Effects of Pb and Bi Cross Sections on ATW Subcriticality Predictions*

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for presentation at the
1999 Winter Meeting and Embedded Topic Meetings
American Nuclear Society
Long Beach, CA
November 14-18, 1999

*Work supported by the U.S. Department of Energy, under Contract N. W-31-109-ENG-38.
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The accelerator-driven transmutation of waste (ATW) system has been proposed for transmuting the long-lived radioactive nuclei of high-level waste to stable or short-lived species. In recent ATW design concepts[1], lead-bismuth eutectic (LBE), consisting of 44.5% Pb and 55.5% Bi by weight, is used as the spallation target, system coolant, and reflector. Because of the excellent neutron reflection properties of LBE, the subcriticality level of ATW is quite sensitive to the cross sections of lead and bismuth. The purpose of this paper is to investigate the effects of these cross sections on subcriticality and other core characteristics of ATW and to compare the results obtained using cross sections in different evaluated nuclear data files.

The effects of lead and bismuth cross sections on the core characteristics of ATW were studied using 33 group cross section sets derived from the ENDF/B-VI, ENDF/B-V, JENDL-3.2, and BROND-2.2 nuclear data. A 2000 MW(thermal) ATW configuration similar to that described in Reference 1 was used in this study. In this configuration, the spallation target region is 55 cm high and 25 cm in radius, and is surrounded by a 15-cm thick LBE buffer. The adjacent fueled region is ~65 cm thick and 200 cm high. The volume fractions of fuel, coolant, and structure are 25.7%, 59.3%, and 15%, respectively. The metal alloy fuel is composed of roughly 70 % zirconium, 25 % transuranics (TRU), and 5 % Tc-99 by weight. A thick LBE reflector surrounds the whole core; its axial thickness is 250 cm, and its radial thickness is 295.2 cm.

Region-dependent 33-group isotopic cross sections were generated based on ENDF/B-VI data using the MC^2-2 code[2]. In these calculations, ^{204}Pb was combined with ^{206}Pb since ^{204}Pb data is not available in ENDF/B-VI. The cross sections of lead and bismuth isotopes were also generated based on ENDF/B-V, JENDL-3.2, and BROND-2.2 data for comparison. In the case of ENDF/B-V, only natural Pb data are available and hence the Pb isotopes were aggregately modeled. In the cases of JENDL-3.2 and BROND-2.2, four lead isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb) were separately represented.

The flux distribution was computed for an R-Z system model using the TWODANT[3] transport theory code. Preliminary calculations showed that the multiplication factor and neutron balance components of homogeneous eigenvalue problems are very close to those of fixed source problems with the spallation neutron source. Thus, for computational convenience, this study was performed with homogeneous eigenvalue calculations without the spallation neutron source.

The multiplication factor and components of the neutron balance in the core are summarized in Table 1. These results show that the lead and bismuth cross sections in different nuclear data differ significantly from each other. In particular, the ENDF/B-V cross sections deviate substantially from those in the other three data sets. Compared to ENDF/B-VI, the Bi cross sections in ENDF/B-V reduce the multiplication factor by ~2.8% and the Pb cross sections increase it by ~1.4%. The effect of using the JENDL-3.2 bismuth data is to increase the multiplication factor by only 0.027%; use of the JENDL-3.2 lead data reduces the multiplication factor by ~1.1% compared to ENDF/B-VI. Finally, the bismuth and lead cross sections in BROND-2.2 data reduce the multiplication factor by 0.004% and 0.045%, respectively.

The differences in multiplication factor are caused mainly by the differences in elastic scattering cross sections. A sensitivity analysis using the DPT perturbation theory code[4] showed that the elastic scattering cross sections of Pb-208 and Bi-209 have very large effects on the multiplication factor. Increased scattering cross sections of Pb and Bi result in a softer spectrum and reduced leakage. Spectral softening produces a negative effect on the multiplication factor because of the decrease in neutron importance with decreasing energy, while reduced leakage yields a positive effect. In the ATW configuration analyzed here, the leakage effect is larger than the spectral effect. However, the JENDL-3.2 lead cross section results in a slightly softer spectrum and slightly increased leakage from the core, and hence its use reduces the multiplication factor by ~1.1% compared to ENDF/B-VI. The absorption cross-section differences have smaller effects on the multiplication factor than the scattering cross-section differences, but they are not negligible. Specifically, the lead cross sections have comparatively large effects due to the relatively large absorption cross sections of ^{206}Pb and ^{207}Pb. For example, use of the ENDF/B-V lead absorption cross section increases the multiplication factor by ~1.1% relative to that obtained with ENDF/B-VI.

In summary, the sub-criticality level of the ATW core is quite sensitive to the lead and bismuth cross sections. In view of the safety significance of the subcriticality level and its impact on system requirements such as accelerator power, accurate prediction of ATW subcriticality is extremely important. The results presented here suggest that more detailed study using experimental data and possibly re-evaluation of lead and bismuth cross sections need to be performed.

References

1. F. Venneri, N. Li, M. Williamson, M. Houts, and G. Lawrence, "Disposition of Nuclear Waste Using Subcritical Accelerator-Driven Systems: Technology Choices and Implementation Scenario," *Proc. 6th Intl. Conf. on Nuclear Engineering*, San Diego, CA, May 10-15, 1998, p619 (1998).

2. H. Henryson II, B. J. Toppel, and C. G. Stenberg, "MC^2-2: A Code to Calculate Fast Neutron Spectra and Multigroup Cross Sections," ANL-8144, Argonne National Laboratory (1976).

3. R. E. Alcouffe, F. W. Brinkley, D. R. Marr, and R. D. O'Dell, "User's Guide for TWODANT: A Code Package for Two-Dimensional, Diffusion-Accelerated, Neutral-Particle Transport," LA-10049-M, Los Alamos National Laboratory (1990).

4. T. J. Downar, J. G. Stevens, and W. S. Yang, "Sensitivity Theory for the Equilibrium Burnup Cycle," *Proc. Intl. Conference on the Physics of Reactors*, Marseilles, France, April 23-27, 1990, Vol. II, p. XI-84, American Nuclear Society (1990).

Table 1. Multiplication Factor and Neutron Balance Components in the Core (Normalized to One Fission Neutron)

Case	k-effective	(n,2n) Source	Absorption				Leakage
			Pb	Bi	Others	Sum	
Base Case (ENDF/B-VI)	0.98806	0.00146	0.02063	0.01167	0.73536	0.76766	0.24588
ENDF/B-V for Bi	0.96014	0.00159	0.02106	0.02077	0.71905	0.76088	0.28222
ENDF/B-V for Pb	1.00215	0.00154	0.00952	0.01168	0.74249	0.76369	0.23570
ENDF/B-V for Bi & Pb	0.97389	0.00166	0.00979	0.02101	0.72536	0.75617	0.27231
JENDL-3.2 for Bi	0.98833	0.00137	0.02053	0.01135	0.73535	0.76723	0.24595
JENDL-3.2 for Pb	0.97720	0.00155	0.02257	0.01179	0.73832	0.77268	0.25220
JENDL-3.2 for Bi & Pb	0.97747	0.00146	0.02242	0.01135	0.73865	0.77242	0.25209
BROND-2.2 for Bi	0.98802	0.00157	0.02093	0.01269	0.73622	0.76984	0.24386
BROND-2.2 for Pb	0.98761	0.00152	0.01925	0.01179	0.73422	0.76526	0.24881
BROND-2.2 for Bi & Pb	0.98629	0.00165	0.01957	0.01289	0.73441	0.76687	0.24868