The Revised OB-1 Method for Metal-Water Systems*

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INTRODUCTION

The OB-1 method for the calculation of the minimum critical mass (mcm) of fissile actinides in metal/water systems was described in a 2008 Nuclear Science and Engineering (NS&E) article [1]. The purpose of the present work is to update and expand the application of this method with current nuclear data, including data uncertainties. The mcm and the hypothetical fissile metal density (ρ_F) in grams of metal/liter are obtained by a fit to values predicted with transport calculations. The input parameters required are thermal values for fission and absorption cross sections and nubar. A factor of $(\sqrt{\pi})/2$ is used to convert to Maxwellian averaged values. The uncertainties for the fission and capture cross sections and the estimated nubar uncertainties are used to determine the uncertainties in the mcm, either in percent or grams.

METHODOLOGY

Initially, Eqs. (1) and (2) are used in a least-squares fit to the values of mcm and ρ_F from the transport calculations for seven nuclides [1].

$$\text{mcm} = \exp\,[A + B \times \ln\,(\text{xk1})] \qquad (1)$$

$$\rho_F = \exp\,[C + D \times \ln\,(\text{xk1})] \qquad (2)$$

where A = 14.152, B = −1.151, C = 9.068890124, D = –0.79587973, and the extended criticality parameter xk1 is:

$$\text{xk1} = [\eta(\eta - 1)/\eta_{235}] \times \sigma_A$$

where $\eta = \nu\sigma_F/\sigma_A$.

Note that σ_F and σ_A are Maxwellian averaged values. The values of A and B have been determined for the nuclear data utilized in this study. The values of C and D remain the same as the values applied in the NS&E article [1]. Subsequent to the least-squares fits, Eqs. (1) and (2) are used directly to calculate the mass and density values for the remaining nuclides.

NUCLEAR DATA

In the NS&E article [1] the input cross sections and values of nubar were taken from either ENDF/B-VI or JENDL−3.2. The current evaluated data files are ENDF/B-VII, JENDL−3.3, and JEFF−3.1. Results reported here are based on the use of cross sections and nubar values from the Atlas of Neutron Resonances (ANR) by S. F. Mughabghab [2]. This is a standard reference for these values, which are usually applied in performing the cross section evaluations.

This study includes several nuclides that are of "academic interest" as well as fissile nuclides from the total list of nuclides of criticality concern in the DOE Order 420.1.

^{231}Pa
^{232}U, ^{233}U, ^{234}U, ^{235}U
^{237}Np
^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu
^{241}Am, ^{242m}Am, ^{243}Am
^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm
^{249}Cf, ^{250}Cf, ^{251}Cf, ^{252}Cf
^{254}Es

Eleven of the 13 fissile nuclides in this DOE list are included in this summary.

RESULTS AND UNCERTAINTIES

The calculated values of xk1, mcm, metal density, and volume are given in Table I. For the low-worth fissile nuclides, ^{232}U, ^{249}Cm, ^{252}Cf, and ^{254}Cf, the calculated values of mcm are greater than 5 kg. Since these values are inaccurate, these nuclides are not included in Table I. The calculated values of the mcm and metal densities are also shown in Fig. 1 in which the systematic variation can be observed.

One important goal of the study was to obtain uncertainties in the minimum critical mass resulting from uncertainties in the basic cross sections. The uncertainties for the mcm values for 14 nuclides are included in Table I. These include new values of uncertainties for the two nuclides: ^{236}Np and ^{232}Pa.

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TABLE I. OB1 Calculations for 24 Nuclides

Nuclide	xk1	mcm (g)	Density[a] (g/liter)	Mcm (g) Ref.1
Fm-255	21085	14.77		
Am-242m	15834	20.53 ± 2.1		19.18 ± 1.9
Cf-251	13636	24.38 ± 7.4		26.16 ± 8.3
Es-254	10305	33.66 ± 8.3	5.555	34.46 ± 9.2
Np-236	7899.03	45.71 ± 5.7	6.864	
Cf-253	7102.72	51.67 ± 16	7.470	52.68 ± 16
Cm-245	6824.49	54.09 ± 4.0	7.711	54.91 ± 5.2
Cf-249	5385.68	71.04 ± 4.7	9.310	64.89 ± 6.2
Am-242g	5336.00	71.80	9.379	
Am-244g	4624.49	84.65	10.51	83.50
Pu-237	4121.67	96.60	11.52	97.41
Am-244m	3264.00	126.4	13.87	
Np-238	2360.45	183.6	17.95	112.1
Bk-250	2359.60	183.7	17.96	196.3
Cm-241	1698.23	268.2	23.33	241.9
Cm-243	1650.19	277.2 ± 22	23.87	276.9 ± 30
Pu-241	1480.00	272.9 ± 11	29.96	289.7 ± 7.8
Pa-232	1399.36	335.1 ± 28	27.21	1583
Pu-239	1024.53	479.8 ± 14	34.88	469.2 ± 13
U-233	728.32	562.6 ± 9	57.80	564.3 ±15
U-235	654.23	804.0 ± 12	49.84	804.9 ± 16
Pu-243	269.56	2231	100.9	
Pu-236	270.88	1310 ± 346	170.2	1259 ± 320
Cm-247	164.65	3934	149.4	

[a]The calculated values of the first three densities are inaccurate due to reflector worth approximations, and therefore, are not quoted.

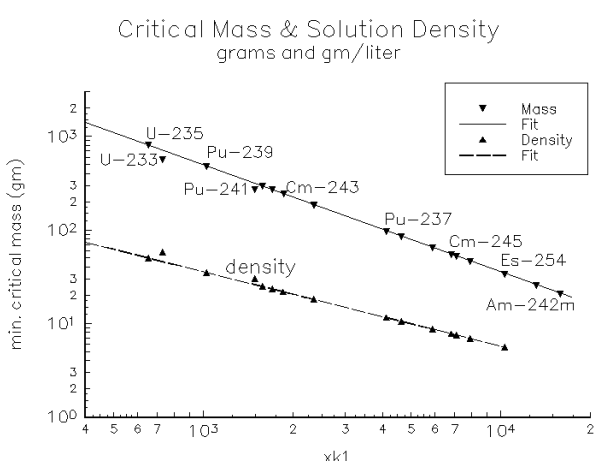

Fig. 1. Variation of critical mass and density.

The final column in Table 1 includes values from Tables IV and VI of the NS&E article. In comparison with the present values, several observations can be made. For eight nuclides, the mcm values are essentially in agreement. For the nuclides ^{232}Pa, ^{238}Np, ^{242m}Am, ^{241}Cm, and ^{249}Cf, the differences in mcm values are due to changes in input cross sections. Due to a data input error, the earlier reported value for ^{243}Cm of 199.7±22 g should have been 276.9±30g, as shown in Table 1.

Also in comparison with the NS&E article, the mcm values of ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu, ^{242m}Am, ^{245}Cm, and ^{254}Es are compared with those from the earlier XSDRN calculations [1]. For this comparison, the standard deviation for these seven nuclides is 2.6%. For the primary fissile nuclides ^{233}U, ^{235}U, and ^{239}Pu, the results from the OB-1 approximate method are in reasonable agreement with the results from more rigorous transport calculations.

CONCLUSIONS

Generally, due to improved cross section values, the results in terms of critical masses and their uncertainties are improved from those presented in the earlier NS&E article. Eight of the actinides in this summary are included in the ANS-8.15 standard [3]. Therefore, in addition to the DOE order, results from the present work should be of interest for the maintenance of the standard regarding its incorporation of the latest nuclear data.

REFERENCES

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