Neutronics and Photonics Study of Fusion Reactor Blankets

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Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

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M. A. Abdou
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C. W. Maynard

Nuclear Engineering Department
The University of Wisconsin
Madison, Wisconsin 53706

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Summary of a paper to be presented at the First Topical Meeting on the Technology of Controlled Nuclear Fusion in April 1974.

A study of various important aspects in the design of CTR first walls, blankets, and reflectors was carried out(1). The following is a summary of the most important results.

Niobium, vanadium, molybdenum, stainless steel and SAP are the prime candidates for use as first wall and structural materials. SAP is 90% pure aluminum strengthened by about 10% by weight Al_2O_3 and its utilization in fusion systems has been proposed(2) as a competitor to vanadium(3) from low radioactivity and afterheat points of view. Table 1 shows a comparison of the radiation damage parameters, tritium production, and nuclear heating for various structural materials in a system consisting of a 1 cm first wall, 42 cm of 95% lithium plus 5% structure, 20 cm stainless steel reflector and 5 cm lithium plus structure. In addition to the (n,α) and (n,p) reactions, the reaction rates were also calculated for the (n,n'p) and (n,n'α) reactions. The results show that the contribution of these latter reactions to helium and hydrogen production is quite significant, e.g. the (n,n'p) is larger than the (n,p) reaction rate in a SAP first wall. Table 1 also shows that the nuclear heating in niobium is about 2.3 times that in a vanadium or SAP and 1.2 times that in a stainless steel first wall. The comparison of the total energy deposition in the blanket shows that using niobium increases the recoverable energy by about 1 MeV over stainless steel and vanadium and 0.7 MeV over SAP systems. It can also be seen that the total energy per fusion in these systems is about 19 to 20 MeV (including 3.5 MeV α's). This is about 2 MeV or more less than previously reported in the literature. The main reason for the difference is that we have used self consistent and energy preserving sets of neutron kerma factors and gamma production cross sections (4-6). More detailed results, analysis and conclusions are given in the paper.

Table 2 shows the effects of enriching the lithium in Li^6 and adding beryllium on the energy multiplication and tritium production in a blanket similar to that described above with a vanadium first wall and structure. The results show that the gain in energy multiplication as the Li^6 isotropic ratio is increased is only .06% for 15% Li^6, and 0.5% for 50% Li^6. However, adding 4 and 10 cm of beryllium to the blanket increases the energy production by 9 and 18%, respectively. Additional investigation showed that enriching lithium in Li^6 can increase the energy multiplication significantly if a few centimeters of beryllium are present in the lithium region.

An intermediate region, called a reflector, between the lithium and shield regions is required. A comparative study of several materials showed that iron-in nonmagnetic form- has several advantages as a reflector material over other possible condidates. A 20 cm thick iron reflector increases the energy production per fusion by about 1.5 MeV relative to a graphite reflector of equal thickness.

An investigation of the associated magnet shield is given in another paper in this conference.

Table 1

Comparison of Neutronics Parameters for Various Structural Materials

First Wall and Structure Response	Zone†	Niobium	Vanadium	St. Steel	SAP
(n,α) in structural material (reactions per fusion neutron x 10^4)	3	9.4470	28.9301	124.0960	166.590
	4	4.3312	12.3060	55.1620	87.942
	5	0.9119	2.2741	10.3739	20.922
	6	0.4181	1.0062	4.6977	10.1643
	S*	15.117	44.536	194.43	285.825
(n,p) in structural materials (reactions per fusion neutron x 10^3)	3	3.1985	5.4179	25.0850	11.7886
	4	1.5423	2.7168	12.0252	6.8261
	5	0.3440	0.6203	2.6478	1.8007
	6	0.1601	0.2915	1.7909	0.8728
	S*	5.2482	9.0522	41.585	21.3078
displacements per atom per 10^{21} fusion neutron	3	10.6349	9.9863	14.3119	
Tritium breeding	T_6	0.7734	0.9042	0.8161	0.7555
	T_7	0.4918	0.5547	0.4944	0.5970
	T	1.2652	1.4589	1.3105	1.3525
Total (Neutron plus gamma) heating in MeV per fusion neutron	3	1.6635	0.7089	1.3748	0.7089
	4	7.8765	7.8981	7.6064	7.6563
	5	2.7961	2.8487	2.6704	2.7892
	6	1.8562	1.9211	1.7792	1.8835
	7	2.5263	2.3676	2.1953	2.9535
	S*	16.8921	15.9324	15.7890	16.1758
Total (Neutron plus gamma) Leakage in MeV/fusion neutron		0.1039	0.1158	0.0973	0.1350

* Sum over zones 3 through 8

† Zone 3 is 1 cm first wall, zones 4, 5, and 6 (20, 12 and 10 cm) are 95% Li plus structure, zone 7 is 20 cm SS reflector, and zone 8 is 5 cm 95% Li plus 5% structure.

Table 2

Effect of Enriching Lithium in Li^6 and adding Beryllium on the Energy Multiplication in the Blanket

(Results are normalized to one fusion neutron)

a/o of Li^6 in lithium		7.42*	15.0	30.0	50.0	7.42*	7.42*
v/o of Be in blanket		0.0	0.0	0.0	0.0	9	20
Neutron Heating in							
	Li^6	4.9966	6.1338	7.6839	9.3943	6.4462	7.9520
	Li^7	6.0376	5.4082	4.3270	2.9924	4.7795	3.5067
	V	0.3953	0.3750	0.3590	0.3481	0.3756	0.3528
	Fe	0.2340	0.2278	0.2208	0.2153	0.1507	0.0774
	Ni	0.0801	0.0785	0.0765	0.0749	0.0519	0.0269
	Cr	0.0538	0.0521	0.0502	0.0487	0.0347	0.0179
	Be	0.0	0.0	0.0	0.0	2.2193	4.3891
Total Neutron Heating (MeV)		11.7974	12.2754	12.7174	13.0737	14.0579	16.3497
Total Gamma Heating (MeV)		4.2533	3.7893	3.3851	3.0627	3.4891	2.6623
Total Heating (MeV)		16.0507	16.0647	16.1025	16.1364	17.5470	19.0120
Tritium Breeding	T_6	0.9042	0.9901	1.0529	1.0878	1.2361	1.5803
	T_7	0.5547	0.5013	0.4052	0.2824	0.4410	0.3249
	T	1.4589	1.4914	1.4581	1.3702	1.6771	1.9052

*Corresponds to natural lithium

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