Comparative Study of Nuclear Heating in Fusion Reactor Blankets

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M.A. Abdou and Robert W. Conn

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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Robert W. Conn

Nuclear Engineering Department

The University of Wisconsin

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We report here on a comparative study of nuclear heating in several recent fusion reactor blanket designs using three different calculational approaches. The blanket designs studied are from UWMAK-I[1], ORNL,[2] LLL,[3] and PPPL[4] and are summarized in Table 1.

Three approaches were used to calculate the nuclear heating: 1) Method 1. The recently developed MACK program[5,6,7] was used to calculate neutron kerma factors from ENDF/B3;[8] 2) Method 2. The neutron kerma factors of Ritts et. al.[9] were used; (For both methods 1 and 2, the gamma production cross sections were processed from ENDF/B3 with LAPHANO,[10] except for ^{6}Li,^{7}Li,C, and Nb, which came from ref. 9 and for flourine which was calculated by the authors); 3) Method 3. An integral energy balance method described in ref. 5 was used. This method is quite accurate in predicting the total energy deposition in any system, though it does not provide the spatial distribution of the heating. In all cases, the neutron and gamma fluxes were calculated using ANISN[11] in the S_8-P_3 approximation with nuclear data from ENDF/B3 processed by SUPERTOG[12] and MUG.[13] (An exception is the neutron cross sections for flourine, which are from the GAM-II library[14]).

Table 2 gives the results for neutron, gamma, and total nuclear heating in the four designs outlined in table 1 using the three calculational procedures just described. The following conclusions may be drawn from these results: 1) The total nuclear heating calculated from methods 1 and 3 agree to within the consistency of the basic data as discussed in references 5 and 15. Hence, we conclude the results from the MACK program[6,7] are reliable. 2) Method 2, using neutron kerma factors from Ritts et.al.,[9] overestimates the neutron heating in all designs by 15 to 25%. (Dudziak[16] came to a similar conclusion for the RTPR design.) 3) The total nuclear heating in the ORNL[2] and PPPL[4] designs are overestimated by approximately 17% and 29%, respectively. The total thermal power output of those designs will therefore also be overestimated by the same percentages.

Table 1

Description of Various Blanket Designs*

zone	UWMAK-I[1] (cylindrical geometry)		ORNL[2] (cylindrical geometry)	
	outer radius (cm)	Composition†	outer radius (cm)	Composition†
1	500	plasma	280	plasma
2	550	vacuum	350	vacuum
3	550.4	stainless steel	350.25	Niobium
4	567.4	95% Li + 5% SS	380.25	99% Li + 1% Nb
5	584.4	95% Li + 5% SS	380.5	Niobium
6	601.4	95% Li + 5% SS	420.5	Graphite
7	616.4	stainless steel	420.75	Niobium
8	621.4	95% Li + 5% SS	450.75	99% Li + 1% Nb
9	623.4	stainless steel	451.0	Niobium

zone	PPPL[4] (cylindrical geometry)		LLL[3] (spherical geometry)	
1	290	plasma	320	plasma
2	360	vacuum	480	vacuum
3	366	16.4% PE-16	480.1	stainless steel
4	376	0.731% Flibe + 5.7% PE-16	481	Lithium[a]
5	376.36	PE-16	490	85% Li + 5% SS
6	388.36	78.8% Flibe + 4.5% PE-16	510	85% Li + 5% SS
7	388.72	PE-16	510.9	Lithium
8	408.72	82.0% Flibe + 3.8% PE-16	511	stainless steel
9	409.09	PE-16	512	graphite
10	439.64	91.2% Flibe + 3.8% PE-16	540	40% Li + 40% C + 10% SS
11	440.0	PE-16	580	40% Li + 40% C + 10% SS

*All these blankets were followed by shields. While these shields were included in our calculations, their description is not given here as they do not significantly affect the results.

†All composition percentages are by volume.

a-4.0% ^{6}Li; all other designs utilize natural lithium (7.56% ^{6}Li).

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Table 2

Neutron, Gamma, and Total Heating for Various Designs

in MeV per Fusion Neutron as Calculated by Various Methods

Design	Neutron Heating		Gamma Heating	Total Heating			
	MACK[6] (A)	Ritts etal[9] (B)	LAPHANO[10] & Ref. (9)	MACK (A+C)	Ritts etal (B+C)	Integral Energy Balance[5]	Values previously reported
UWMAK-I	12.43	15.09	4.13	16.56	19.22	16.44	16.56 [1]
ORNL	12.95	15.65	2.73	15.68	18.38	15.31	18.38 [2]
PPPL	12.88	16.12	4.99	17.87	21.12	17.87	23.1 [4]
LLL	12.18	14.10	3.61	15.79	17.71	15.53	15.82 [3]