LETTERS TO THE EDITOR

COMMENTS ON "MULTIPLICATION OF 14-MeV NEUTRONS IN BULK BERYLLIUM"

The authors of Ref. 1 report on an important, careful, precise experiment and on its detailed and painstaking analysis. This experiment resolves the longstanding discrepancy between calculated and measured total neutron multiplication factors for 14-MeV neutrons in beryllium. However, the agreement found between the two calculated multiplications based on the ENDF/B-VI and the Young and Stewart[2] beryllium data evaluations is rather surprising and needs further clarification.

The two evaluations differ strongly from each other with respect to the magnitude of the $(n,2n)$ cross sections, which, at around 14-MeV incident neutron energy, is ~10% higher in the Young-Stewart evaluation compared with ENDF/B-VI, and to the spectra and angular distributions of neutrons emitted from collisions with beryllium nuclei [secondary energy and angle distributions (SED/SAD)]. The agreement to better than 2% between the calculated total neutron leakages, well within the experimental uncertainty of 3 to 4%, is obviously caused by a mutual compensation of such differences. In fact, Smith et al. have mentioned[1,3] compensation effects due to differing absorption cross sections.

The Be$(n,2n)$ reaction rate, however, depends on both the reaction cross section and the SED because with a harder secondary spectrum, a larger fraction of these neutrons can, in addition to the primary neutrons, induce further $(n,2n)$ reactions. This effect becomes significant for larger beryllium shell thicknesses (e.g., for the shells Be 2, Be 3, and Be 4 of the experiment discussed in Ref. 1). It will influence the absorption rate even for equal absorption cross sections.

Clearly, such compensation effects are generally spectrum dependent. If they lead to equal results for the total neutron leakage multiplication in pure beryllium, this need not hold for a reactor blanket where structural, breeder, and coolant materials are present. Moreover, the ultimate quantity of interest in the reactor blanket is the tritium breeding ratio. This also depends on (among other parameters) the neutron spectrum, which in turn depends, in a blanket containing beryllium, on the beryllium SED. Remarkable variations of the breeding ratio in a solid-breeder International Thermonuclear Experimental Reactor (ITER) blanket calculated using different beryllium data sets were reported, e.g., in Ref. 4. Therefore, it is also necessary to test beryllium nuclear data evaluations against measurements of the energy-dependent neutron leakage.

Table I presents experimental results for a 14-MeV neutron transmission experiment on a 5-cm-thick beryllium spherical shell,[5] together with calculated neutron leakages using beryllium data from the EFF-1 and EFF-2 (European Fusion File) and ENDF/B-VI data files. The EFF-1 actually contains the Young-Stewart beryllium data evaluation, whereas EFF-2 makes use of a very recent evaluation of the double-differential Be$(n,2n)$ cross section by Field et al.[7] using an exact analytical model for the kinematical description of the involved breakup reactions. Note that the cross sections themselves are taken from ENDF/B-VI; i.e., EFF-2 and ENDF/B-VI differ only with respect to their SED/SAD. The angle-integrated SED calculated from these three libraries at 14-MeV incident energy are presented in Fig. 1 to give an impression of their differences.

As Table I shows, the energy integrated neutron leakages (bottom line) are, again, close to each other. The one calculated with EFF-1 data (Young-Stewart beryllium evaluation) agrees perfectly with the experiment [actually, such an agreement is obtained even for the now obsolete ENDF/B-IV beryllium data containing the same 14-MeV $(n,2n)$ cross section]. Its spectral breakdown, however, shows that this perfect agreement is caused by compensating over- and underestimations, respectively, in the lower and upper parts of the neutron leakage spectrum. For EFF-2 and ENDF/B-VI data, this holds in a similar way, with a slightly worse agreement for the total leakage due to significant underestimations at neutron energies below ~2 MeV. Note that the differences between the EFF-2 and the ENDF/B-VI based calculations are caused by the different SED/SAD; i.e., the larger neutron multiplication in the case of the EFF-2 data is due to the harder SED, as pointed out earlier.

Therefore, total absorption experiments by themselves are obviously not sufficient to determine whether a given nuclear data evaluation is satisfactory. They have to be complemented by transmission experiments with spectroscopy of the leakage neutrons (e.g., Refs. 5 and 8). Consequently, the conclusion of Smith et al., mentioned in Ref. 1 as well as in an earlier paper[3] on the same results, that either one of the beryllium data sets they tested "can be used with confidence in predicting the neutron multiplication of neutrons in fusion reactor blankets containing beryllium" is not justified. Only if a nuclear data set reproduces both the total leakage and its

TABLE I

Measured Neutron Leakage from a 5-cm-thick Spherical Beryllium Shell with a Central 14-MeV Neutron Source and Calculation-Over-Experiment Ratios Obtained with the ANTRA-1 Code[6] and Various Nuclear Data Libraries

Leakage Neutron Energy Window (MeV)	Measured Leakage (Leakage Neutrons per Source Neutron)[a]	C/E from ANTRA-1 Calculations[b]		
		EFF-1 (Young-Stewart)	EFF-2	ENDF/B-VI
0.4 to 0.8	7.718×10^{-2}	1.06	0.83	0.88
0.8 to 1.4	8.388×10^{-2}	1.05	0.88	0.81
1.4 to 2.5	8.574×10^{-2}	1.20	1.14	0.96
2.5 to 4.0	4.521×10^{-2}	1.15	1.29	1.09
4.0 to 6.5	6.121×10^{-2}	1.13	1.12	1.05
6.5 to 10.5	0.1081	0.90	0.86	0.89
>10.5	0.6797	0.96	0.98	0.98
>0.4	1.141	1.00	0.98	0.96

[a]Taken from Ref. 5.
[b]Taken from Ref. 6.

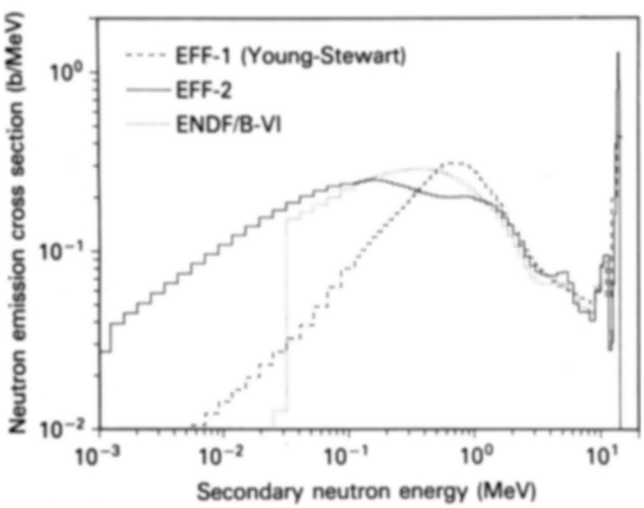

Fig. 1. Angle-integrated energy spectrum of neutrons emitted from beryllium at 14-MeV incident neutron energy, calculated from three nuclear data libraries.

spectral shape can it be employed with confidence in blanket calculations.

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RESPONSE TO "COMMENTS ON 'MULTIPLICATION OF 14-MeV NEUTRONS IN BULK BERYLLIUM' "

Our studies of neutron multiplication were directed at one problem only: the question of whether the multiplication of