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AN IMPROVED MATERIALS TESTING MODULE FOR MAGNETIC FUSION

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Summary

The REGAT module, an improved materials testing module for magnetic fusion engineering test facilities, is presented. The damage gradients in the module are reduced by exposing the sides of the module to direct fusion neutrons. A neutronics analysis is presented to assess the effectiveness of using the REGAT module in reducing damage gradients and increasing average damage levels.

Introduction

Recent advances in plasma physics have prompted the interest in designing near term engineering test facilities. Test facilities based on the tokamak concept, such as TETR[1], INTOR[2], ETF[3], and FED[4] have been proposed. TASKA is a new engineering test facility based on the tandem mirror confinement principle[5], which is required to demonstrate that the key technologies required for a DT demonstration power reactor can be successfully integrated into one machine. TASKA will also be a test facility for the blanket, tritium, materials, and plasma engineering technology required for the demo.

One problem with past materials test modules has been the large spatial variation in displacement damage (dpa), gaseous transmutation rates, and nuclear heating from the first wall to the back of the module. In an effort to minimize those gradients, we have designed a Reduced Gradient Test Module (REGAT) for TASKA. In the REGAT design, the blanket region is cut back from the first wall to leave the test module protruding into the vacuum chamber (see Fig. 1). This results in direct exposure of the module sides to source neutrons. Therefore, the damage gradients in the module are reduced as compared to the traditional design which is surrounded on all sides by the normal blanket and shield. The object of this paper is to present the neutronics analysis of the REGAT module to assess its effectiveness in reducing damage gradients and enhancing the materials testing capability.

Calculational Model

The materials testing module is placed at the center of the cylindrical central cell section of the tandem mirror reactor. Fig. 1-a shows a schematic of the traditional test module. The module is immediately behind the first wall and surrounded on all sides by the normal blanket and shield. In Fig. 1-b, the original REGAT design is shown with the test module protruding into the vacuum chamber and directly exposed to neutrons on the sides. An improved REGAT design is shown in Fig. 1-c. In this design, the blanket region surrounding the module is tapered to increase the contribution to the damage in the module from neutrons reflected from the blanket. Further enhancement of damage can be obtained when a neutron multiplier is used in the region of the blanket surrounding the module. In TASKA, neutron multiplication results from using $Pb_{83}Li_{17}$ liquid metal eutectic as a coolant/breeder. The REGAT module, with width a and thickness b, has an inner radius r_w. A blanket consisting of 81 v/o $Pb_{83}Li_{17}$ and 10 v/o structure made of the ferritic steel alloy HT-9 was considered in this work. Although the TASKA design was used in the calculations, the results are more general and can apply to all magnetic fusion devices.

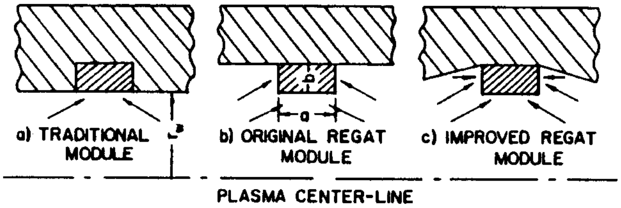

Figure 1. Schematic of REGAT and Traditional Test Modules.

Detailed neutronics calculations have been performed, using the three-dimensional Monte Carlo code MORSE[6] to determine the spatial variation in the damage of different module designs. A coupled 25 neutron - 21 gamma cross section library consisting of RSIC DLC-41B/VITAMIN-C data library[7] and the DLC-60/MACKLIB-IV response data library[8] was used. The combinatorial geometry capability of the MORSE code was used to model the geometry of the problem. The test module was divided into 60 zones with volume detectors used to estimate the quantities of interest in the different zones. An isotropic 14.1 MeV neutron source was sampled uniformly from a cylindrical plasma zone which is 20 m long and 32 cm in radius. Because of symmetry, only half the central cell was modelled with a reflecting albedo boundary used at the center of the module.

Since the width of the test module is much smaller than the central cell length, a position dependent angular source biasing technique was used to get statistically adequate estimates for the neutron flux in the test module. This technique is similar to that used previously for the analysis of the end plug of a tandem mirror fusion reactor[9]. The source direction is picked from a biased distribution which forces 95% of the source neutrons to directly impinge on the test module and the statistical weight of the source is modified by the ratio of the unbiased isotropic and biased distribution functions. There were 50,000 histories used in the Monte Carlo calculations yielding less than 10% statistical uncertainties in the estimates for the damage rate in the different module zones. The results in this work are normalized to a wall loading of 1 MW/m^2 at the front surface of the module.

Analysis of REGAT Module Performance

A series of survey calculations was performed for the REGAT module with different values for the width and thickness to investigate the effect of dimensions on the testing capability of the module. Calculations have also been performed for the traditional module design to assess the effectiveness of the REGAT module in reducing the damage gradients. In these survey calculations, a first wall radius of 40 cm was used. The test module was considered to consist of 50 v/o 316 SS and 50 v/o void. All the results presented here are normalized to a 1 MW - yr/m^2 fluence.

Figure 2 shows the spatial variation of atomic displacement and helium production rates in a 5 cm wide and 100 cm thick REGAT module as compared to the equivalent traditional module. The peak damage rate occurring at the front of the module is decreased in the REGAT module. The reason is that source neutrons missing the module will impinge on the adjacent first wall and after being slowed down can contribute to the damage at the front of the traditional module. The effect is more pronounced on the dpa which can be produced by neutrons with energies as low as ~ 1 keV. However, the gradients for both dpa and helium production rates are reduced considerably when the REGAT module is used. The net effect is that the average damage rates in the REGAT module are greater than those in a traditional module with the same dimensions. The spatial variation of helium to dpa ratio, which is an important parameter affecting microstructure evolution[10], is also shown. A nearly uniform He/dpa ratio is obtained in the REGAT module. This results from the fact that less neutron spectrum softening occurs in the REGAT module when compared to the traditional module.

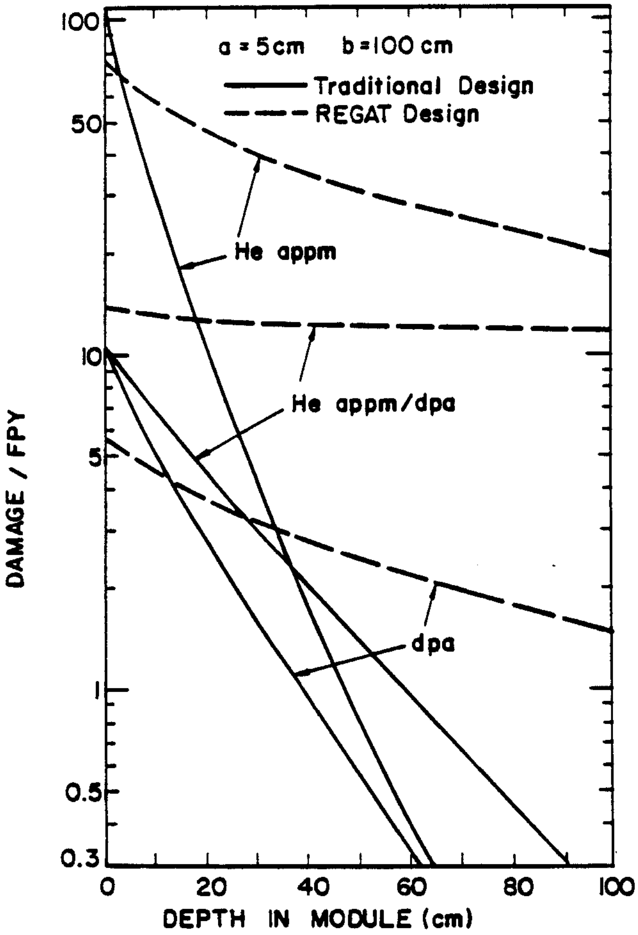

Figure 2. Spatial Variation of Damage in Traditional and REGAT Modules.

Table 1 gives the average and peak/average ratios for dpa and helium production rates for different REGAT module dimensions. Fixing the module width and decreasing the thickness results in increased average damage rates and reduced gradients. This results from the reduced attenuation in the radial direction. Decreasing the width for a fixed thickness results also in increased average damage rates and reduced gradients because of reduced attenuation in the axial direction.

Table 1 Effect of Module Dimensions on Damage Rates in the REGAT Module

a(cm)	b(cm)	dpa/FPY Avg.	dpa/FPY Peak/Avg.	He appm/FPY Avg.	He appm/FPY Peak/Avg.
5	100	2.4	2.3	30.6	2.5
5	50	3.3	2.1	41.6	2.3
7.5	50	3.2	2.3	39.2	2.6

It is clear from the results of Table 1 that decreasing the thickness b has a more pronounced effect on increasing the average damage rates than does decreasing the width a. This results primarily from decreasing the peak damage rate occurring at the center of the front surface of the module as the width, a, decreases. Hence, for a fixed test module volume, it is expected that the average damage rate will increase if one uses a wider module. In Fig. 3, the volume integrated damage rate used as a measure of the testing capability of the module is plotted versus module length for a fixed module volume of 0.153 m^3. For the purpose of comparison, the results for the traditional module are also included. Notice that the two modules give the same results in the limiting case when the testing zone covers the whole central cell surface. The REGAT module has a higher performance factor than that of the traditional module with the improvement being more pronounced when a thick module is used. Hence, one gains significantly by using the REGAT module when the area devoted for materials testing is limited by other considerations such as tritium breeding.

Figure 4 shows the variation of dpa rate with depth in a 7.5 cm wide and 50 cm thick module for the traditional design and three REGAT module cases. In the first case, no neutron reflection from the surrounding blanket is considered. The second case represents the original REGAT design with a flat blanket adjacent to the module and the third case represents the improved REGAT design with the adjacent blanket tapered as shown in Fig. 1. Table 2 shows the average and peak/average ratios for dpa and helium production in these cases. It is clear that, even in the case when no reflection from the blanket is considered, the REGAT module has higher average damage rates and less gradients than the traditional module. However, the peak damage in this case is much lower than that in the traditional module because of the lost contribution from source neutrons missing the module.

When neutron reflection and multiplication in the flat adjacent blanket is considered, the damage rate increases at all points of the module with the effect being more pronounced at the back of the module (which is closest to the blanket where the reflected neutrons originate). This results in higher average damage rates and less damage gradients. The effect on helium

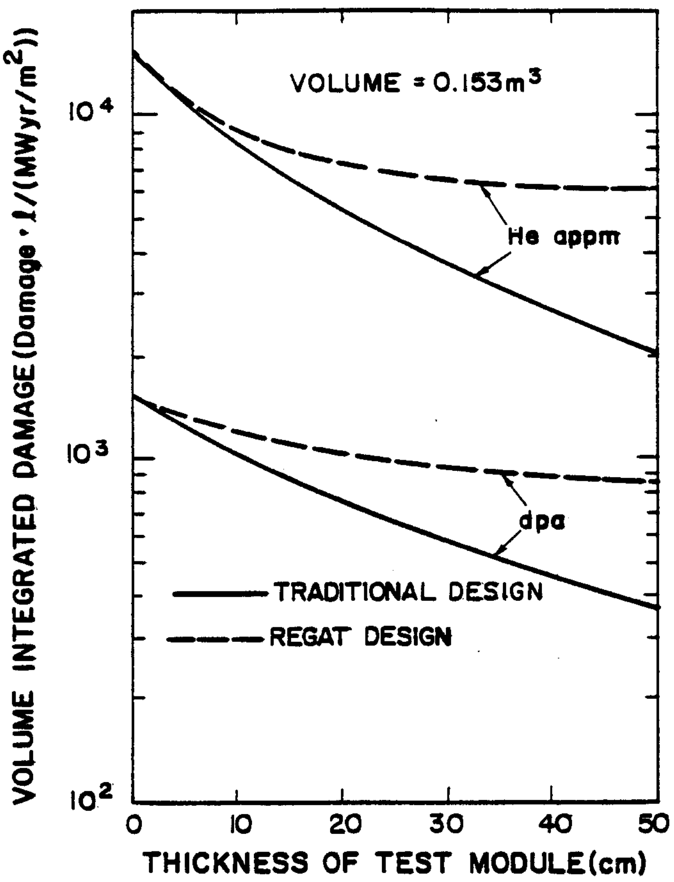

Figure 3. Volume Integrated Damage as a Function of Module Thickness for a Fixed Volume.

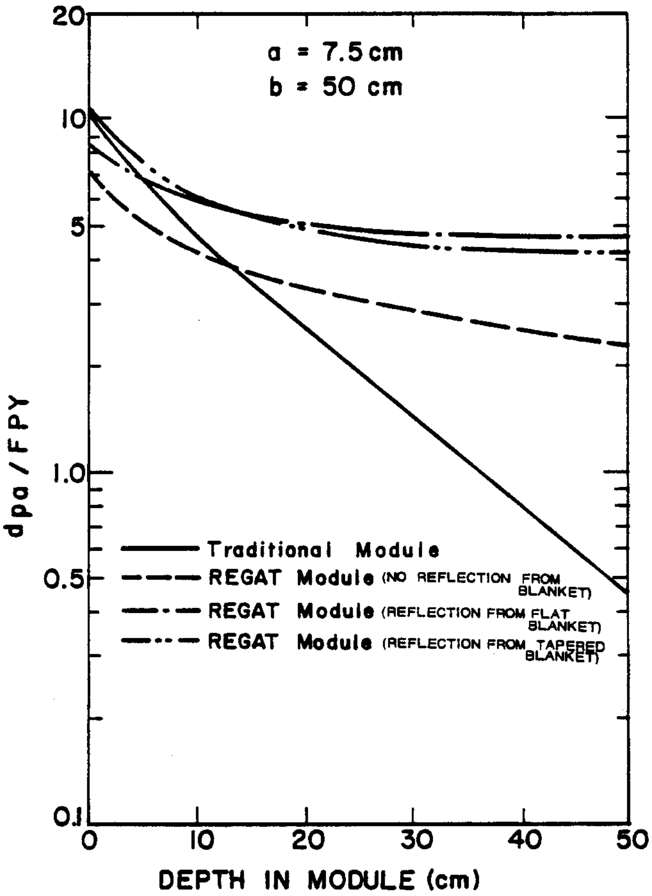

Figure 4. Spatial Variation of dpa Rate for Different Module Designs.

Table 2 Effect of Neutron Reflection From the Blanket on Damage Rates in a 7.5 cm Wide Test Module

	dpa/FPY		He appm/FPY	
	Avg.	Peak/Avg.	Avg.	Peak/Avg.
Traditional module	2.3	4.3	13.0	7.7
REGAT module (no reflection)	3.2	2.3	39.2	2.6
REGAT module (reflection from flat blanket)	5.1	1.6	43.5	2.3
REGAT module (reflection from tapered blanket)	5.3	2.0	39.6	2.5

production is not as pronounced as that on dpa because most of the neutrons produced in (n,2n) reactions with lead in the blanket do not contribute to helium production.

The peak damage rate is increased further by tapering the inner surface of the blanket surrounding the module. On the other hand, the damage rate at the back of the module decreases because less source neutrons impinge directly on the back of the module side. This results in a slightly higher damage gradient. This effect is more pronounced for helium production, most of which is caused by direct source neutrons. The net result is that the average dpa rate increase while the average helium production rate decreases with tapering. Even though the damage gradients are slightly increased, it is recommended to use the improved REGAT design because it results in a higher average dpa rate and allows some test specimens to be exposed to high damage levels.

Figure 5 shows the equal dpa contours in a 80 cm wide and 20 cm thick REGAT module for a fluence of 1 MW - yr/m^2. Note that if the traditional design is used, these contours will reduce to a set of parallel horizontal lines. The effect of using the REGAT design on reducing the damage gradient is clear. These results suggest also that small test specimens might be irradiated at the center of the module while larger specimens can be irradiated at the sides of the module. Similar contours were obtained for the helium production rate.

Preliminary results for the REGAT module used in TASKA show that a gain of ~ 40% in the materials testing capability can be achieved with the REGAT design. These results show also that the REGAT module of TASKA has a dpa times volume figure of merit that is a factor of ~ 6 higher than that for the current INTOR materials testing module[5]. Detailed results for the

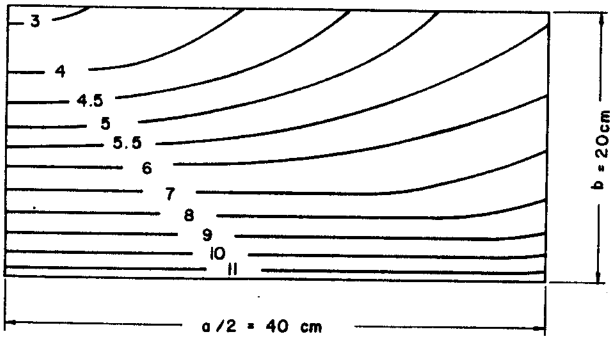

Figure 5. Equal dpa Contours in a REGAT Module 80 cm Wide and 20 cm Thick.

REGAT module of TASKA will be presented in a future paper.

Conclusions

An improved materials testing module for engineering test facilities is presented. Detailed neutronics analysis shows that the REGAT design reduces the damage gradients and increases the average damage levels in the module significantly. The results of the survey calculations show that the improvement over the traditional design is more pronounced when a thick module is used. Hence, one gains significantly by using the REGAT module when the area devoted for materials testing is limited by other considerations such as tritium breeding. Tapering the inner surface of the blanket surrounding the REGAT module increases the contribution to the damage from reflected neutrons and hence increases the average dpa rate and allows more test specimens to be exposed to high damage levels.The damage profiles in the module suggest that large test specimens, such as those required for the tokamak program, can be irradiated at the sides of the module where the lowest damage gradients occur.

Acknowledgment

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