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FMIT AND THEIR IMPLICATIONS**

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SPATIAL VARIATIONS OF DAMAGE PARAMETERS IN FMIT AND THEIR IMPLICATIONS

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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.

1. INTRODUCTION

The Fusion Materials Irradiation Test (FMIT) facility is an accelerator-based neutron source which will provide, within a reasonable test volume, a high damage rate with high energy neutrons in potential fusion reactor materials. In FMIT, neutrons from Li(d,n) reactions are expected to populate spectra throughout the test volume which are broadly distributed in energy compared with fusion first wall spectra, as shown in Figure 1.

Until a fusion test reactor is operating, data from FMIT, Rotating Target Neutron Source-II (RTNS-II), fission reactors, and charged particle irradiation facilities, together with a strong understanding of the physical processes that occur during irradiation will provide the basis for initial component design-life criteria.

The Damage Analysis and Fundamental Studies

(DAFS) program has been formulated primarily to develop damage correlation models and procedures. A key step in the strategy is the verification of the methodology in FMIT. Hence, the Program Plan specifically calls for characterization of the FMIT neutron field, the initial step of which requires analyses of the spatial variation of damage parameters in the irradiation test cell. Characterization of the expected neutron field in terms of damage parameters is also essential for the development of appropriate experimental test assemblies and for the determination of required data accuracies. Since both needs must be reflected in the design of the facility, an FMIT damage parameter sensitivity study is in progress. [1,2] This paper summarizes some of the results thus far obtained.

Spectrum and rate variations among neutron irradiation facilities are typically described in terms of primary knock-on atom (PKA) spectra, spectral-averaged cross sections for displacements per atom (dpa) and gas atoms generated from transmutation reactions (appm He or H), and the respective production rates. We have concentrated on the calculations of displacement and helium production, with emphasis on the assessment of the variations anticipated under likely operating conditions at locations of most interest for irradiation testing (i.e., where the displacement rate in stainless steel is greater than about 6 dpa/yr). Because both damage energy and helium production cross sections are available for copper over the energy range of interest, [3] copper was chosen as the reference material for this study. The results of some stainless steel and iron dpa calculations are also included for comparison. The damage energy and helium production [4] cross sections used in this study are presented in Figure 2.

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/m^2 are about 100 and 130 cm^3 , respectively. Current fusion reactor design studies envision wall loadings up to $3\text{--}5 \text{ MW/m}^2$. Note that the smallest contours in Figures 4 and 5, enclosing $4\text{--}5 \text{ cm}^3$, have displacement and helium production rates in excess of those corresponding to first wall loadings of $6\text{--}7 \text{ MW/m}^2$. 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 x-direction changes fastest near the beam axis where the damage rate is highest.

While test volumes in FMIT are small compared with those available in fission reactors, damage rates are expected to be much higher. Figure 8

shows a bar chart comparing the neutron flux and damage rate in FMIT 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 FMIT source [5] and fission reactors produce displacements at an accelerated rate relative to the first wall, but, unlike FMIT, fission reactors produce transmutants at a far lower rate (except for helium production in nickel). RTNS-II, like FMIT, 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 FMIT bracket the first wall value for copper (7.7 appm He/dpa).

3. CONCLUSIONS

- FMIT 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 FMIT test cell is within a factor of two of that at the fusion reactor first wall (7.7 appm 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; $E_d = 35$ MeV, $I = 0.1$ amp, 1×3 cm Gaussian Source

#	Position			Unperturbed					Perturbed				
	x (cm)	y (cm)	z (cm)	ϕ (10^{14} n/cm ² s)	E_n (MeV)	$\langle \sigma_{disp} \rangle$ (10^3 b)	$\langle \sigma_{He} \rangle$ (10^{-3} b)	appm He dpa	ϕ (10^{14} n/cm ² s)	E_n	$\langle \sigma_{disp} \rangle$	$\langle \sigma_{He} \rangle$	appm He dpa
1	0.0	0.0	0.0	22.3	9.17	2.75	23.0	8.4	24.0	8.48	2.59	20.9	8.0
2	5.0	0.0	0.0	3.54	12.60	3.45	36.4	10.6	2.88	11.0	3.09	31.1	10.1
3	10.0	0.0	0.0	1.53	13.12	3.56	38.7	10.9	.969	11.5	3.18	33.2	10.4
4	15.0	0.0	0.0	.837	13.31	3.61	39.6	11.0	.419	12.1	3.32	35.9	10.8
5	0.0	2.0	0.0	9.49	8.45	2.60	20.3	7.8	10.4	7.71	2.43	18.1	7.5
6	5.0	2.0	0.0	2.13	11.96	3.31	33.7	10.2	1.83	10.1	2.89	27.6	9.5
7	10.0	2.0	0.0	1.07	12.78	3.49	37.1	10.6	.721	10.9	3.06	30.9	10.1
8	0.0	4.5	0.0	1.06	5.99	2.11	11.3	5.3	1.19	5.28	1.93	9.63	5.0
9	2.0	4.5	0.0	.896	7.47	2.40	16.6	6.9	.973	6.21	2.09	13.2	6.3
10	0.0	0.0	2.0	3.29	6.21	2.15	11.9	5.5	3.72	5.56	1.98	10.3	5.2
11	2.0	0.0	2.0	2.35	9.14	2.72	22.6	8.3	2.64	7.81	2.42	18.6	7.7
12	5.0	0.0	2.0	1.48	11.04	3.12	30.1	9.6	1.48	9.24	2.72	24.3	9.0
13	10.0	0.0	1.5	1.09	12.74	3.47	36.8	10.6	.780	10.8	3.03	30.4	10.0
14	0.0	2.0	2.0	2.16	5.86	2.08	10.7	5.1	2.47	5.19	1.91	9.12	4.8
15	2.0	2.0	2.0	1.66	8.44	2.58	20.0	7.8	1.89	7.08	2.27	16.1	7.1
16	5.0	2.0	2.0	1.10	10.6	3.01	28.0	9.3	1.14	8.66	2.59	22.2	8.6
17	0.0	0.0	3.0	1.56	5.66	2.04	9.93	4.9	1.81	4.99	1.86	8.48	4.6

4. REFERENCES

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- [3] C. Y. Fu and F. G. Perey, J. Nucl. Mat. 61, p. 153 (1976).
- [4] The total helium production cross section for copper derived for this study agrees well with recent measurements, see H. Farrar IV and D. W. Neft, Damage Analysis and Fundamental Studies Quarterly Technical Progress Report, January - March 1978, p. 58, DOE/ET/0065/1.
- [5] D. L. Johnson, F. M. Mann, J. W. Watson, J. Ullman, and W. G. Wyckoff, this conference.

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.
2. Damage Energy and Helium Production Cross Sections versus Neutron Energy.
3. Configuration of a Representative Irradiation Test Module and Positions at Which Neutron Spectra Were Calculated.
4. Displacement Rate Contour Maps for a 1×3 cm FWHM Gaussian Source Distribution ($E_d = 35$ MeV and $I = 0.1$ amp).
5. Helium Production Rate Contour Maps for a 1×3 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).

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Figure 1

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K-E SEMI-LOGARITHMIC 5 CYCLES x 72 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

Differential Neutron Flux ($\text{m/cm}^2 \cdot \text{MeV} \cdot \text{s}$)

Neutron Energy (MeV)

Figure 3

461510
 10 X 10 TO THE CENTIMETER 18 X 25 CM
 KEUFFEL & ESSER CO. MADE IN U.S.A.
 Damage Energy (10¹⁰ V.b.)

Figure 4

FMIT C_u - He PRODUCTION RATE CONTOUR MAP

* Reference First Wall Value (1.25 MW/m²)

Figure 5

2000

Figure 6

461510
K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
Displacement Rate (dpa/yr)

Figure 7

461510
(approx He/yr)

Production Rate

K-E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

Helium

2000

1500

130

500

Deuterium Zone

3 cm

1 cm

2 cm

$z = 1.25 \text{ cm}$

$z = 3.75 \text{ cm}$

$y = .25 \text{ cm}$

$y = 1.25 \text{ cm}$

$y = 3.75 \text{ cm}$

* y and z dimensions
vertical & horizontal

x - Direction (cm)

461510

18 X 25 CM.

K-E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.

log RR

1.72

1.32

0.8

0.42

0.0

-0.2

-0.29

-0.42

HFIR/PTP

EBR-II

FTR

RTNS-II

EMIT

flux
He Production Rate
Displacement Rate