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EARLY FUSION REACTOR NEUTRONIC CALCULATIONS: A REEVALUATION

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INTRODUCTION

Several fusion power plant design studies were made at a number of universities and laboratories in the late 1960s and early 1970s. These studies included such designs as the Princeton Plasma Physics Laboratory Fusion Power Plant[1] and the University of Wisconsin UWMAK-I Reactor.[2] Neutronic analyses of the blankets and shields were part of the studies. During this time there were dissertations written on neutronic analysis systems and the results of neutronic analysis on several blanket and shield designs. The results were presented in the literature.

Now in the fifth decade of fusion research, investigators often return to the earlier analyses for the neutronic results that are applicable to current blanket and shield designs, with the idea of using the older work as a basis for the new. However, the analyses of the past were made with cross-section data sets that have long been replaced with more modern versions. In addition, approximations were often made to the cross sections used because more exact data were not available. Because these results are used as guides, it is important to know if they are reproducible using more modern data.

In this paper, several of the neutronic calculations made in the early studies are repeated using the MATXS-11 data library. This library is the ENDF/B-VI version of the MATXS-5 library.[3] The library has 80 neutron groups. Tritium breeding ratios, heating rates, and fluxes are calculated and compared. The transport code used here is the one-dimensional S_n code, ONEDANT.[4] It is important to note that the calculations here are not to be considered as benchmarks because parameter and sensitivity studies were not made. They are used only to see if the results of older calculations are in reasonable agreement with a more modern library.

TRITIUM BREEDING RATIOS

The first comparison was that of the tritium breeding ratio for the Princeton TOKAMAK Fusion Reactor Study, which was published in 1974. The comparison was made with a S_8-P_4 transport approximation.

This reactor was a large TOKAMAK with a radius of 17 meters from the centerline to the outer edge of the coil. It contained a FLIBE blanket, and tritium breeding occurred in the ^{6}Li,

^7Li and Be. The comparison of the results of the breeding ratios shown in Table 1 clearly demonstrates that these neutronic results remain valid as a basis for new studies.

TABLE 1
COMPARISON OF TRITIUM BREEDING RATIOS FROM THE PRINCETON FUSION REACTOR DESIGN AND RESULTS OBTAINED USING ENDF/B-VI DATA

Constituent	Princeton Design	MATXS-11 Results
^6Li	0.9697	0.9832
^7Li	0.0938	0.0759
Be	0.0032	0.0033
Total	1.0667	1.0624

NEUTRON FLUXES

The second comparison was that of the neutron fluxes published in the authors' dissertation.[5] These fluxes were calculated using a modified version of the DTF[6] Code. Following publication, an error was found in the programming. This error was corrected before the code package, INDRA,[7] containing the modified version of DTF was transmitted to the Radiation Shielding Information Center for distribution. Because of the error, no inelastic neutron multiplication occurred when large numbers of energy groups were used. Thus, the flux in the lower energy groups were too small when 100 energy groups were used for results in the dissertation and a subsequent publication.[8] The error did not occur when a small number of energy groups were used.

The reactor used in the comparisons was a conceptual design reactor[9] that was referred to as the "standard blanket." This design was published for the specific purpose of comparing codes and data. The design was widely used in the early 1970s for this purpose. The reactor was constructed of niobium, contained liquid lithium, and had a carbon reflector. The first wall, 0.5-cm thick, was located 2 meters from the centerline of the reactor. It was followed by a 3-cm region containing 94% natural lithium and 6% niobium. A second 0.5-cm wall followed. The main blanket was 60-cm thick containing 94% lithium and 6% niobium; a 30-cm carbon reflector followed. There was a 6-cm zone of 94% lithium and 6% niobium following the reflector. The comparisons were made with a S_6-P_3 approximation, the same as used in the earlier work. The earlier work used the DLC-2 library.[10] This library did not have a thermal group, thus requiring the addition of a thermal cross section. The fluxes calculated are normalized to a 10-MW/m^2 wall load of 14 MeV neutrons. The results of the comparisons of the fluxes in the first wall, a 20-cm region next to the reflector and the reflector, are given in Table 2.

These comparisons suggest that there could be considerable differences in reaction rates calculated using the fluxes from the earlier work and the fluxes from the calculations here. The results from the dissertation, however, were in good agreement with other calculations at that

TABLE 2
COMPARISON OF FLUXES IN THE STANDARD BLANKET

	DLC-2 Library	MATXS-11 Library
First Wall		
14 MeV Flux	7.45e+14	7.50e+14
Thermal Flux	2.42e-02	4.52e+03
Total Flux	3.71e+15	1.91e+15
Last 20 cm of Breeding Blanket		
14 MeV Flux	1.39e+13	1.52e+13
Thermal Flux	8.72e+10	2.98e+11
Total Flux	4.33e+14	1.02e+15
Reflector		
14 MeV Flux	2.38e+12	2.77e+12
Thermal Flux	3.88e+13	3.72e+13
Total Flux	2.23e+14	4.97e+14

time; for example, the results of Steiner[11] or Blow.[12] Thus, some reevaluation is necessary before using any of these results as a basis for new studies.

HEATING RATES

The third comparison was that of the heating rates calculated for The University of Wisconsin UWMAK-I Reference Design. This reactor was a large TOKAMAK with a radius of 3 meters from the centerline to the first wall. The first wall was followed by a 42-cm natural lithium breeding blanket. The structure was 5% of the breeding blanket. A stainless steal reflector followed. Three different structural materials were used in the calculations. Here the comparisons were with the blanket containing stainless steel. The results of the heating rate comparisons are shown in Table 3. Here, the new calculations are in reasonable agreement with the earlier evaluation.

TABLE 3
COMPARISON OF NEUTRON HEATING RATES IN UNMAKE-I AND RESULTS OBTAINED USING END/B-VI DATA

Zone	UNMAKE-I MeV/ neutron	MATXS-12 MeV/neutron
first wall	0.60	0.41
blanket	10.06	9.19
reflector	0.32	0.56

CONCLUSION

It appears that the studies made in the 1960s and 1970s provide a reasonable basis for new studies. Absolute calculational values from this era, however, should be used with caution.

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