron field

Figure 3 shows the configuration and composition of a representative irradiation test module. Neutron spectra were calculated with and without this test module in the irradiation cell. Both the pristine and test module perturbed spectra at four positions are plotted in Figure 1. As shown in Table 1, at points near the source the total flux is higher in the perturbed spectra than in the unperturbed spectra, and the reverse is true far from the source. These effects are due to neutron backscattering throughout the test assembly. The backscattering lowers the high energy flux and raises the low energy flux, as shown, with the result that the spectral-averaged damage energy and helium production cross sections are lower in the perturbed spectra. However, the test module lowers the helium-to-dpa ratio by less than ten percent throughout the volume encompassed by the module (see Table 1). Note that the copper helium-to-dpa ratios in MIT bracket the first wall value for copper (7.7 ppm He/dpa).

3. CONCLUSIONS

• MIT test volumes for which the displacement and the total helium production rates in copper are greater than those at a D-T fusion reactor first wall, with a loading of 1.25 MW/m², are about 100 and 130 cm³, respectively.
• The copper helium-to-dpa ratio in the MIT test cell is within a factor of two of that at the fusion reactor first wall (7.7 ppm He/dpa).
• While throughout the cell volume encompassed by the test module the neutron flux varies by
as much as a factor of twenty, the helium-to-dpa ratio varies by less than a factor of two. Hence, damage rates are expected to be much more affected by variations in flux than variations in spectra.

TABLE 1. Spectral-Averaged Cross Sections for Copper Within the FMIT Test Volume; \( E_d = 35 \text{ MeV}, I = 0.1 \text{ amu}, 1 \times 3 \text{ cm Gaussian Source} \)

<table>
<thead>
<tr>
<th>#</th>
<th>#(cm)</th>
<th>#(cm)</th>
<th>#(cm)</th>
<th>( \phi ) ( \text{cm}^{-2} \text{s}^{-1} )</th>
<th>( E_n ) ( \text{MeV} )</th>
<th>( \phi ) ( \text{appm He} ) ( \text{dpa} )</th>
<th>( \phi ) ( \text{appm He} ) ( \text{dpa} )</th>
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REFERENCES


FIGURE CAPTIONS

1. Calculated Neutron Spectra at Four Positions Within the FMIT Irradiation Cell. (few $E_d = 35$ MeV and $I = 0.1$ amp) Compared with a D-T Fusion Reactor First Wall Spectrum.


4. Displacement Rate Contour Maps for a 1 x 3 cm FWHM Gaussian Source Distribution ($E_d = 35$ MeV and $I = 0.1$ amp).

5. Helium Production Rate Contour Maps for a 1 x 3 cm FWHM Gaussian Source Distribution ($E_d = 35$ MeV and $I = 0.1$ amp).

6. Displacement Rate versus Distance Normal to the Source Surface.

7. Helium Production Rate versus Distance Normal to the Source Surface.

8. Ratio of Damage Rates in Various Neutron Irradiation Facilities to Values at 1 MW/m$^2$ Fusion Reactor First Wall (RR).
Figure 1

Differential Neutron Flux (r/m^2 MeV s)

Neutron Energy (MeV)
Figure 2

- Carbon-Helium Production
- Co-Damage Energy
- Fe and Stainless Steel Damage Energy

Neutron Energy (MeV)
Displacement Rate (dp/yr)

10 x 10 TO THE CM.

K & E

KEUFFEL & ELLISON CO.

2 cm

10 cm

1 cm

2 cm

0 cm

y = 1.25 cm

y = 2.25 cm

y = 0.25 cm

y = 0.105 cm

y = 0.875 cm

x - Direction (cm)