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Temperature-Dependent Bondarenko Factors for ^{243}Cm, ^{244}Cm, and ^{245}Cm

Felix C. Difilippo

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Engineering Physics and Mathematics Division

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CONTENTS

LIST OF FIGURES iv

ACKNOWLEDGEMENTS v

ABSTRACT vii

1. INTRODUCTION 1

2. DESCRIPTION AND RESULTS OF THE CALCULATIONS 3

3. CONCLUSIONS AND RECOMMENDATIONS 11

4. REFERENCES 13

LIST OF FIGURES

Fig.		Page
1	^{243}Cm total cross sections at temperatures of 293, 1000 and 2000°K	4
2	^{244}Cm total cross sections at temperatures of 293, 1000 and 2000°K	5
3	^{245}Cm total cross sections at temperatures of 293, 1000 and 2000°K	6
4	Capture cross section of ^{243}Am around 10 KeV at different temperatures calculated with the URR code as function of the number of pairs of resonances around E=10 KeV. The case corresponds to infinite dilution and 5000 samples	7
5	Capture cross section of ^{243}Am around 250 eV at different temperatures calculated with the URR code as function of the number of pairs of resonances around E=250 eV. The case corresponds to infinite dilution and 5000 samples. Bars indicate statistical error	8
6	Infinite diluted cross sections in the unresolved region. Histogram calculated with the AMPX system, points calculated with the URR code	9
7	Bondarenko factors for the more shielded isotopes of Table 1, they correspond to the capture process, σ_o = 100 barns and T=293°K. Histogram calculated with the AMPX system, symbols with the URR code.	10

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ABSTRACT

The computer codes SAMMY and URR were used to calculate energy group averaged capture and fission cross sections of ^{243}Cm, ^{244}Cm and ^{245}Cm in, respectively, the resolved and unresolved resonance regions. Bondarenko factors were then tabulated as a function of temperature and dilution.

1. INTRODUCTION

This report is a continuation of the work described in Ref. 1 and related to the calculation of Bondarenko factors of higher actinides relevant to the design of Actinide Burner Reactors (ABR). Reference 2 describes the feasibility, from the neutronic and thermal-hydraulic point of view, of burning higher actinides in especially designed reactors. Based on Ref. 2, Table 1 describes the equivalent escape cross section of the proposed fuel cell to burn higher actinides from reprocessed PWR fuel.

Table 1. Scattering Cross Section Per Absorbing Atom for the Cells of Reference 2

	Heterogeneous Cell[c] σ_e (barn)	
Absorbing Atom	Isolated Lump	Interactive Lumps
^{237}Np	173.0	52.0
^{241}Am[a]	237.0	71.0
^{243}Am	520.0	156.0
^{243}Cm[b]	210,000.0	63300.0
^{244}Cm	1230.0	372.0
^{245}Cm	22600.0	6800.0

[a]87.63% Am in Am/Cm alloy; 68.7% ^{241}Am; 31.3% ^{243}Am.
[b]0.55% ^{243}Cm; 94.28% ^{244}Cm; 5.17% ^{245}Cm.
[c]Mean chord: 0.4cm; Dancoff Coefficient: 0.7. σ_e denotes the escape cross section in the Wigner's rational approximation.

Capture and fission cross sections of ^{243}Cm, ^{244}Cm, ^{245}Cm were calculated as function of temperature in the resolved region with the code SAMMY[3] and as a function of temperature and dilution in the unresolved region with the code URR.[4] Resonance parameters are (Single-Level Breit-Wigner, SLBW) from the ENDF/B-V evaluation and Table 2 summarizes the available parameters (note that the parameters of Cm isotopes were left unchanged in the new version ENDF/B-VI).

Table 2. Summary of Resonance Parameters (ENDF/B-V)

Resolved Region

Isotope	I	Upper Energy Limit (eV)	Number of Resonances	Spin Assignment
^{243}Cm	5/2	27.0	16	None[a]
^{244}Cm	0	525.0	38	None
^{245}Cm	7/2	60.5	39	None

Unresolved Region

Isotope	Energy Range	D	Γ_n	Γ_γ	Γ_f
^{243}Cm	27 eV–10 KeV	Constant	Constant	Constant	Constant
^{244}Cm	525 eV–10 KeV	Depends on J	Depends on J and ℓ	Constant	Depends on J
^{245}Cm	60.5 eV–10 KeV	Depends on J	Depends on J and ℓ	Constant	Constant

Additional Background to the Resonance Contribution

Isotope	Background Cross Section
^{243}Cm	None
^{244}Cm	Capture, fission and total, 2 to 10 KeV
^{245}Cm	None

[a]Pseudo spin assignment (i.e., J=I; g=0.5).

2. DESCRIPTION AND RESULTS OF THE CALCULATIONS

The multilevel Breit-Wigner (MLBW) option (ENDF/B prescription) of the SAMMY code was selected to compute the capture, fission and total cross sections. The only interference term that the MLBW ENDF/B prescription maintains is for the scattering cross section. In order to minimize this interference term (to be in agreement with the original ENDF/B-V evaluation which prescribed SLBW), we divided the resonances into two alternating families both with pseudospin $J = I$ so $g = 0.5$. Figures 1, 2, and 3 show the total cross sections so obtained as a function of energy for the three curium isotopes at temperatures of 293, 1000 and 2000°K.

The cross sections for the unresolved resonance region were calculated with the URR code that plays Monte Carlo with a collection of resonances around a prescribed input energy E; the number of pairs, N, of resonances around E is also an input data. The distribution and the type of the N pairs of resonances around E are sampled according to the statistical distributions prescribed by ENDF/B-V. The acceptance of the ergodic hypothesis allows us to associate the average values so obtained to a broad energy group around energy E.

Before massive calculation, numerical experiments were performed to choose the optimum N. We have found that the calculated cross sections are sensitive to the value of N, especially at high neutron energies (KeV) and high temperatures. Figures 4 and 5 show the sensitivity of the cross sections to the value of N for ^{243}Am. Very similar patterns were found for ^{237}Np and ^{241}Am so a value of $N = 20$ was chosen for all the calculations to be sure that we are well inside the plateau suggested by Figs. 4 and 5.

To check the method, the cross section calculated with the URR code were compared with the ones calculated with the AMPX[5] system for the more shielded isotopes of Table 1: ^{237}Np, ^{241}Am, and ^{244}Cm. The results appear in Fig. 6 and show remarkable consistency. ^{237}Np exhibits the structure of the subthreshold fission so a suitable energy grid would have been necessary to fully describe it which was not intended in the calculations of Fig. 6.

Bondarenko factors for the unresolved region are compared in Fig. 7 with values computed with the AMPX system for the case of the more shielded materials of Table 1; there is an overall good agreement between the two methods. Bondarenko factors computed with the methodology described here are available on diskettes (ASCII format) for ^{237}Np, ^{241}Am, ^{243}Am, ^{243}Cm, ^{244}Cm and ^{245}Cm.

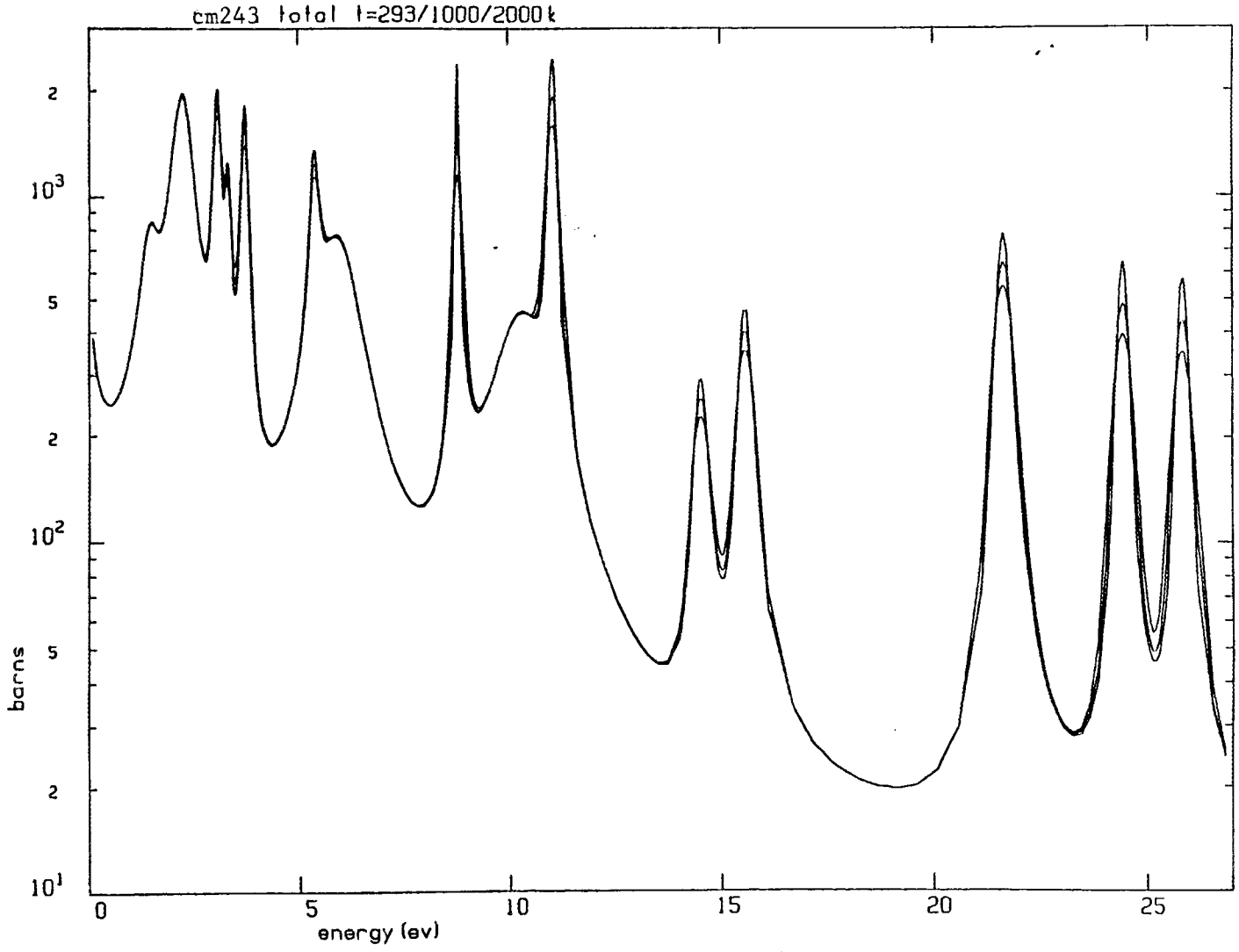

Fig. 1. ^{243}Cm total cross sections at temperatures of 293, 1000 and 2000°K.

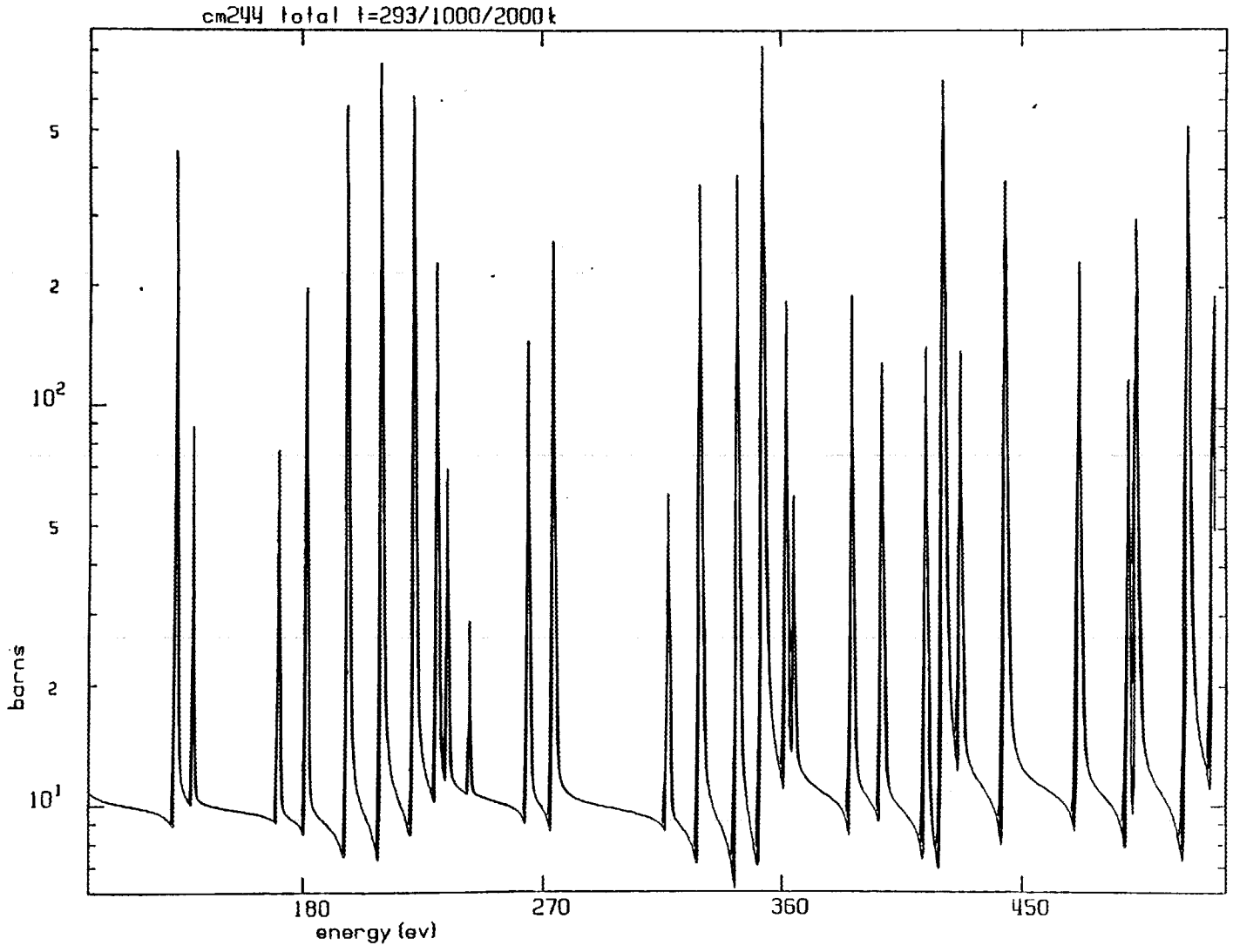

Fig. 2. ^{244}Cm total cross sections at temperatures of 293, 1000 and 2000°K.

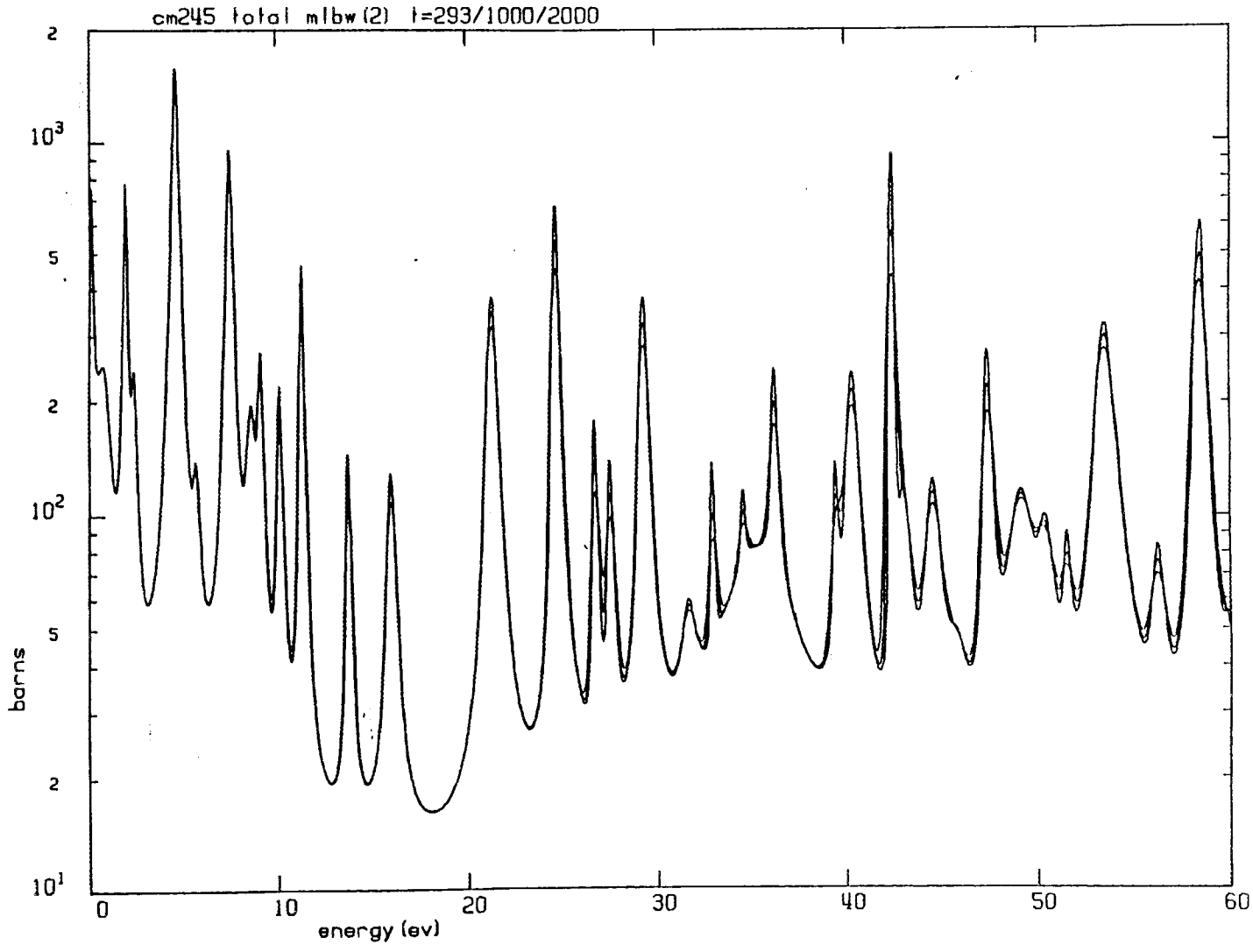

Fig. 3. ^{245}Cm total cross sections at temperatures of 293, 1000 and 2000°K.

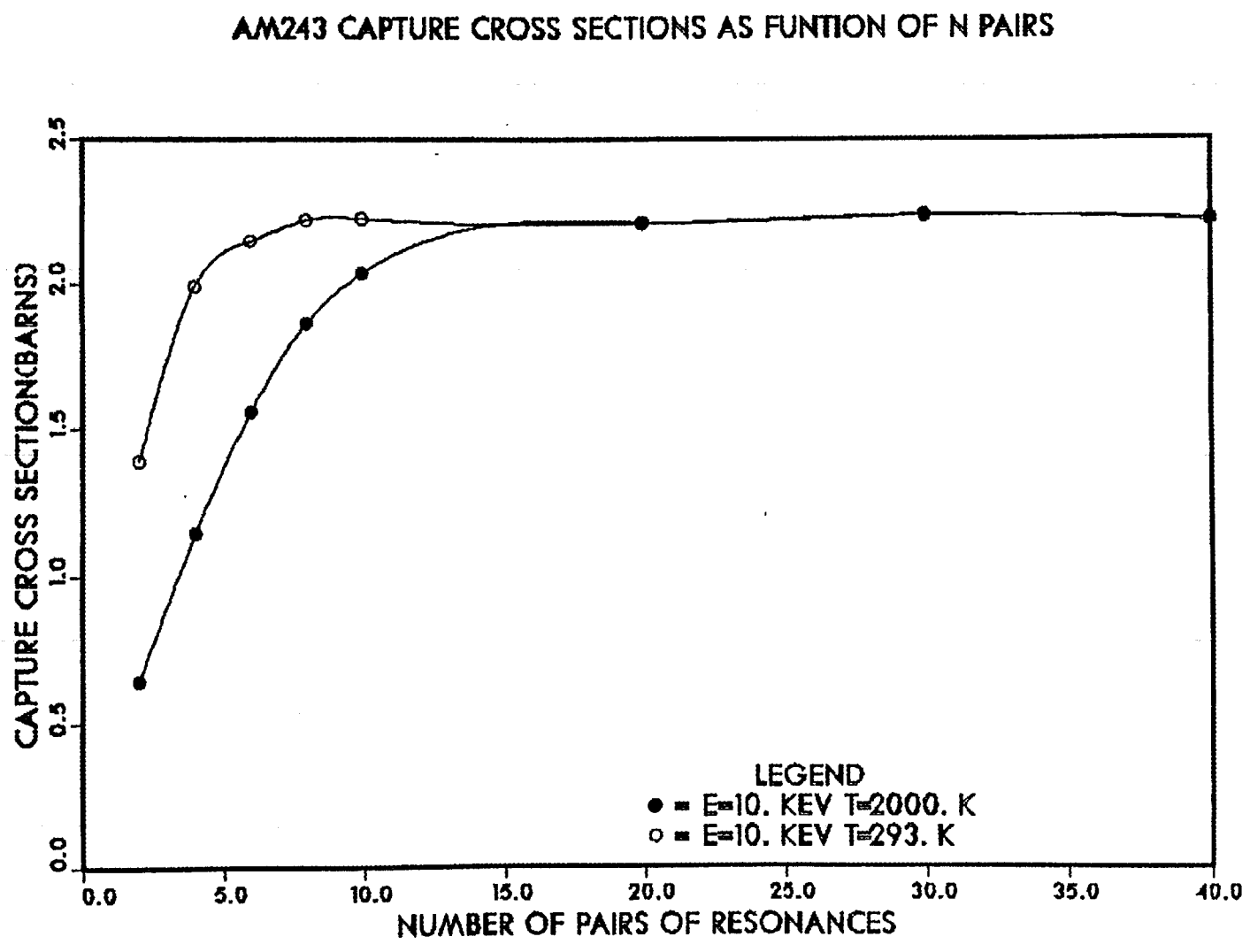

Fig. 4. Capture cross section of ^{243}Am around 10 KeV at different temperatures calculated with the URR code as function of the number of pairs of resonances around E=10 KeV. The case corresponds to infinite dilution and 5000 samples.

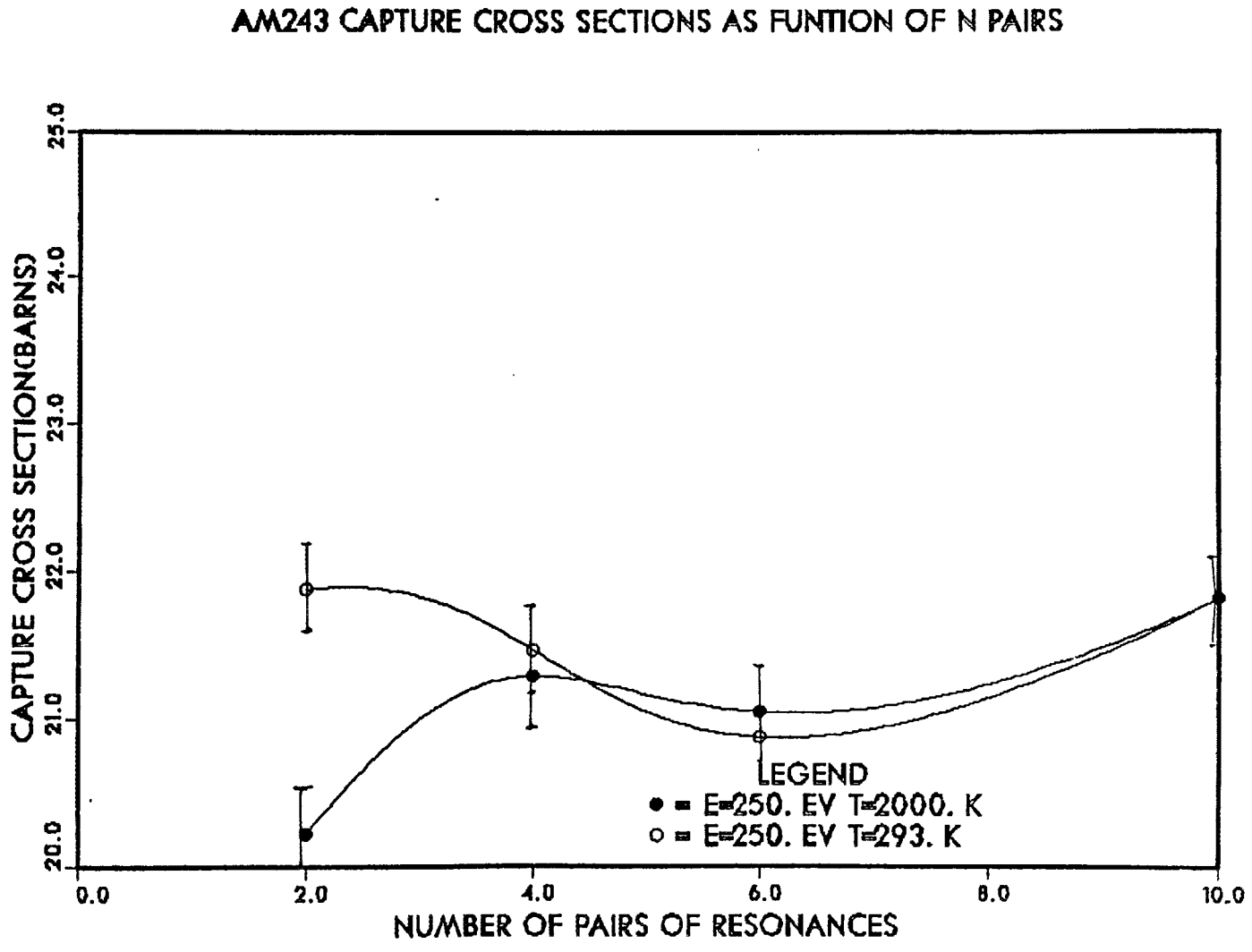

Fig. 5. Capture cross section of ^{243}Am around 250 eV at different temperatures calculated with the URR code as function of the number of pairs of resonances around E=250 eV. The case corresponds to infinite dilution and 5000 samples. Bars indicate statistical error.

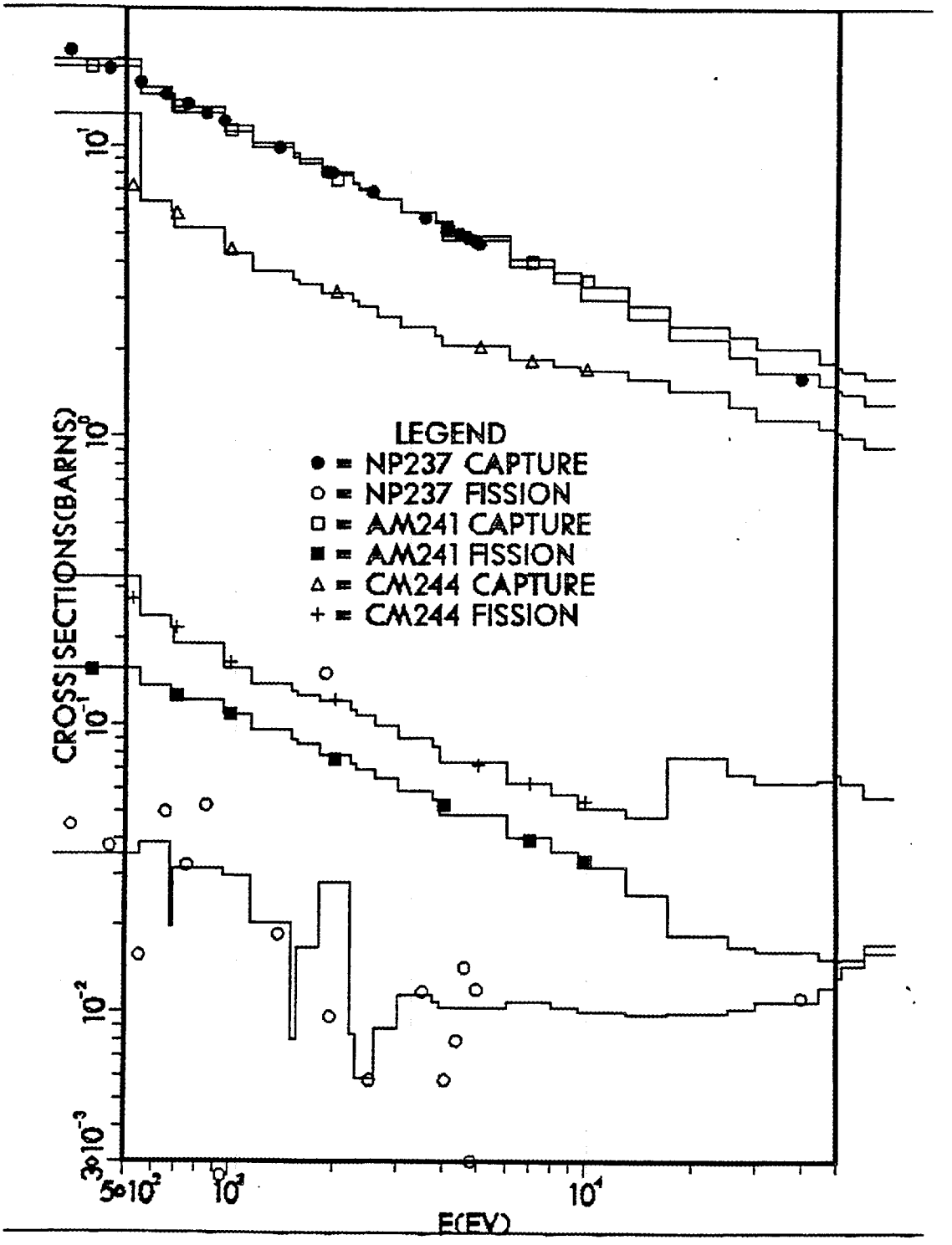

Fig. 6. Infinite diluted cross sections in the unresolved region. Histogram calculated with the AMPX system, points calculated with the URR code.

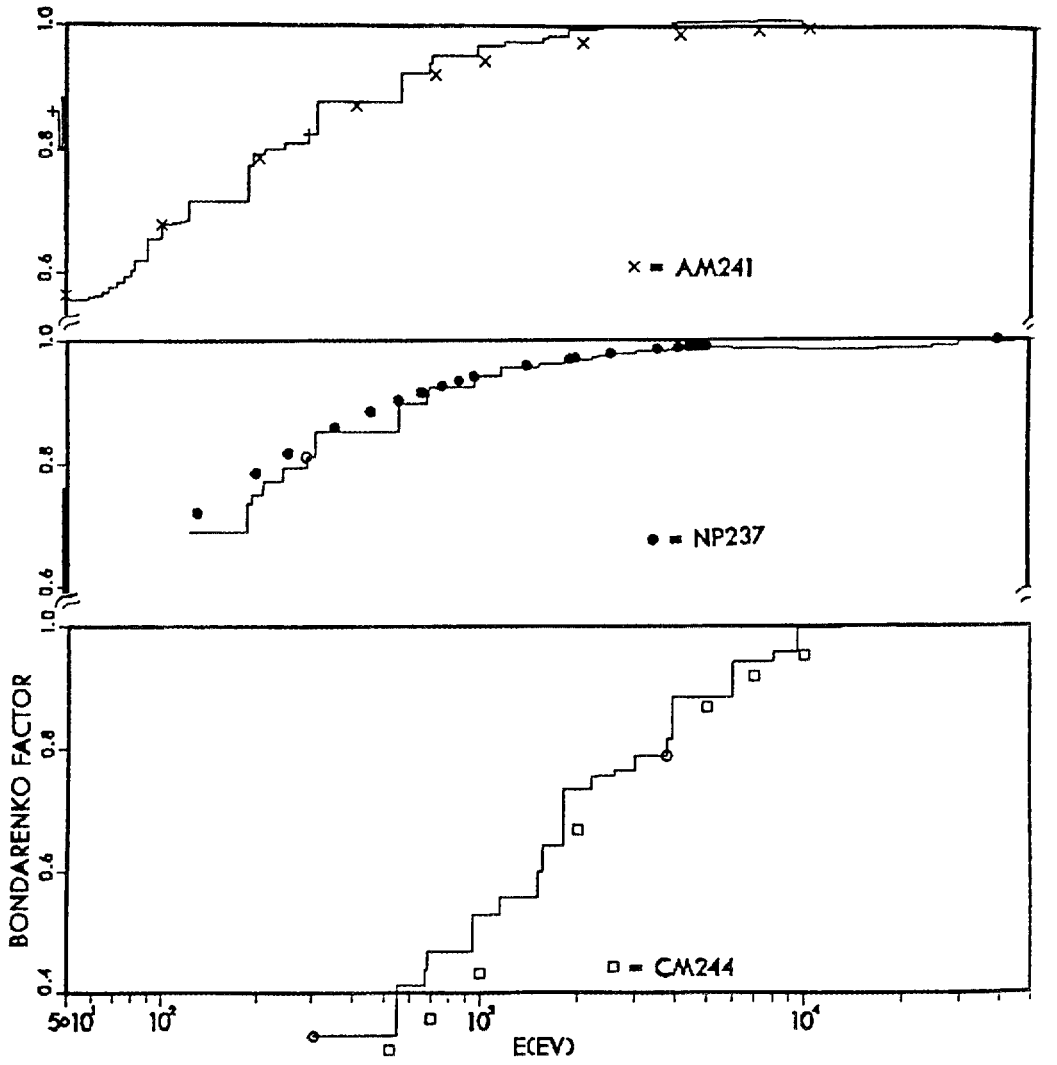

Fig. 7. Bondarenko factors for the more shielded isotopes of Table 1, they correspond to the capture process, σ_o = 100 barns and T=293°K. Histogram calculated with the AMPX system, symbols with the URR code.

3. CONCLUSIONS AND RECOMMENDATIONS

Because of the major presence of higher actinides in ABRs of innovative design and their consequent impact in the Doppler coefficient of reactivity, effective capture and fission cross sections and Bondarenko factors were calculated for ^{243}Cm, ^{244}Cm and ^{245}Cm in the resolved and unresolved resonance regions. The calculations were done with the computer codes SAMMY and URR, which are codes mainly used for the analysis of experimental data. This new approach has the following advantages: (1) It uses the same numerical tool already used in the analysis of experimental data, i.e., the method is more transparent to the original data; (2) improvements in the analysis of experimental data (e.g., the R matrix analysis performed by SAMMY) can be introduced directly in the preparation of the cross sections; and (3) the ergodic hypothesis implemented in the code URR is faster than explicit calculations of ladders of resonances in a broad energy group. Extensive calculations as functions of dilution factors and temperature were made with resonance parameters from ENDF/B-V (single Breit-Wigner resonance parameters).

The method as it is implemented can be used to produce effective cross sections in the resolved resonance energy region based on an R-matrix description of the cross section (as in ENDF/B-VI). Recognition of the limitations of the Bondarenko approximation within this energy region is important. Thus, one can envision an ideal code that combines the accuracy of SAMMY for describe the cross sections with the accuracy of the module NITAWL of the AMPX system for computing the energy dependence of the neutron flux.

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