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TWO-DIMENSIONAL HEATING ANALYSIS OF FUSION BLANKETS FOR SYNFUEL PRODUCTION*

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Abstract

Fusion reactors could be used to generate electric power and produce synthetic fuels with relatively high efficiencies (about 60%) [1]. A two temperature zone blanket coupled to a high temperature electrolysis system would be used. An important parameter in this system is the ratio of the fusion neutron kerma energy absorbed by the hot interior (the higher temperature zone) to the total energy/fusion. This parameter is calculated as ∿.5 for both a one and two-dimensional model of the blanket module, and is a reasonable value for efficient energy production.

Introduction

The high energy neutrons from DT fusion reactions can penetrate very deeply into materials before their kinetic energy is transformed to heat. This unique feature of fusion energy, and the fact that about 80% of the energy released per DT fusion reaction is carried by 14 MeV neutrons, can dramatically increase the efficiency of electric power generation (to about 60%) as well as produce H_2 and H_2-based synthetic fuels at high efficiency (about 50-70%). This deep penetration of the primary neutrons makes two temperature region blankets feasible. In this concept, a relatively low temperature (300-400^{o}C) metallic structure is the vacuum/coolant pressure boundary, while the interior of the blanket, which is a simple packed bed of non-structural material, operates at a very high temperature (∿1500^{o}C process steam or 800^{o}C He). Separate coolant circuits are required for the two temperature regions, as well as a thermal insulator between them.

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The analysis consisted of the following steps:

1. Determination of the geometry and atomic concentration of the blanket module producing high temperature steam for a high temperature electrolysis (HTE) process. The overall toroidal structure is shown in Figure 1, and the blanket module cross section in Figure 2.

2. A one-dimensional case was run on the blanket module using the computer program ANISN [2]. A one-dimensional heating analysis was performed. Also, the calculated flux was plotted and analyzed to determine an appropriate collapsed energy group structure of the scattering cross sections. A P_0 Legendre expansion and an S-4 angular quadrature were used (i.e., P_0S_4). It has been determined that a P_0S_4 calculation is accurate enough for scoping studies, but that for accurate calculations of a particular design, P_3S_8 must be used. Cross sections from the Radiation Shielding Information Center (RSIC) data library DLC-37D [3] were used. It consists of 121 coupled energy groups (100 neutron + 21 photon groups). That library was collapsed to 20 energy groups (14 neutron + 6 photon groups). This was used as part of the input to the two-dimensional calculation.

3. The 121 group kerma (kinetic energy released in material) factors were collapsed into a consistent 20 group structure.

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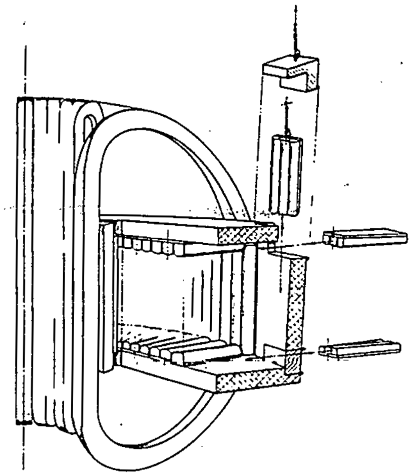

SCHEMATIC SHOWING MODULE REMOVAL

Figure 1

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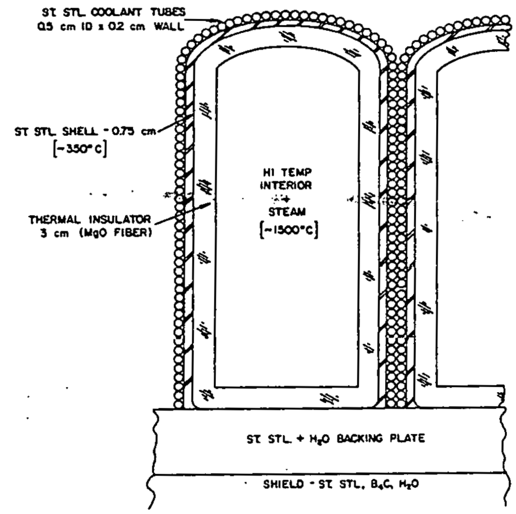

BLANKET CROSS SECTION
HTE PROCESS HEAT MODULE

Figure 2

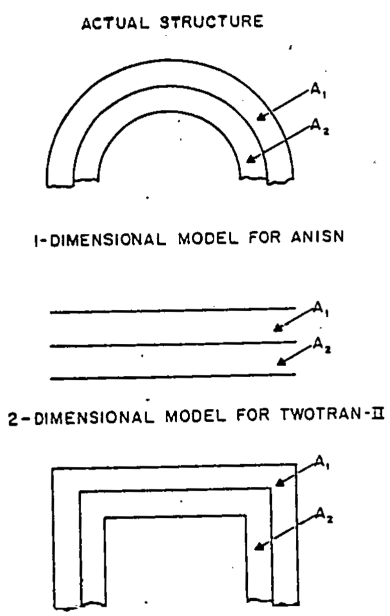

Figure 3. Blanket Models

4. The two-dimensional case was run on the blanket module using the computer program TWOTRAN-II [4] which generated the neutron and photon flux. The geometry used was R-Z, with the Z-axis lying along the magnetic axis (i.e., the center of the plasma axis or, equivalently, the minor axis), and the R-axis going into the blanket (i.e., the minor radius). In Figure 2 the Z-axis is horizontal above the picture and increases to the right. The R-axis is vertical, and increases downward. The plasma is a horizontal band at the top of the picture and the curved layer of coolant tubes is the first wall.

5. The heat energy absorbed was calculated, using the TWOTRAN-II two-dimensional flux, the geometry and atomic concentrations and the appropriate kerma factors.

Geometry, Materials and Results

The real structure, shown in Figure 2, which has a cross section which is constant into the paper, is modelled differently for the one-and two-dimensional cases. The rounded part at the top (closest to the plasma) consists of four regions--the tubes, the shell, the fiber and the "dome" (the "dome" is the top part of the hot interior and has a curved edge - roughly a half-ellipse. The first three regions are curved strips. In the one-dimensional case, the cross section of each of the four regions is modelled as a horizontal band parallel to the plasma. In the two-dimensional case, each curved strip is modelled as an open-ended rectangle (bottom side missing and three remaining sides having thickness). The "dome" is modelled as a rectangle. (See Figure 3)

The thickness of these model figures is determined by equating the cross sectional areas of the regions of the actual module and those of the models. The material compositions are shown in Table I. The dimensions, together with the fractional neutron and photon energy absorbed, are shown in Tables II and III. Note that these fractions sum to unity, and do not include the alpha particle energy (3.5 MeV).

The calculation for a stainless steel structural shield, M_gO-steam cooled high temperature interior results in .57 as the fraction of neutron and photon energy absorbed by the high temperature interior. If the alpha particle energy is included, the fractional energy absorbed by the hot interior is .48. This is to be compared with .53 from the one-dimensional ANISN calculation using 121 groups. The calculated Q values (total energy/fusion) are 22.1 MeV for the one-dimensional case and 22.2 MeV for the two-dimensional case. While the agreement between the one-and two-dimensional results is good, no general conclusions should be drawn since the results may be design dependent.

Acknowledgment

The authors are extremely grateful to Arnold Aronson, Brookhaven National Laboratory, for his valuable assistance.

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[3] RSIC Data Library Collection, DLC-37D, "EPR-Coupled 100-Group Neutron 21-Group Gamma Ray Cross Sections for EPR Neutronics".

[4] LATHROP, K.D. and BRINKELY, F.W., "TWOTRAN-II: "An Interfaced, Exportable Version of the TWOTRAN Code for Two-Dimensional Transport", LA4848 MS, Los Alamos Scientific Lab. of the University of California, Los Alamos, New Mexico.

Table I

Material Compositions

Material	Element	10^{24} Atoms/cc
Tubes	NI (Nat)	.005147
	CR (Nat)	.008233
	FE (Nat)	.031114
	MN-55	.000917
	0-16	.004868
	H-1	.009736
Shell	NI (Nat)	.009479
	CR (Nat)	.015163
	FE (Nat)	.057300
	MN 55	.001688
Fiber	MG (Nat)	.010698
	0	.010698
Hot Interior, Part 1 (no walls, "dome")	MG (Nat)	.043328
	0	.043328
Hot Interior, Part 2 (with walls)	NI (Nat)	.000474
	CR (Nat)	.000758
	FE (Nat)	.002865
	MN-55	.000084
	0-16	.040266
	H-1	.000402
	MG (Nat)	.040065
Backing Plate	NI (Nat)	.003792
	CR (Nat)	.006065
	FE (Nat)	.022920
	MN-55	.000675
	0-16	.002006
	H-1	.004012
Shield	NI (Nat)	.003792
	CR (Nat)	.006065
	FE (Nat)	.022920
	MN-55	.000675
	C-12	.013858
	0-16	.002006
	B-10	.010903
	H-1	.004012
	B-11	.044033

Table II

Fractionsl Energies Absorbed - One-Dimensional Case

$$F \equiv \frac{E_{abs_{n+\gamma}}}{E^{total}_{abs_{n+\gamma}}} = \frac{\text{Neutron and } \gamma \text{ Energy Absorbed in that Part of the Blanket Shield System}}{\text{Total Neutron and } \gamma \text{ Energy Absorbed in the Entire Blanket Shield System}}$$

Region #	Name	Coordinates	F
		0.00	
1	Plasma		.00
		225.68	
2	Vacuum		.00
		282.10	
3	Tubes		.11
		283.30	
4	Shell		.12
		284.25	
5	Fiber		.05
		287.64	
6	Hot Interior-Part 1 ("Dome")		.25 (contains no fiber & walls)
		293.55	
7	Hot Interior-Part 2		.45 (incl. fiber & walls)
		355.44	
8	Fiber		.00
		358.83	
9	Backing Plate		.01
		370.13	
10	Shield		.00
		483.13	

$E^{total}_{abs_{n+\gamma}} = 18.59$ MeV

$Q \equiv E^{total}_{abs_{n+\gamma}} + E_\alpha = 18.59 + 3.52 = 22.11$ MeV

For the Hot Interior: $F = .63$, not including E_α

$$\frac{E_{abs_{n+\gamma}}}{Q} = .53, \text{ including } E_\alpha$$

Table III

Fraction Energies Absorbed - Two-Dimensional Case

$$F \equiv \frac{E_{abs_{n+\gamma}}}{E^{total}_{abs_{n+\gamma}}} = \frac{\text{Neutron and Gamma Energy Absorbed in that Part of the Blanket Shield System}}{\text{Total Neutron and Gamma Energy Absorbed in the Entire Blanket Shield System}}$$

	Boundary	Tubes (.00 – 0.90)	Shell (0.90 – 1.65)	Fiber (1.65 – 4.65)	Hot Interior (4.65 – 24.15)
	0.00				
Plasma		0	0	0	0
	225.68				
Vacuum		0	0	0	0
	282.10				
Tubes		<.006	<.006	<.006	.06
	282.90				
Shell		<.006	<.006	.01	.07
	283.57				
Fiber		.01	.01	<.006	.04
	286.23				
Hot Interior-Part I ("Dome")		.02	.02	.01	.254
	293.55				
Hot Interior-Part II		.04	.06	.02	.314
	355.44				
Fiber		<.006	<.006	<.006	<.006
	358.83				
Backing Plate		<.006	<.006	<.006	.02
	370.13				
Shield		<.006	<.006	<.006	<.006
	483.13				

$E^{total}_{abs_{n+\gamma}} = 18.70$ MeV

$Q = E^{total}_{abs_{n+\gamma}} + E_\alpha = 18.70 + 3.52 = 22.22$ MeV

For the Hot Interior: F = .57, not including E_α

$$\frac{E_{abs_{n+\gamma}}}{Q} = .48\text{, including } E_\alpha$$