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Abstract Benchmark problems representing the leading fusion blanket concepts are presented. Benchmark calculations for self-cooled $Li_{17}Pb_{83}$ and helium-cooled blankets were performed. Multigroup data libraries generated from ENDF/B-IV and V files using the NJOY and AMPX processing codes with different weighting functions were used. The sensitivity of the TBR to group structure and weighting spectrum increases as the thickness and Li enrichment decrease with up to 20% discrepancies for thin natural $Li_{17}Pb_{83}$ blankets.

INTRODUCTION

Accurate calculation of tritium breeding in a D-T fueled fusion reactor is of prime importance due to required tritium self-sufficiency. A natural Li blanket with Nb structure was proposed previously for tritium breeding ratio (TBR) benchmark calculations.[1] Results in excellent agreement were obtained for this blanket using different codes and data libraries.[1,2] However, recent progress in fusion blanket design led to a variety of blanket concepts utilizing different breeders, coolants and structural materials. In some cases, discrepancies up to ~ 20% in TBR calculation were observed. Based on the findings of the Blanket Comparison and Selection Study,[3] we propose several benchmark problems representative of the leading blanket concepts. We present results of benchmark calculations for representative self-cooled $Li_{17}Pb_{83}$ and helium-cooled blankets. Different multigroup data libraries were used and the results compared against the MCNP continuous energy calculations.

DESCRIPTION OF BENCHMARK PROBLEMS

Four benchmark problems, representing the self-cooled Li and $Li_{17}Pb_{83}$, He-cooled Li_2O and H_2O-cooled Li_2O concepts, are proposed for nuclear data comparison. The blankets are modeled in one-dimensional cylindrical geometry with a uniform 14.1 MeV isotropic neutron source in the plasma zone. The discrete ordinates calculations use the P_3S_8 approximation with the P_N angular quadrature set. A 1 cm interval size is used. Two blanket thicknesses and Li enrichments are considered (Table I) to investigate the effect of these parameters on the TBR calculation accuracy. Detailed specifications including geometrical configurations, material compositions and nuclide number densities are available from the authors. The specifications are detailed enough to enable researchers to duplicate the calculational model such that the only variable will be the nuclear data library used. Results for total as well as spatial and energy variation of tritium breeding, nuclear heating and radiation damage calculated with different codes and data libraries should be compared with the aim of determining the multigroup library most appropriate for each blanket concept. The study will help identify specific areas of improvement for the data libraries.

TABLE I. Some specifications for the benchmark blankets.

Blanket concept	Blanket thickness (m)	Li enrichment	Blanket composition
Self-cooled Li	0.4, 0.8	7.42, 20% ^6Li	92.5% Li, 7.5% PCA
Self-cooled $Li_{17}Pb_{83}$	0.4, 0.8	7.42, 90% ^6Li	80% $Li_{17}Pb_{83}$, 10% HT-9
He-cooled Li_2O	0.2, 0.42	7.42, 20% ^6Li	85% Li_2O, 6% PCA
H_2O-cooled Li_2O	0.2, 0.51	7.42, 20% ^6Li	75% Li_2O, 10% H_2O, 10% PCA

RESULTS FOR SELF-COOLED $LI_{17}PB_{83}$ BENCHMARK BLANKETS

We performed calculations for $Li_{17}Pb_{83}$ blankets with 10% HT-9 and 10% void. Breeding blanket thicknesses of 0.6, 0.8 and 1 m and Li enrichments of 7.42 and 90% ^6Li were considered.[2] The blanket is surrounded by a 5 mm HT-9 first wall and a 0.3 m 316 SS reflector with 10% water. The plasma and wall radii are 0.35 and 0.5 m, respectively. The MCNP, ANISN and ONEDANT codes were used. With the continuous energy MCNP calculation as a reference, the broad group libraries tend to overestimate the TBR. This is related to the inadequacy of the group structure in representing the mostly elastic scattering resonances for iron in the 1 keV - 1 MeV range leading to underestimating neutron leakage and overestimating TBR. The effect is more pronounced in thin blankets with large steel content. Up to 15% and 4% discrepancies were obtained with 25 and 46 neutron groups, respectively. These effects are less pronounced for systems highly enriched in ^6Li due to the dominant ^6Li absorption. However, when very thin blankets are used the overestimate is large even with highly enriched Li. Ten percent higher TBR was obtained with 46 groups for a 10 cm thick blanket with 90% ^6Li.

We used different weighting functions to collapse the LANL library MATXS6 (80 groups) into different broad group structures. The spectrum used to generate MATXS6 results in less accurate results compared to 1/E spectrum which is closer to the actual spectrum in the low energy region. The MATXS6 spectrum results in underestimating the TBR with the deviation increasing as the blanket thickness increases due to the increased spectrum softening. TBR is underestimated by 14% for a 1 m thick blanket with 30 groups. When the calculated blanket midpoint spectrum was used for group collapsing more accurate results were obtained. These effects are less pronounced in highly enriched systems since harder spectra are obtained and ^6Li absorption dominates.

RESULTS FOR HELIUM-COOLED BENCHMARK BLANKETS

Benchmark calculations were performed for helium-cooled blankets with Li_2O, Li and $Li_{17}Pb_{83}$ breeders.[4] The plasma and wall radii are 2.53 and 2.73 m, respectively. The 60 mm first wall consists of 6.6% structure and the balance is helium (void). The 0.42 m breeding zone for the liquid metal blankets consists of 10% structure, 75% breeding material (Li or $Li_{17}Pb_{83}$) and 15% helium (void). For the Li_2O blanket, 6% structure, 85% Li_2O (80% dense) and 9% helium (void) was used. $Li_{17}Pb_{83}$ is enriched to 90% ^6Li while the other breeders have natural lithium. A 0.22 m gas plenum that has 10% structure follows the blanket and is backed by a 0.3 m shield.

The neutronics calculations were performed using both discrete ordinates and Monte Carlo methods with the fine multigroup libraries, VITAMIN-E (174 groups) and MATXS8 (187 groups), and a continuous energy library. Broad group libraries were also generated from these libraries. The results of

Table II show that good agreement (within 2%) with MCNP results was obtained for these blankets where ^6Li absorption dominates. However, discrepancies up to 20% occur for very thin blankets with strong structural absorption as in the case of natural $Li_{17}Pb_{83}$.

TABLE II. TBR for helium-cooled benchmark blankets.

Blanket concept	Discrete ordinates 187 groups	Discrete ordinates 30 groups	MCNP Continuous Energy
Li_2O	1.208	1.202	1.212 (± 0.9%)
$Li_{17}Pb_{83}$	1.242	1.252	1.229 (± 0.8%)
Li	1.069	1.073	1.094 (± 1%)

CONCLUSIONS

Benchmark problems representing the leading blanket concepts were proposed. TBR benchmark calculations were performed for self-cooled $Li_{17}Pb_{83}$ and helium-cooled blankets. The sensitivity of TBR to group structure and weighting spectrum increases as thickness and Li enrichment decrease due to dominant resonance interaction with the structure. While discrepancies up to 20% were obtained for the natural $Li_{17}Pb_{83}$ case, less than 2% deviations were observed for the natural Li and Li_2O blankets where the ^6Li content implies a dominant neutron absorption in ^6Li. In thin blankets or blankets not dominated by ^6Li absorption a group structure that is fine enough in the iron resonance region should be used together with the appropriate weighting function representative of the blanket system.

REFERENCES

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2. J. Huang and M. Sawan, Fusion Technology, 6, 240 (1984).
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APPENDIX

I. Specifications for the Benchmarks

- One-dimensional cylindrical geometry

- Uniform source in the plasma zone emitting isotropic monoenergetic 14.1 MeV neutrons.

- In the discrete ordinates calculations an interval size of 1 cm is to be used everywhere except in the plasma and vacuum zones and zones which are less than 1 cm thick.

- The P_3S_8 approximation is to be used in discrete ordinates calculations. Table I gives the angular quadrature set to be used in the calculations.

- Vacuum right boundary condition is to be used in the self-cooled liquid Li and $Li_{17}Pb_{83}$ benchmarks. An albedo of 0.3 is to be used for all groups at the right boundary of the Li_2O benchmarks.

- Two lithium enrichments are to be used for each of the blanket benchmarks as follows:

self-cooled Li	:	natural and 20% ^6Li in lithium
self-cooled $Li_{17}Pb_{83}$	:	natural and 90% ^6Li in lithium
He cooled Li_2O	:	natural and 20% ^6Li in lithium
H_2O cooled Li_2O	:	natural and 20% ^6Li in lithium

- Two breeding blanket zone thicknesses are to be used for each of the blanket benchmarks as follows:

self-cooled Li	:	40 and 80 cm
self-cooled $Li_{17}Pb_{83}$	:	40 and 80 cm
He cooled Li_2O	:	20 and 42 cm
H_2O cooled Li_2O	:	20 and 51 cm

- Table II gives the nuclide number densities for the different materials used in these benchmarks. The numbers in parentheses correspond to the enriched Li cases.

- Figures I, II, III, and IV show the configurations and material compositions (in vol. %) for the four blanket benchmarks. Notice that only one of the two breeding blanket thicknesses, to be considered for each benchmark, is indicated in the figures.

Table I. The S_8 Angular Quadrature Set

Cosine	Weight
-0.983032	0.0
-0.960290	0.050614
-0.796667	0.055595
-0.525532	0.052284
-0.183435	0.045335
0.183435	0.045335
0.525532	0.052284
0.796667	0.055595
0.960290	0.050614
-0.850774	0.0
-0.796667	0.055595
-0.525532	0.052284
-0.183435	0.045335
0.183435	0.045335
0.525532	0.052284
0.796667	0.055595
-0.604419	0.0
-0.525532	0.052284
-0.183435	0.045335
0.183435	0.045335
0.525532	0.052284
-0.279004	0.0
-0.183435	0.045335
0.183435	0.045335

Table II. Nuclide Densities for Materials Used in the Blanket Benchmarks

Material	Constituent Element	Nuclide Density (nuclei/b.cm)
H_2O	H	0.06700
	O	0.03350
Li	^6Li	0.00341 (0.00920)
	^7Li	0.04259 (0.03680)
$Li_{17}Pb_{83}$	^6Li	0.00041 (0.00500)
	^7Li	0.00515 (0.00055)
	Pb	0.02715
Li_2O (theoretical density)	^6Li	0.00608 (0.01640)
	^7Li	0.07592 (0.06560)
	O	0.04100
PCA	Fe	0.05499
	Cr	0.01274
	Ni	0.01290
HT-9	Fe	0.07678
	Cr	0.01019
316 SS	Fe	0.06996
	Cr	0.01576
	Ni	0.00984
	Mo	0.00076
Fe-1422	Fe	0.06953
	Mn	0.01219
	C	0.00231
	Cr	0.00185
	Ni	0.00158

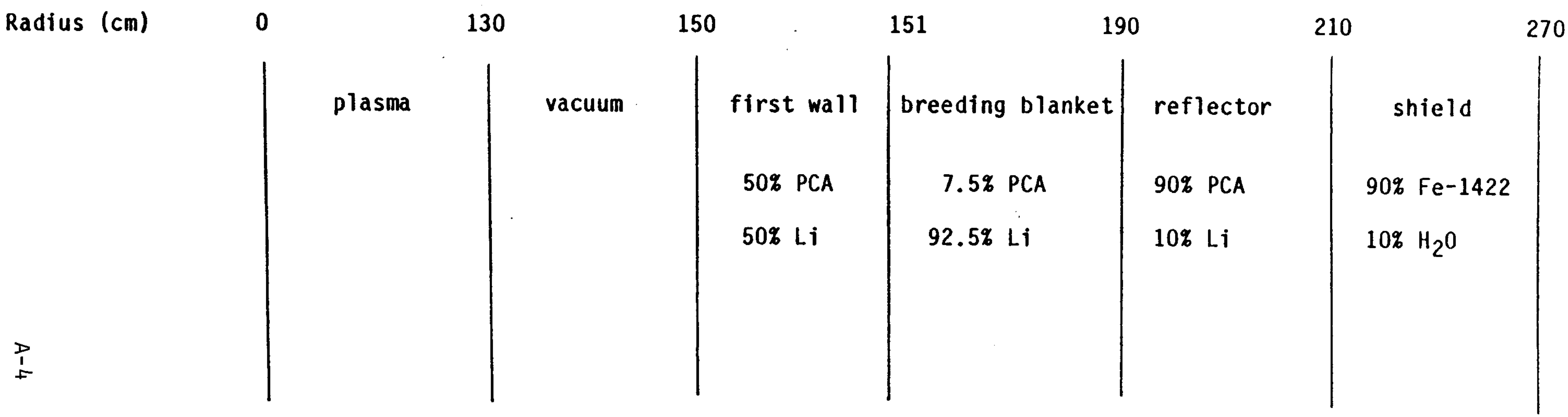

Fig. I. Configuration and Composition of the Self-Cooled Liquid Li Blanket Benchmark

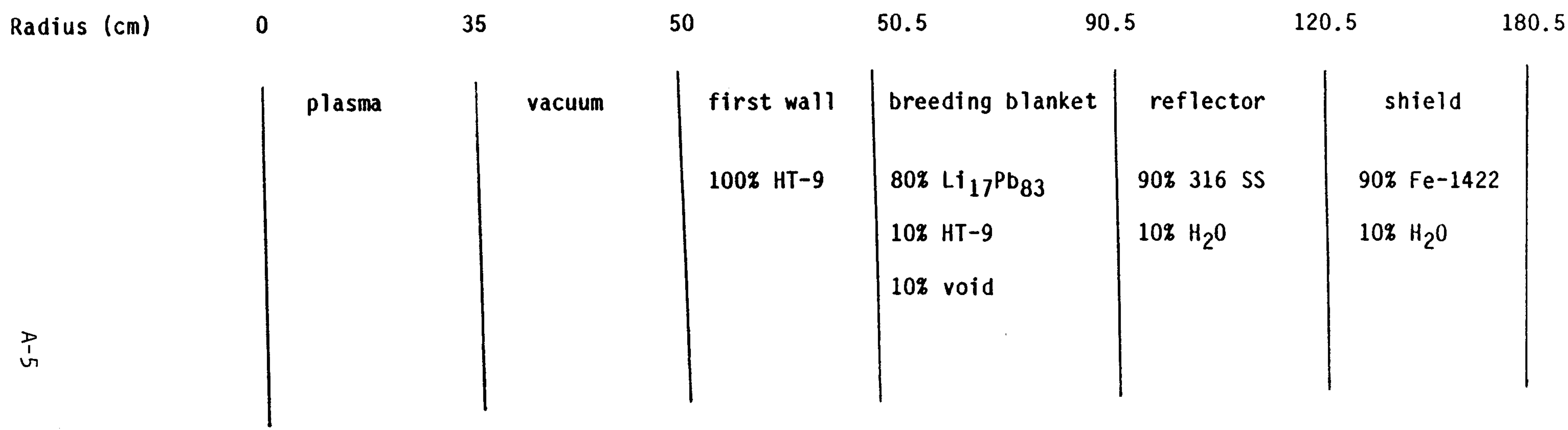

Fig. II. Configuration and Composition of the Self-Cooled Li17Pb83 Blanket Benchmark

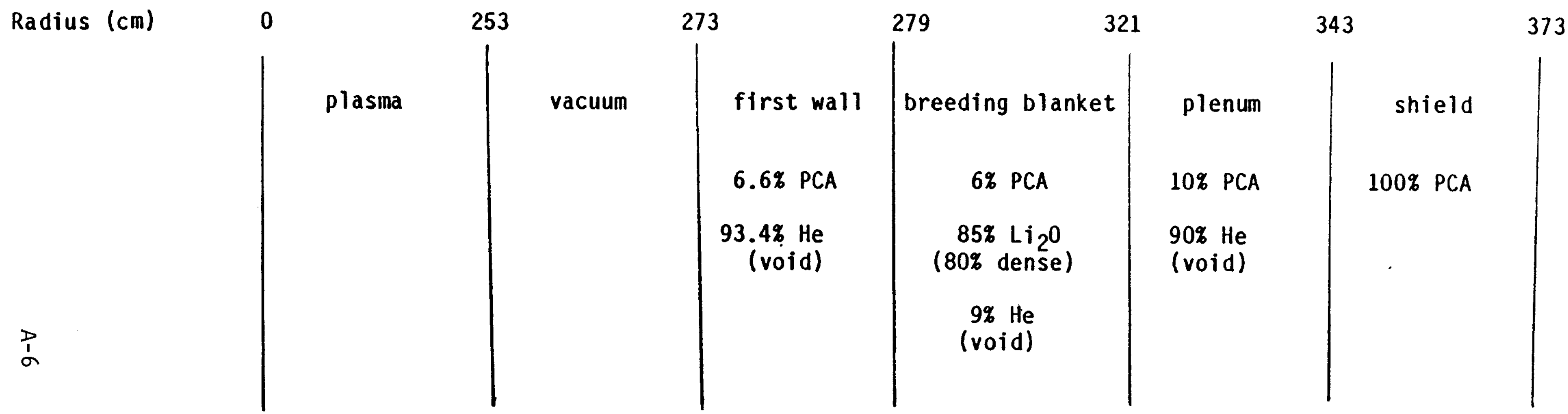

Fig. III. Configuration and Composition of the He Cooled Li_2O Blanket Benchmark.

Radius (cm)	0 – 253	253 – 273	273 – 274	274 – 325	325 – 343	343 – 358
	plasma	vacuum	first wall	breeding blanket	plenum	shield
			20% H_2O	10% H_2O	75% H_2O	20% H_2O
			80% PCA	10% PCA	25% PCA	80% Fe-1422
				75% Li_2O (85% dense)		
				5% void		

Fig. IV. Configuration and Composition of the H20 Cooled Li20 Blanket Benchmarks

II. Parameters to be Calculated for the Blanket Benchmarks

Members of the fusion neutronics community are requested to perform calculations for these blanket benchmarks using multigroup libraries based on the different available cross section evaluations (e.g. ENDF/B-IV, ENDF/B-V, ENDL, ...). Fine-group libraries generated using different processing codes (e.g., NJOY, MINX, ...) can be used. Different codes such as TRANSX and AMPX can be used to generate broad group data from the available fine-group libraries using different weighting spectra and group structures. These different libraries can then be used in the benchmark calculations. To facilitate comparing the different nuclear data libraries, the results for the following parameters need to be reported:

Tritium breeding:	Total as well as spatial and energy variation. Breakdown between the $^6Li(n,\alpha)t$ and $^7Li(n,n'\alpha)t$ reactions is also required.
Nuclear heating:	Total as well as spatial and energy variation. Breakdown between neutron and gamma heating is also required.
Radiation damage:	Spatial variation of dpa, He production, and H production.

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