CONF-820566--6

The CSRL-V ENDF/B-V 227-Group Neutron Cross-Section Library and Its Application to Thermal-Reactor and Criticality Safety Benchmarks*

MASTER

W. E. Ford, III
B. R. Diggs
J. R. Knight
N. M. Greene
L. M. Petrie
C. C. Webster
R. M. Westfall
R. Q. Wright

CONF-820566--6

DE82 017497

Computer Sciences
at Oak Ridge National Laboratory
Union Carbide Corporation, Nuclear Division

M. L. Williams

Engineering Physics Division
Oak Ridge National Laboratory

* Research was sponsored by (1) the Office of Nuclear Regulatory Research and the Office of Nuclear Material Safety and Safeguards, U. S. Nuclear Regulatory Commission under Interagency Agreements DOE 40-550-75 and 40-549-75, (2) the Electric Power Research Institute under EPRI Contract RP 975-3, and (3) the U. S. Department of Energy under contract (W-7405-eng-26) with Union Carbide Corporation.

EDB

The CSRL-V ENDF/B-V 227-Group Neutron Cross-Section Library and Its Application to Thermal-Reactor and Criticality Safety Benchmarks

W. E. Ford, III, B. R. Diggs, J. R. Knight, N. M. Greene, L. M. Petrie, C. C. Webster, R. M. Westfall, R. Q. Wright
Computer Sciences, ORNL, Union Carbide Corportion, Nuclear Division

M. L. Williams
Engineering Physics Division, Oak Ridge National Laboratory

ABSTRACT

Characteristics and contents of the CSRL-V (Criticality Safety Reference Library based on ENDF/B-V data) 227-neutron-group AMPX master and pointwise cross-section libraries are described. Results obtained in using CSRL-V to calculate performance parameters of selected thermal reactor and criticality safety benchmarks are discussed.

I. INTRODUCTION

The U. S. Nuclear Regulatory Commission sponsored the development of a pseudo-problem-independent, comprehensive, 227-neutron-group, cross-section library derived primarily from ENDF/B-V data. The library, designated CSRL-V (Criticality Safety Reference Library based on ENDF/B-V data),[1,2] is a data base in AMPX master format[3] for the subsequent generation of problem-dependent fine- and/or broad-group cross sections for a broad range of applications, including reactor core and shielding analyses, criticality safety analyses, and shipping cask calculations. The CSRL-V library is available from the Radiation Shielding Information Center (RSIC) at the Oak Ridge National Laboratory (ORNL).[a] Characteristics of CSRL-V, including the recent expansion of the library to include Bondarenko factor data for unresolved resonance processing, are described in Section II.

Problem-dependent cross sections derived from CSRL-V data can be used with the SCALE[4] system and with codes such as KENO-IV,[5] ANISN,[6] XSDRNPM,[7] VENTURE,[8] DOT,[9] MORSE[10] or any computer code which uses data in the traditional multigroup cross-section table format. CSRL-V data can be coupled with photon-production and photon-interaction multigroup data produced with the AMPX system[3] to produce coupld neutron-gamma cross-section libraries. Modules of the AMPX system offer a full spectrum of cross-section processing capabilities for the CSRL-V data, including energy group collapsing, interpolating on Bondarenko factors for self-shielding of unresolved resonance data and temperature corrections, resonance processing with the Nordheim integral method, reformatting, editing, etc. The AMPX system is available from RSIC.[11]

CSRL-V has been used in a variety of benchmark calculations. Among the thermal reactor benchmarks calculated were selected CSEWG and Babcock & Wilcox lattice critical experiments. Criticality safety benchmarks calculated included homogeneous, uranyl fluoride and uranyl nitrate spheres with hydrogen-to-uranium ratios varying from 76 to 972. Representative results from the series of CSRL-V benchmark calculations are discussed in Section III.

II. CHARACTERISTICS OF CSRL-V

Favorable experiences gained from the generation and utilization of an ENDF/B-IV fine-group cross-section library generated with the AMPX system for criticality safety, reactor, and shielding studies[12-14] (CSRL, circa 1975) influenced the processing procedures, the selection of the group structure, and the point-to-multigroup weighting functions used to generate CSRL-V. Basic sources of nuclear data, specifications, processing system, library formats and contents, and first-order data checks of CSRL-V are described in subsections below.

---

[a]The United States Department of Energy has determined that fine-group and/or pointwise data derived from ENDF/B-V will, for the present, be limited to users within the United States and AECL (Chalk River), except for data derived from the ENDF/B-V Standards, Dosimetry, Actinide (special purpose), and Fission Product Files, which are available to everyone.

II.A. Materials

A list of the master cross-section data sets in the CSRL-V 227-group library is given in Table. 1. The library contains data for approximately 130 materials, including processed data for all evaluations in the ENDF/B-V General Purpose File.[15] In addition, cross sections for selected materials not in the latest edition of ENDF/B were prepared from LENDL data,[16,17] e.g., Ar, ^{45}Sc, ^{64}Zn, Ga, Sn, ^{191}Ir, and ^{193}Ir. Hydrogen with water- and polyethelene-bound thermal scattering kernels, deuterium with D_2O-bound thermal kernels, carbon with a graphite thermal kernel, a special 1/V data set normalized to unity at 0.0253 eV, and a dose factor data set were also included in the library.

II.B. Group Structure

The CSRL-V 227-neutron-group structure includes 79 thermal groups in the 10^{-5} to 3.00 eV range to accommodate the effects of low-energy resonance and thermal-neutron upscatter. The 148 groups in the 3-eV to 20-MeV range permit fine-group consideration of the resonance structure of prominent nuclei, the thresholds of important reactions, and various fission spectra. Specifically, boundaries were chosen to fit the reaction thresholds and major resonance levels of the following nuclides: Be, ^{10}B, C, N, O, F, Na, Mg, Al, Si, K, Ca, Cr, Mn, Fe, Ni, Cu, Zr, Mo, Ag, Cd, In, Sn, Ba, Gd, Hf, Pb, ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Pu.

Of the 148 epithermal groups, 58 groups span the fission-neutron-euergy range from 20 MeV to 8.03 keV. This energy range includes most of the cross-section structure for the light and intermediate-mass nuclides. It also includes inelastic scattering and fission thresholds for certain of the heavy nuclides. The 90 groups between 8.03 keV and 3.00 eV were chosen to bracket major resonance levels in the intermediate-mass and heavy nuclides.

In the thermal energy range, several of the fuel and neutron absorbing nuclides have large resonances which are broad relative to the neutron energy exchange per collision. The closely-spaced thermal groups are designed to account for the effects of those resonances in the presence of thermal upscatter.

Table 1. The ENDF-V 227-Group AMPX Master Cross-Section Library

Nuclide	ENDF-V Identifier	ENDF/B-V Data[a]: MAT (MOD)	ENDF/B-V Data[a]: Authors	ENDF/B-V Data[a]: Lab	Weighting Function[d]	1-d Processes in Data Set[f]	2-d Processes in Data Set[f]	Maximum Order of Scattering	Number of Resolved Resonances Processed	Unresolved Resonance Bondarenko Factor Data[b]: Energy Range (eV)	Unresolved Resonance Bondarenko Factor Data[b]: σ_0's	Unresolved Resonance Bondarenko Factor Data[b]: Temperatures (°K)	Remarks
1/V	500	N/A	N/A	N/A	B	1,27,1099		0	0				Normalized to unity at 0.0253 eV.
H-1	1001	1301	L. Stewart, R. LaBauve, P. Young	LASL	A	1,2,27,101,102,251-253,1099	2,1007	5[g]	0				MAT 1002 H_2O bound thermal @ 296, 350,400,450,500,600,800, and 1000°F.
H-2	1002	1302	L. Stewart, A. Horsley	LASL	A	1,2,16,27,101,102,251-253,1099	2,16,1007	5[g]	0				MAT 1004 D_2O bound thermal @ 296, 350,400,450,500,600,800, and 1000°F
H-3	1003	1169	L. Stewart	LASL	A	1,2,16,151,252,253,1099	2,16,1007	3	0				
H-1	1901	1301	L. Stewart, A. LaBauve, P. Young	LASL	A	1,2,27,101,102,251-253,1099	2,1007	5[g]	0				MAT 1063 poly bound thermal @ 296 and 350°K.
He-3	2003	1146	L. Stewart	LASL	A	1,2,27,101,103,104,251-253,1099	2,1007	3	0				
He-4	2004	1270	Nisley, Hale, Young	LASL	A	1,2,251-253,1099		3	0				
Li-6	3006	1303	G. Hale, L. Stewart, P. Young	LASL	A	1,2,4,24,27,101-103,105,251-253,1099	2,24,51-81,1007	3	0				
Li-7	3007	1272	R. LaBauve, L. Stewart, M. Battat	LASL	A	1,2,4,16,24,27,101,103,104,251-253,1099	2,16,24,51,91,1007	3	0				
Be-9	4009	1304	Howerton, Perkins	LLL	A	1,2,16,27,101-105,107,251-253,1099	2,6-9,46-49,1007	3	0				
B-10	5010	1305	G. Hale, L. Stewart, P. Young	LASL	A	1,2,4,27,101-104,107,113,251-253,1099	2,51-85,1007	3	0				
B-11	5011	1160	C. Cowan	GE-NMPO	A	1,2,4,16,27,101-103,105,107,251-253,1099	2,16,51-53,91,1007	3	0				
C-12	6012	1306	C. Fu, F. Perey	ORNL	A	1,2,4,27,101-104,107,203,204,207,251-253,1099	2,51-68,91,1007	3	0				Free gas thermal data @ 300, 900 and 1200°K.
Graphite	6312	1306	C. Fu, F. Perey	ORNL	A	1,2,4,27,101-104,107,209,210,1099	2,51-68,91,1007,1200	5[g]	0	10^{-5}-1.999x10^{7}	10^{10}	296,500,600,1200,2000	MAT 1065 Graphite thermal scattering kernel @ 296,500,600,1200, and 2000°K. Bondarenko factor data for MT's 1,2, and 102.
N-14	7014	1275	P. Young, D. Foster, Jr., G. Hale	LASL	A	1,2,4,16,27,101-105,107,108,251-253,1099	2,16,51-82,1007	3	0				
N-15	7015	1262	E. Arthur, P. Young, G. Hale	LASL	A	1,2,4,16,22,27,28,101-105,107,251-253,1099	2,16,22,28,51-57,91,1007	3	0				
O-16	8016	1276	P. Young, D. Foster, Jr., G. Hale	LASL	A	1,2,4,27,101-104,107,251-253,1099	2,51-89,1007	3	0				
O-17	8017	1317	B. Magurno	BNL	A	1,2,4,16,22,27,28,101-104,107,251-253,1099	2,16,22,28,51-62,91,1007	3	0				
F-19	9019	1309	C. Fu, D. Larson, F. Perey	ORNL	A	1,2,4,16,22,27,28,101-105,107,251-253,1099	2,16,22,28,51-72,91,1007	3	0				
Na-23	11023	1311	D. Larson	ORNL	B	1,2,4,16,27,101-103,107,251-253,1021,1022,1099	2,16,51-68,91,1007	3	4				
Mg	12000	1312	D. Larson	ORNL	A	1,2,4,16,22,27,28,101-103,107,251-253,1099	2,16,22,28,51-52,91,1007	3	0				
Al-27	13027	1313	P. Young, D. Foster, Jr.	LASL	A	1,2,4,16,27,101-105,107,251-253,1099	2,16,51-92,1007	3	0				
Si	14000	1314	Larson, Perey, Drake, Young	ORNL	A	1,2,4,16,22,27,28,101-104,107,251-253,1099	2,16,22,28,51-72,91,1007	3	0				
P-31	15031	1315	R. Howerton	LLL	A	1,2,4,16,27,28,101-103,107,251-253,1099	2,16,28,91,1007	3	0				
S-32	16032	1316	R. Howerton	LLL	A	1,2,4,16,27,28,101-103,105,107,251-253,1099	2,16,28,91,1007	3	0				
Cl	17000	1149	M. Allen, M. Drake	GGA	A	1,2,4,16,22,27,28,101-103,107,251-253,1099	2,16,22,28,51-65,91,1007	3	0				
Ar	18000	7124[c]	R. Howerton	LLL	A	1,2,4,16,27,101-103,107,1099	2,16,91,1007	3	0				
K	19000	1150	M. Drake	GGA	A	1,2,4,16,22,27,28,101-103,107,251-253,1099	2,16,22,28,51-67,91,1007	3	0				
Ca	20000	1320	C. Fu, F. Perey	ORNL	A	1,2,4,16,22,27,28,101-108,111,112,251-253,1099	2,16,22,28,51-71,91,1007	3	0				
Sc-45	21045	7127[c]	R. Howerton	LLL	A	1,27,101,102,1099		0	0				
Ti	22000	1322	C. Philis, A. Smith, R. Howerton	BNL	A	1,2,4,16,17,22,27,28,101-107,111,112,203,207,251-253,1099	2,16,17,22,28,51-62,91,1007	3	0				
V	23000	1323	A. Smith, R. Howerton, F. Mann	ANL	B	1,2,4,16,22,27,28,101-105,107,203,207,251-253,1099	2,16,22,28,51-57,91,1007	3	0				
Cr	24000	1324	A. Prince, T. Burrows	BNL	B	1,2,4,16,17,22,27,28,101-107,203-207,251-253,1022,1099	2,16,17,22,28,51-92,1007	3	86				

Table 1. (cont.)

Nuclide	ENDF-V Identifier	MAT (ENDF)	Authors	Lab	Weighting Function[d]	1-d Processes in Data Set[f]	2-d Processes in Data Set[f]	Maximum Order of Scattering	Number of Resolved Resonances Processed	Unresolved Resonance Bondarenko Factor Data[b]: Energy Range (eV)	σ0's	Temperature (°K)	Remarks
Mn-55	25055	1325	S. Mughabghab	BNL	B	1,2,4,16,17,22,27,28,101-104,106,107,251-253, 1021,1099	2,16,17,22,28,51-60,91,1007	3	45				
Fe	26000	1326	C. Fu, F. Perey	ORNL	B	1,2,4,16,22,28,30,101-109,251-253,1021,1022, 1099	2,16,22,28,51-76,91,1007	3	62				
Co-59	27059	1327	S. Mughabghab	BNL	B	1,2,4,16,22,28,30,101-107,251-253,1021,1023, 1099	2,16,22,28,51-61,91,1007	3	74				
Ni	28000	1328	M. Divadeenam	BNL	B	1,2,4,16,22,28,30,101-104,107,111,203,204,107, 251-253,1021,1023,1099	2,16,22,28,51-76,91,1007	3	124				
Cu	29000	1329	Fu, [illegible], Fricke	ORNL, SAI	B	1,2,4,16,17,22,27,28,101-104,106,107,251-258, 1021,1023,1099	2,16,17,22,28,51-61,91,1007	3	49				
Zn-64	30064	7139[c]	R. Howerton	LLL	A	1,27,102,103,1099		0	0				
Zn	30000	7140[c]	R. Howerton, P. Young	LLL, LASL	B	1,2,4,16,27,101-103,107,109	2,16,91,1007	3	0				
Kr-78	36078	1330	A. Prince	BNL	B	1,2,4,16,27,101-107,251-253,1021,1022,1099	2,16,51-53,91,1007	3	5				
Kr-80	36080	1331	A. Prince	BNL	B	1,2,4,16,27,101-107,251-253,1021,1022,1099	2,16,51-56,91,1007	3	6				
Kr-82	36082	1332	A. Prince	BNL	B	1,2,4,16,27,101-107,251-253,1021,1022,1099	2,16,51-59,91,1007	3	3				
Kr-83	36083	1333	A. Prince	BNL	B	1,2,4,16,17,27,101-107,251-253,1021,1023,1099	2,16,17,51-56,91,1007	3	4				
Kr-84	36084	1334	A. Prince	BNL	B	1,2,4,16,27,101-107,251-253,1021,1022,1099	2,16,51-63,91,1007	3	3				
Kr-86	36086	1336	A. Prince	BNL	B	1,2,4,16,17,27,101-105,251-253,1021,1023,1099	2,16,17,51-64,91,1007	3	3				
Zr	40000	1340	M. Drake, D. Sargis, T. Huang	SAI	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-69,91,1007	3	88				
Zr-90	40090	1340	M. Drake, D. Sargis, T. Huang	SAI	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-55,91,1007	3	17				
Zr-91	40091	1506	M. Drake, D. Sargis, T. Huang	SAI	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-61,91,1007	3	15				
Zr-92	40092	1307	M. Drake, D. Sargis, T. Huang	SAI	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-56,91,1007	3	17				
Zr-94	40094	1306	M. Drake, D. Sargis, T. Huang	SAI	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-58,91,1007	3	25				
Zr-96	40096	1309	M. Drake, D. Sargis, T. Huang	SAI	B	1,2,4,16,27,101,102,107,251-253,1022,1023,1099	2,16,51-54,91,1077	3	15				
Zirc-2	40302				B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-69,91,1007	3	88				
Nb-93	41093	1189	R. Howerton, A. Smith	LLL, ANL	B	1,2,4,16,17,22,27,101-105,107,251-253,1021, 1023,1099	2,16,17,22,51-67, 91,1007	3	97	7.500×10^3-10^5	1,10,30,10^2, 10^3, 10^4,10^{10}	300,600,900, 1200,2100	Processed from [illegible]
Mo	42000	1321	Howerton, Schmittroth, Schenter	LLL, HEDL	B	1,2,4,16,17,27,101,102,251-253,1021,1023,1099	2,16,17,91,1007	3	33	10^3-10^5	30,10^2,10^3, 10^4,10^{10}	300,600,900, 1200,2100	[illegible]
Tc-99	43099	1308	Schenter, Livolsi, Schmittroth	HEDL, B&W	B	1,2,4,16,27,101,103,251-253,1021,1022,1099	2,16,51-61,91,1007	3	44	8.000×10^2-1.414×10^5	1,10,30,10^2, 10^3,10^4,10^{10}	300,600,900, 1200,2100	
Rh-103	45103	1310	Schenter, Livolsi, Schmittroth	HEDL, B&W	B	1,2,4,16,27,101,102,251-253,1021,1022,1099	2,16,51-64,91,1007	3	61				
Ag-107	47107	1371	Schenter, Bhat, Prince, Johnson	HEDL, BNL	B	1,2,4,16,27,101-105,107,251-253,1022,1023,1099	2,16,51-56,91,1007	3	61				
Ag-109	47109	1373	Schenter, Bhat, Prince, Johnson	HEDL, BNL	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-55,91,1007	3	63				
Cd	48000	1281	S. Pearlstein	BNL	A	1,2,4,16,27,107,251-253,1099	2,16,51-54,91,1007	3	0				
Cd-113	48113	1318	Pearlstein, Mann, Schenter	BNL, HEDL	B	1,2,4,16,27,101-103,107,251-253,1022,1023,1099	2,16,51-53,91,1007	3	16				
Sn	50000	7150[c]	R. Howerton	LLL	B	1,2,4,16,17,27,101102,1099	2,16,17,91,1007	3	0				

Table 1. (Cont.)

	ENDF/B-V Data[c]									Unresolved Resonance Bondarenko Factor Data[h]			
Nuclide	ENDF/B Identifier	MAT (BNL)	Authors	Lab	Weighting Function[d]	1-d Processes in Data Set[f]	2-d Processes in Data Set[f]	Maximum Order of Scattering	Number of Resolved Resonances Processed	Energy Range (eV)	σ_0's	Temperatures (°K)	Remarks
Xe-124	54124	1396	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-102,251-253,1021,1022,1099	2,16,17,51-54,91,1007	3	5				
Xe-126	54126	1339	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-102,251-253,1021,1022,1099	2,16,17,51-54,91,1007	3	5				
Xe-128	54128	1348	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-102,251-253,1021,1022,1099	2,16,17,51-53,91,1007	3	11				
Xe-129	54129	1349	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-105,107,251-253,1021,1022,1099	2,16,17,51-56,91,1007	3	71				
Xe-130	54130	1350	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-105,107,251-253,1021,1022,1099	2,16,17,51-56,91,1007	3	22				
Xe-131	54131	1351	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-105,107,251-253,1021,1022,1099	2,16,17,51-56,91,1007	3	41				
Xe-132	54132	1352	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-105,107,251-253,1021,1022,1099	2,16,17,51-54,91,1007	3	3				
Xe-134	54134	1354	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-105,107,251-253,1021,1022,1099	2,16,17,51-53,91,1007	3	4				
Xe-135	54135	1294	R. Leonard, Jr., K. Stewart	BNW	0	1,2,4,27,102,107,251-253,1099	2,51,91,1007	3	0				
Xe-136	54136	1356	M. Bhat, S. Mughabghab	BNL	0	1,2,4,16,17,27,102-105,107,251-253,1099	2,16,17,51-53,91,1007	3	0				
Cs-133	55133	1355	Schenter, Bhat, Prince, Johnson	HEDL, BNL	0	1,2,4,16,27,102-103,107,251-253,1021,1022,1099	2,16,51-55,91,1007	3	125				
Ba-138	56138	1353	D. Brown	LLL	0	1,2,4,16,17,27,102-103,107,251-253,1099	2,16,17,91,1007	3	0				
Sm-149	62149	1319	Schenter, Leonard, Stewart	HEDL, BNW	0	1,2,4,16,17,27,102-103,107,251-253,1021,1022,1099	2,16,17,51-60,91,1007	3	34				
Eu-151	63151	1357	S. Mughabghab	BNL	0	1,2,4,16,17,22,27,28,102-107,251-253,1021,1022,1099	2,16,17,22,28,51-59,91,1007	3	98	$9.001\times10^{1}-10^{5}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	
Eu-152	63152	1292	T. Takahashi	BNL	0	1,2,4,16,17,22,27,28,102-107,251-253,1021,1022,1099	2,16,17,22,28,51-55,91,1007	3	94	$6.190\times10^{1}-10^{5}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	
Eu-153	63153	1359	S. Mughabghab	BNL	0	1,2,4,16,17,22,27,28,102-107,251-253,1021,1022,1099	2,16,17,22,28,51-61,91,1007	3	73	$9.722\times10^{1}-10^{5}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	
Eu-154	63154	1293	H. Takahashi	BNL	0	1,2,4,16,17,22,27,28,102-107,251-253,1021,1022,1099	2,16,17,22,28,51-55,91,1007	3	73	$6.000\times10^{1}-10^{5}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	
Gd-152	64152	1362	B. Magurno	BNL	0	1,2,4,16,22,27,28,102-103,107,251-253,1021,1022,1099	2,16,22,28,51-64,91,1007	3	19				
Gd-154	64154	1364	B. Magurno	BNL	0	1,2,4,16,22,27,28,102-103,107,251-253,1021,1022,1099	2,16,22,28,51-64,91,1007	3	30				
Gd-155	64155	1365	B. Magurno	BNL	0	1,2,4,16,22,27,28,102-103,107,251-253,1021,1022,1099	2,16,22,28,51-64,91,1007	3	96	$1.034\times10^{2}-1.009\times10^{4}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	
Gd-156	64156	1366	B. Magurno	BNL	0	1,2,4,16,22,27,28,51-64,91,101-103,107,251-253,1007,1021,1022,1099	2,16,22,28,51-64,91,1007	3	32				
Gd-157	64157	1367	B. Magurno	BNL	0	1,2,4,16,22,27,28,102-103,107,251-253,1021,1022,1099	2,16,22,28,51-64,91,1007	3	58	$2.065\times10^{2}-1.009\times10^{4}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	
Gd-158	64158	1368	B. Magurno	BNL	0	1,2,4,16,22,27,28,102-103,107,251-253,1021,1022,1099	2,16,22,28,51-64,91,1007	3	[illegible]				
Gd-160	64160	1370	B. Magurno	BNL	0	1,2,4,16,22,27,28,102-103,107,251-253,1021,1022,1099	2,16,22,28,51-58,91,1007	3	46				
Dy-164	66164	1604	R. Leonard, Jr., K. Stewart	BNW	0	1,2,4,16,17,27,102-103,107,251-253,1021,1022,1099	2,16,17,51-62,91,1007	3	3	$3.739\times10^{2}-10^{5}$	$10^{2},10^{3},10^{4},10^{10}$	300,600,900,1200,2100	

Table 1. (cont.)

Nuclide	ENDF-V Identifier	ENDF/B-V Data[a]: MAT (ENDF)	ENDF/B-V Data[a]: Authors	ENDF/B-V Data[a]: Lab	Weighting Function[d]	1-D Processes in Data Set[f]	2-D Processes in Data Set[f]	Maximum Order of Scattering	Number of Resolved Resonances Processed	Unresolved Resonance Bondarenko Factor Data[b]: Energy Range (eV)	Unresolved Resonance Bondarenko Factor Data[b]: σ_0's	Unresolved Resonance Bondarenko Factor Data[b]: Temperatures (°K)	Remarks
Lu-175	71175	1030	B. Leonard, Jr., K. Stewart	BNW	B	1,2,4,16,17,27,101-103,107,251-253,1021, 1023,1099	2,16,17,51-58,91,1007	3	18	6.000×10^1-10^4	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Lu-176	71176	1032	B. Leonard, Jr., K. Stewart	BNW	B	1,2,4,16,17,27,101-103,107,251-253,1021, 1023,1099	2,16,22,28,51-58,91,1008	3	25	4.000×10^1-10^4	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf	72000	1372	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-62,91,1007	3	242	1.500×10^4-10^5	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf-174	72174	1374	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-53,91,1007	3	33	3.900×10^2-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf-176	72176	1376	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-58,91,1007	3	24	1.000×10^3-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf-177	72177	1377	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-60,91,1007	3	101	3.000×10^2-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf-178	72178	1378	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-53,91,1007	3	37	2.100×10^3-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf-179	72179	1380	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-54,91,1007	3	34	4.900×10^2-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Hf-180	72180	1386	M. Drake, D. Sargent, T. Young	SAI	B	1,2,4,16,27,101-103,251-253,1021,1023,1099	2,16,51-53,91,1007	3	32	1.300×10^4-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Ta-181	73181	1285	Howerton, Perkins, MacGregor	LLL	B	1,2,4,16,17,27,101-103,251-253,1021,1023,1099	2,16,17,51-60,91,1007	3	77	3.300×10^2-5.000×10^3	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Ta-182	73182	1127	J. Otter, C. Dunford, R. Ottewitte	AI	B	1,2,4,16,17,27,101,102,251-253,1021,1023,1099	2,16,17,51-56,91,1007	3	22	3.500×10^1-10^4	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
W-182	74182	1128	Otter, Ottewitte, Rose, Young	AI, LASL	B	1,2,4,16,17,27,28,101-103,107,251-253,1021, 1023,1099	2,16,17,20,51-58,91,1007	3	70	4.500×10^3-10^5	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
W-183	74183	1129	Otter, Ottewitte, Rose, Young	AI, LASL	B	1,2,4,16,17,27,28,101-103,107,251-253,1021, 1023,1099	2,16,17,20,51-59,91,1007	3	24	7.630×10^2-4.500×10^4	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
W-184	74184	1130	Otter, Ottewitte, Rose, Young	AI, LASL	B	1,2,4,16,17,27,28,101-103,107,251-253,1021, 1023,1099	2,16,17,20,51-59,91,1007	3	39	2.650×10^3-10^5	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
W-186	74186	1131	Otter, Ottewitte, Rose, Young	AI, LASL	B	1,2,4,16,17,27,28,101-103,107,251-253,1021, 1023,1099	2,16,17,20,51-59,91,1007	3	42	3.300×10^3-10^5	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Re-185	75185	1083	W. Henderson, J. Svich	GE	B	1,2,4,16,17,27,28,101,102,251-253,1021, 1023,1099	2,16,17,20,51-58,91,1007	3	31	9.980×10^1-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Re-187	75187	1084	W. Henderson, J. Svich	GE	B	1,2,4,16,17,27,28,101,102,251-253,1021, 1023,1099	2,16,17,20,51-61,91,1007	3	35	9.300×10^1-10^5	$10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	
Ir-191	77191	7100[e]	R. Howerton	LLL	B	1,27,101,102,1099		0	0				
Ir-193	77193	7101[e]	R. Howerton	LLL	B	1,27,101,102,1099		0	0				
Au-197	79197	1379	S. Mughabghab	BNL	B	1,2,4,16,17,27,101-103,107,251-253,1099	2,16,17,51-64,91,1007	3	0				
Pb	82000	1382	C. Fu, F. Perey	ORNL	A	1,2,4,16,17,27,101,102,251-253,1099	2,16,17,51-87,91,1007	3	0				
Th-232	90232	1390	Bhat, Smith, Leonard, De Saussure	BNL, ORNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-65,91,1007	3	240	4.000×10^3-5.000×10^4	$1,10,30,10^2,10^3,10^4,10^{10}$	300,600,900, 1200,2100	

Table 2. (cont.)

		ENDF/B-V Data[a]								Unresolved Resonance Bondarenko Factor Data[b]			
Nuclide	ENDL-V Identifier	MAT (MOD)	Authors	Lab	Weighting Function[d]	1-d Processes in Data Set[f]	2-d Processes in Data Set[f]	Maximum Order of Scattering	Number of Resolved Resonances Processed	Energy Range (eV)	σ_0's	Temperatures (°K)	Remarks
Th-232	90232	1390	Mann, Schenter, Smith	HEDL, BNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021,1023,1099	2,16,17,51-55,91,1007	3	38	$3.000\times10^{3}-10^{5}$	$10^{2},10^{3},10^{4}$, 10^{10}	300,600,900, 1200,2100	
U-233	92233	1393	Stewart, Weston, Mann, et.al.	LASL, ORNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1099	2,16,17,51-54,91,1007	3	0	$6.000\times10^{1}-10^{5}$	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
U-234	92234	1394	Divadeenam, Mann, Drake, Smith	BNL, HEDL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1020-1023,1099	2,16,17,51-56,91,1007	3	180	$1.500\times10^{3}-10^{5}$	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
U-235	92235	1395	M. Bhat	ORNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-66,91,1007	3	131	$8.200\times10^{1}-$ 2.500×10^{4}	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
U-236	92236	1396	Divadeenam, Mann, McCrosson, Smith	BNL, HEDL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-56,91,1007	3	198	$4.110\times10^{3}-10^{5}$	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
U-238	92238	1398	E. Pennington, A. Smith, W. Poenitz	ANL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-77,91,1007	3	145	$4.000\times10^{3}-$ 1.490×10^{5}	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Np-237	93237	1337	Mann, Benjamin, Smith, Stein, Weisch	HEDL, SRL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-61,91,1007	3	170	$1.300\times10^{2}-$ 4.000×10^{4}	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Pu-238	94238	1338	Mann, Schenter, Alter, Dunford	HEDL, AI	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-65,91,1007	3	56	$2.000\times10^{2}-10^{5}$	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Pu-239	94239	1399	E. Kujawski, A. Stewart	GE, LASL	C	1,2,4,16-18,27,37,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-76,91,1007	3	129	$3.010\times10^{2}-$ 2.500×10^{4}	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Pu-240	94240	1380	L. Weston	ORNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-62,91,1007	3	282	$3.910\times10^{3}-$ 4.000×10^{4}	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Pu-241	94241	1381	L. Weston, R. Wright, R. Howerton	ORNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1099	2,16,17,51-65,91,1007	3	0	$1.000\times10^{2}-$ 4.020×10^{4}	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Pu-242	94242	1342	Mann, Benjamin, Madland, Howerton	HEDL, SRL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-69,91,1007	3	69	$9.860\times10^{2}-10^{5}$	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Am-241	95241	1361	Mann, Schenter, Weston	HEDL, ORNL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-68,91,1007	3	67	$5.000\times10^{1}-10^{5}$	$1,10,50,10^{2}$, $10^{3},10^{4},10^{10}$	300,600,900, 1200,2100	
Am-242m	95601	1369	Mann, Benjamin, Howerton, et.al.	HEDL, SRL, LLL	C	1,2,4,16-18,27,37,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-63,91,1007	3	8	$3.330-10^{5}$	$10^{2},10^{3},10^{4}$, 10^{10}	300,600,900, 1200,2100	
Am-243	95243	1363	Mann, Benjamin, Howerton, et.al.	HEDL, SRL, LLL	C	1,2,4,16-18,27,37,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-67,91,1007	3	221	$2.500\times10^{2}-10^{5}$	$10^{2},10^{3},10^{4}$, 10^{10}	300,600,900, 1200,2100	
Cm-243	96243	1343	Mann, Benjamin, Howerton, et.al.	HEDL, SRL, LLL	C	1,2,4,16-18,27,37,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-63,91,1007	3	17	$5.700\times10^{2}-10^{5}$	$10^{2},10^{3},10^{4}$, 10^{10}	300,600,900, 1200,2100	
Cm-244	96244	1344	Mann, Benjamin, Howerton, et.al.	HEDL, SRL, LLL	C	1,2,4,16-18,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-53,91,1007	3	39	$5.250\times10^{2}-10^{5}$	$10^{2},10^{3},10^{4}$, 10^{10}	300,600,900, 1200,2100	

Table 1. (cont.)

	ENDF/B-V Data[a]									Unresolved Resonance Bondarenko Factor Data[b]			
Nuclide	ENDL-V Identifier	MAT (ENDF)	Authors	Lab	Weighting Function[d]	1-6 Processes in Data Set[f]	2-6 Processes in Data Set[f]	Maximum Order of Scattering	Number of Resolved Resonances Processed	Energy Range (eV)	σ_0's	Temperatures (°K)	Remarks
Cm-246	96246	1346	Benjamin, Howerton	SRL, LLL	C	1,2,4,16-18,22,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51,1007	3	9				
Cm-248	96248	1348	[illegible]	SRL, SRL, LLL	F	1,2,4,16-18,22,27,101,102,251-253,452,1018, 1021-1023,1099	2,16,17,51-61,91,1007	3	15	5.016x10[2]-10[4]	10[2],10[3], 10[4], 10[10]	300,600,900 1200,2100	
Dose Factors	300000	N/A			B	9001-9038,1099							

Footnotes for Table 1.

a. All neutron data from ENDF/B-V unless otherwise noted.

b. Unless otherwise noted, Bondarenko factors are available for MT's 1, 2, 4, 18 (for fissionable nuclei), 102, and 1000.

c. An evaluation from the LENDL library, not an ENDF/B-V evaluation.

d. The following code is used to identify the weighting functions:

Code	Weight Function
A	10^{-5}-0.1265 eV Maxwellian; 0.1265 eV-1.4 MeV 1/E; 1.4-20 MeV fission spectrum.
B	10^{-5}-0.1265 eV Maxwellian; 0.1265 eV-0.75 MeV 1/E; 0.75-20 MeV fission spectrum.
C	10^{-5}-0.1265 eV Maxwellian; 0.1265 eV-0.1 MeV 1/E; 0.1-20 MeV fission spectrum.

e. Order of scattering in the fast range is P_5; in the thermal range, it's P_3.

f. See Appendix C of Ref. 1 for the definitions of the process identifiers (MT numbers).

II.C. Weighting Function

All materials in the CSRL-V library were processed with a fission-1/E-Maxwellian weighting function. Temperature of the fission spectrum component of the weighting function was 1.27×10^6 eV; temperature of the Maxwellian component was 300 °K. The energy at which the fission component was joined to the 1/E component generally was 1.4 MeV for the light materials, 0.75 MeV for the intermediate-mass materials, and 0.1 MeV for the heavy materials. The 1/E component was joined to the Maxwellian component at 0.1265 eV for the processing of all materials.

II.D. Legendre Order of Scattering

The special 1/V data set and the ^{64}Zn, ^{191}Ir, and ^{193}Ir data sets were processed with a P_0 order of scattering. Group-to-group transfer matrices for ^{1}H, ^{2}H, and C were expanded to P_5 in the epithermal range and P_3 in the thermal range. All other materials were processed with a P_3 expansion.

II.E. Codes Used to Process CSRL-V

As shown in Fig. 1, current versions of modules from the AMPX and NJOY[18,19] cross-section processing systems were used to process CSRL-V. ENDF/B-V evaluations containing resolved resonance data were "preprocessed" with NPTXS (AMPX) to make pointwise files (i.e., neutron energy, cross-section pairs) for the total, fission, elastic scattering, and (n,γ) reactions. The pointwise elastic scattering data were used to augment the ENDF data selected in a subsequent module (XLACS2) used to process the multigroup scattering matrices.

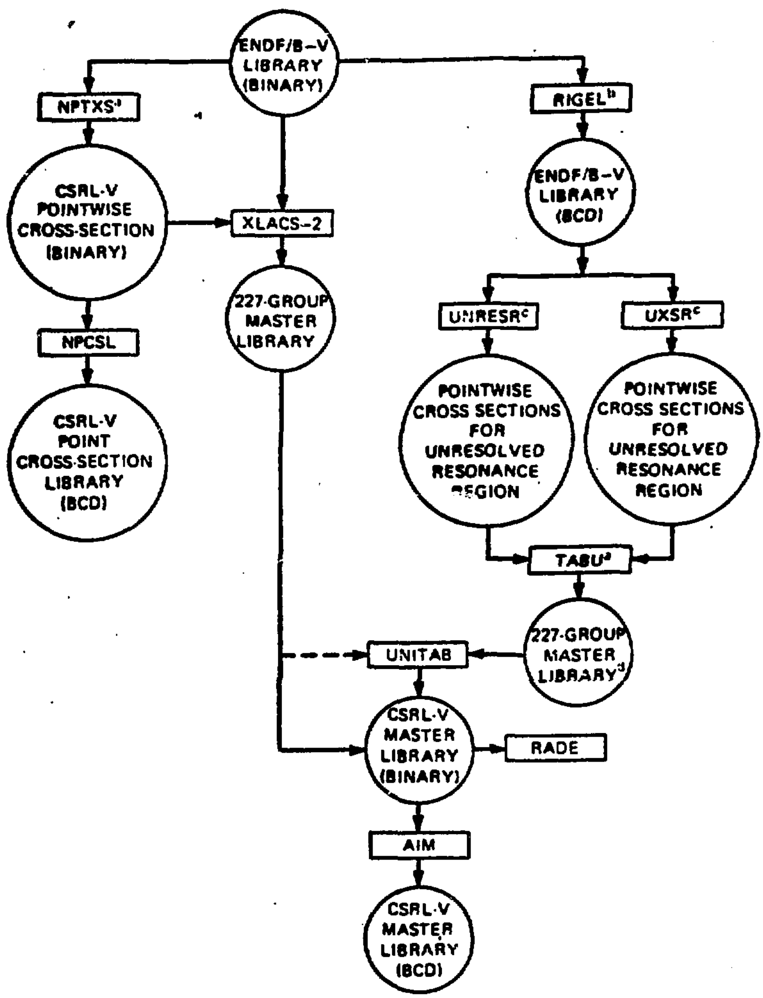
XLACS2 (AMPX) was used to produce full-energy-range multigroup neutron cross sections in AMPX master format (see below). The module processes ENDF/B resolved resonance data into a form suitable for use (i.e., resonance parameters) in the calculation of self-shielded cross sections with the Nordheim integral treatment[20] provided in the NITAWL (AMPX) module.

The NJOY modules UNRESR and UXSR, an improved version of UNRESR, were used to compute effective pointwise self-shielded cross sections for the unresolved resonance region. TABU (AMPX) was used to process the pointwise unresolved data into group-averaged Bondarenko[21] data which were a function of material, process, temperature, background cross section, and energy. UNITAB (AMPX) was used to merge the Bondarenko data and the XLACS2-produced data into a final master data set.

XLACS2 has not been programmed to process Adler-Adler resonance data in ENDF formats. Consequently, NJOY was used to process the two ENDF/B-V evaluations which contain Adler-Adler data — MAT 1393 (^{233}U) and MAT 1381 (^{241}Pu). The resulting CSRL-V data sets have Bondarenko factor data for both the resolved and unresolved energy ranges.

Other codes were used for data management and format conversion. NPCSL (NJOY) was used to convert binary pointwise data sets to BCD format. RIGEL, an ENDF code, was used to change the mode of ENDF data from binary to BCD, or vice versa. AJAX (AMPX) was used to merge AMPX master data sets. AIM (AMPX) was used to convert binary master libraries to BCD-formatted master libraries, or vice versa.

ORNL-DWG 82-8604A



[a]AMPX MODULE
[b]ENDF PROCESSING CODE
[c]NJOY MODULE
[d]CONTAINS ONLY BONDARENKO FACTOR DATA FOR THE UNRESOLVED ENERGY REGION.

Fig. 1. Codes used to generate CSRL-V libraries

II.F. Thermal Range Processing

A feature of the code used to process the CSRL-V multigroup data (XLACS2) is the ability to process normal ENDF/B data in the fast and epithermal energy regions and to couple the data in a consistent fashion with thermal data taken from another ENDF/B evaluation to produce a single full-energy-range master data set. This means, for example, that a multithermal-group master data set can be prepared for hydrogen using the normal ENDF/B hydrogen evaluation for the energy region above the thermal-epithermal cutoff, i.e., for the fast groups, and using an ENDF thermal evaluation containing $S_{\alpha,\beta}$ data based on a water model for the region below the cutoff energy (the thermal groups). Two advantages of this approach are the convenience of dealing with a single set of processed data and the generation of multigroup cross sections representing the correct distributions for neutrons elastically or inelastically scattered into the thermal range. This procedure was used to process water-bound and polyethylene-bound hydrogen, CSRL-V ID's 1001 and 1301, D_2O-bound deuterium (1002), and graphite (6312).

Only the very light moderators need the special ENDF thermal evaluations for the preparation of multithermal-group cross sections. For those nuclides which have no special thermal evaluations, XLACS2 allows the following options for generating thermal scattering matrices based on the free gas treatment:

1. The code will generate free gas $S_{\alpha,\beta}$ data. This process was used with light nuclides — $A \leq 19$.

2. The code will use an analytic free gas treatment to generate P_0 thermal matrices. The thermal values are normalized to the free-atom scattering cross section in the epithermal range. This process was used for nuclides with mass > 19 and with no resonances in the thermal range.

3. The same analytic routines used in #2 are used but the scattering matrices are normalized to the average values of the scattering cross section in the thermal range. (Note that this will not preserve the Doppler broadening inherent in the free gas equations unless it is present in the thermal point values.) This approach was used for nuclides with thermal resonances -- nuclides such as ^{235}U and ^{240}Pu.

II.G. Resolved Resonance Processing

Resolved resonance processing for CSRL-V involved the calculation of two arrays of cross-section data for the elastic scattering, n-γ capture, and fission reactions, i.e., XLACS2 calculates MT 2 and 1023 data for elastic scattering, MT 18 and 1022 data for fission, and MT 102 and 1021 data for n-γ capture. The MT 1021, 1022, and 1023 arrays contain the averaged values of the cross sections for the resonance bodies. These averaged values are weighted over the weighting spectrum specified for the XLACS2 problem.

The MT 18 and MT 102 arrays contain "everything" except the MT 1022 and MT 1021 data, respectively. "Everything" includes the following:

a. The wings of the resonances (recall that the Nordheim treatment only applies to a region close to the resonance peak.)

b. The contributions from all ℓ=1, 2, 3, . . . resonances.

c. The interference terms (even in the resonance body) for the case of multilevel Breit-Wigner fits.

d. The ENDF File 3 background data.

Conversely, the calculated MT 2 data are the sum of the above "everything" contributions and the 1023 data, i.e., the MT 2 data are for total elastic scattering.

Data calculated for MT 1, 27, and 101 follow the same rules as for MT 2, 18, and 102. For example,

$$(\text{MT } 27) = (\text{MT } 101) + (\text{MT } 18) \tag{1}$$

$$(\text{MT } 101) = \sum_{i=2}^{14} (\text{MT } 100+i) \tag{2}$$

II.H. Fission Spectrum

XLACS2 calculates a full group-to-group fission matrix as a prelude to calculating an averaged fission spectrum. This two-dimensional array is reduced to the one-dimensional array placed on the master library (MT 1018) by the following expression:

$$\overline{\chi}_g = \frac{\sum_{g'} \nu_{g'} \sigma^f_{g'} \phi_{g'} \chi(g' \to g)}{\sum_{g'} \nu_{g'} \sigma^f_{g'} \phi_{g'}} \tag{3}$$

II.I. Format of the CSRL-V Master Library

Among the many types of cross-section libraries that can be produced with the AMPX system (libraries such as ANISN-formatted libraries, CCCC-formatted libraries, "working" libraries, etc.), the format of an AMPX master cross-section library is the most general way to store multigroup neutron cross-section data. Included in a master library are one-dimensional multigroup cross-section data, transfer matrices for elastic and inelastic scattering reactions and for neutron producing reactions [e.g., (n,2n)] with arbitrary orders of scatter for fast and thermal data where required, resonance self-shielding parameters (including Bondarenko factors) for subsequent problem-dependent processing, fission spectrum data, weighting function data, etc. These data are available in a compacted magic word format to remove extraneous zeros and consequently to substantially reduce tape storage requirements. One-dimensional and transfer matrix data (two-dimensional data) in each CSRL-V master data set are identified by MT number in Table 1. Format of an AMPX master library is given in Ref. 1.

III. CSRL-V BENCHMARK CALCULATIONS

Data from CSRL-V have been used to calculate performance parameters for the CSEWG TRX-1 and TRX-2 benchmarks[22] and for the Babcock & Wilcox B&W-XIII and B&W-XX benchmarks.[23] Results of the TRX calculations are summarized in Section III.A and the B&W calculations are summarized in Section III.B. Eigenvalue calculations for selected criticality safety benchmarks are discussed in Section III.C.

III.A. CSEWG TRX-1 and TRX-2 Benchmarks

The CSEWG TRX-1 and TRX-2 benchmarks were water-moderated, fully reflected assemblies with aluminum-clad fuel rods of 1.3% ^{235}U-enriched uranium. The 0.983-cm-diameter rods were arranged in triangular arrays with lattice spacings of 1.8060 and 2.1740 cm and with moderator/fuel volume ratios of 2.35 and 4.02 for TRX-1 and TRX-2, respectively. Integral parameters which were measured at the center of each lattice included the epithermal/thermal ratio of ^{238}U capture (ρ^{28}) and of ^{235}U fission (δ^{25}), the ratio of ^{235}U capture to ^{235}U fission (C*), and the ratio of ^{238}U fission to ^{235}U fission (δ^{28}).

Problem-dependent cross sections processed from CSRL-V were used to calculate the benchmark performance parameters. A typical code calculational sequence is depicted in Fig. 2. Axial bucklings given in Ref. 22 were used to determine the representative assembly cylinder heights for the discrete ordinates calculations.

Calculated performance parameters for TRX-1 and TRX-2 are compared in Tables 2 and 3, respectively, with experimental values and with the average of ENDF/B-V calculations by laboratories which contributed to the CSEWG ENDF/B-V thermal benchmark studies.[24] CSRL-V calculations for TRX-1 were made with the 227-group CSRL-V data. TRX-2 calculations were made with a 27-group subset of the fine-group CSRL-V cross sections. The TRX-2 cell-averaged flux was used to collapse the CSRL-V data sets to the broad-group structure.

Comparison of the CSRL-V results with the CSEWG results shows that ρ^{28} for both TRX-1 and TRX-2 is higher (~2%) than the CSEWG average, which in turn is higher than the experimental ρ^{28}. This parameter strongly influences k_{eff}. The CSRL-V eigenvalue is ~0.3% lower than the CSEWG average k_{eff} for both TRX-1 and TRX-2. In depth studies are in progress to either substantiate the CSRL-V results or to identify the cause(s) of the discrepancies.

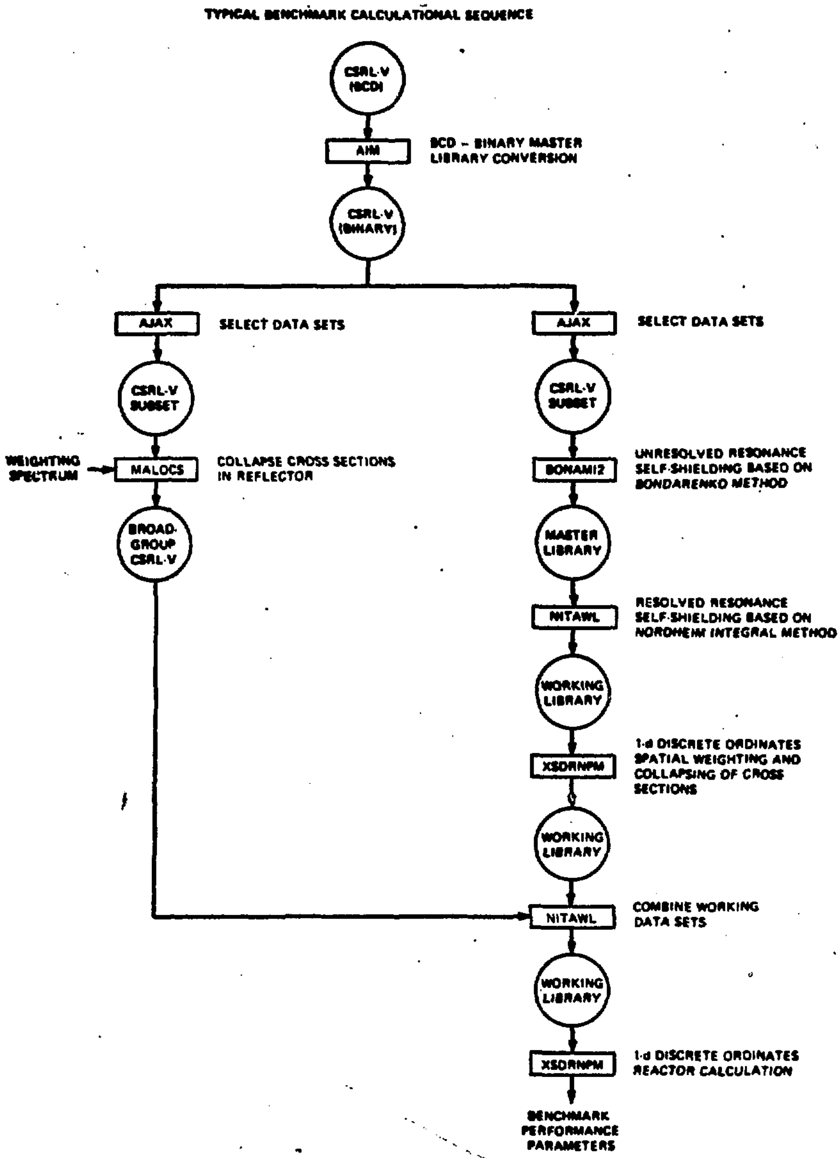


Fig. 2. Typical benchmark calculational sequence

Table 2. Integral Parameters for TRX-1

Parameter[a]	Experiment	Five-Lab Average[b]	ENDF/B-V Calculation CSRL-V	$\left(\frac{\text{Calc.}}{\text{Exp.}}\right) - 1 \times 100$ 5-Lab. Avg.	CSRL-V
ρ^{28}	1.320±0.021	1.359±0.016	1.388	3.0	5.2
δ^{25}	0.0987±0.0010	0.1003±0.0010	0.09984	1.6	1.2
δ^{28}	0.0946±0.0041	0.0989±0.0003	0.09824	4.5	3.8
C*	0.797±0.008	0.798±0.005	0.8081	0.1	1.4
k_{eff}	1.0	0.9961±0.0031	0.9929	-0.39	-0.71

[a] Parameter definitions (measured at core center):

ρ^{28} ≡ ratio of epithermal-to-thermal ^{238}U capture
δ^{25} ≡ ratio of epithermal-to-thermal ^{235}U fissions
δ^{28} ≡ ratio of ^{238}U fissions to ^{235}U fissions
C* ≡ ratio of ^{238}U captures to ^{235}U fissions

[b] Electric Power Research Institute (EPRI), ORNL (not this work), Brookhaven National Laboratory (BNL), Chalk River Nuclear Laboratories (CRNL), and Combustion Engineering, Inc. (CE) results as reported by Weisbin, Hardy et al. as a part of the CSEWG ENDF/B-V data testing program.[24]

Table 3. Integral Parameters for TRX-2

		ENDF/B-V Calculation			
				$\left(\frac{\text{Calc.}}{\text{Exp.}} - 1\right) \times 100$	
Parameter	Experiment	Four-Lab Average[a]	27-Group CSRL-V	4-Lab. Avg.	27-Gp. CSRL-V
ρ^{28}	0.837±0.016	0.846	0.865	1.1	3.3
δ^{5}	0.0614±0.0008	0.0614	0.0612	0.0	−0.33
δ^{28}	0.0693±0.0035	0.0699	0.0696	0.9	0.43
C*	0.647±0.006	0.642	0.648	−0.8	0.15
k_{eff}	1.0	0.9984	0.9948	−0.16	−0.52

[a] EPRI, ORNL (not this work), CRNL, and CE results reported by Weisbin, Hardy et al. as a part of the CSEWG ENDF/B-V data testing program.[24]

III.B. B&W-XIII and B&W-XX Benchmarks

CSRL-V data were used to calculate eigenvalues for two slightly-enriched (2.46% ^{235}U) UO_2, water-moderated critical assembly experiments reported by the Babcock & Wilcox Company — B&W-XIII and B&W-XX. The critical assembly was erected in a 5-foot-diameter by 6.5-foot-high aluminum core tank mounted inside an existing 9-foot-diameter tank. Fuel rods consisted of pellets in 1.206-cm-diameter, 156.4-cm-long, aluminum-clad cylinders arranged in a 1.511 cm lattice pitch. Nonmoderator-to-moderator volume ratio was 1.001. The two experiments differed in the presence (or absence) of boron in the moderator, the number of fuel rods and the radial and axial parameters as follows:

Core No.	Boron in moderator (gm B/ℓ)	Number of fuel rods	Radial parameters (cm): Core radius	Radial parameters (cm): Reflector thickness	Axial parameters (cm): Moderator height	Axial parameters (cm): Reflector thickness
XIII	0	596	20.82	55.38	141.1	12.3
XX	1.675	5137	61.11	15.09	93.2	60.2

Calculated eigenvalues for B&W-XIII and B&W-XX are compared in Table 4 with eigenvalues calculated with two other ENDF/B-V cross-section libraries—the 97-group EPRI-CELL (E-C/PDQ) and a 127-group in-house library used in other thermal benchmarking studies. The E-C/PDQ values were obtained by EPRI by feeding cell-averaged, broad-group cross-sections computed with the EPRI-CELL code into a 1-d PDQ diffusion theory calculation. The 127-group results used a Bondarenko resonance shielding calculation with the same background cross sections (σ_0's) as in the EPRI-CELL calculation, which partially accounts for the good agreement with the E-C/PDQ results. The cell-averaging and 1-d core calculation for the 127-group library was done with XSDRNPM. Note that again the CSRL-V NITAWL-XSDRNPM eigenvalue results are lower than the other methods.

Table 4. Calculated Eigenvalues for B&W-XIII and -XX Lattices

Parameter	Calculated Eigenvalue: E-C/PDQ	Calculated Eigenvalue: 127-Group XSDRN	Calculated Eigenvalue: CSRL-V	$\left(\frac{\text{Calculated}}{\text{Experimental}} - 1\right) \times 100$: E-C/PDQ	$\left(\frac{\text{Calculated}}{\text{Experimental}} - 1\right) \times 100$: 127-Group XSDRN	$\left(\frac{\text{Calculated}}{\text{Experimental}} - 1\right) \times 100$: CSRL-V
B&W-XIII k_∞	1.327	1.328	1.320	—	—	—
B&W-XIII k_{eff}	1.003	1.002	0.995	0.3	0.2	-0.5
B&W-XX	1.089	1.089	1.084	—	—	—
B&W-XX	1.002	1.000	0.995	0.2	0.0	-0.5

III.C. Criticality Safety Benchmarks

Adequacy of the CSRL-V group structure and validity of selected data sets from the library were further tested by a series of P_3 S_8 fine- and broad-group calculations of k-eff for a series of criticality safety benchmarks. Characteristics of five selected uranium solution experiments with various $H/^{235}U$ atom ratios are given in Table 5. The experiments were water-reflected and unreflected critical spheres of uranyl nitrate or uranyl fluoride aqueous solutions. Calculated eigenvalues for the benchmarks are given in Table 6. CSRL-V results are compared with results obtained using the 16-group P_1 Hansen-Roach cross-section library.[29]

Table 5. Critical Conditions for Bare and Reflected Spheres

Experiment Designation	Sphere Radius (cm)		Atom Density[c] (atoms/bn·cm)									Reflector Condition	Reference
	Inner	Outer	^{234}U	^{235}U	^{236}U	^{238}U	H	O	F	N	B		
CS1	11.32[a]	11.60	8.70-6	5.326-4	4.30-6	4.73-5	6.336-2	3.35-2	1.786-3			Reflected	25
CS2	13.30[a]	13.35	2.87-6	2.419-4	1.31-6	1.36-5	6.553-2	3.30-2	5.214-4			Reflected	26
CS4		25.39[b]	7.00-7	1.161-4	9.00-7	2.186-3	5.689-2	3.31-2	4.607-3			Bare	
CS5	18.35[a]	18.50	1.65-6	1.333-4	9.20-7	9.90-6	6.538-2	3.40-2		3.32-4		Bare	27
CS7	34.60[a]	34.92		6.796-5		4.93-6	6.603-2	3.39-2		2.35-4	1.28-5		

---

[a] Sphere constructed of Aℓ (6.016×10^{-2} atoms/bn cm).

[b] Container wall, supporting members, and solution filling correction of 16.8¢ is made to calculated eigenvalues.

[c] Atom densities given as a number and an exponent, e.g., 1.00-1 means 1.00×10^{-1}.

Table 6. Calculated Results for Uranium Solution Critical Experiments

Experiment Designation	Experiment Description	H/U-235 Atom Ratio	k_{eff} $\left(\frac{\text{Calculated}}{\text{Experimental}} - 1\right) \times 100$ Hansen-Roach 16 Group, P_1	CSRL-V
CS1	93.2% enriched uranyl fluoride solution spheres, infinite water reflector	76.1	0.0	0.19
CS2		269.8	-0.37	0.07
CS4	4.98% enriched uranyl fluoride solution sphere	490.0	-1.20	-0.30
CS5	93.2% enriched uranyl nitrate solution sphere	425.1	-0.79	0.15
CS7	Borated 93.2% enriched uranyl nitrate solution sphere	971.6	0.45	-0.58

IV. CONCLUSIONS AND FUTURE OBJECTIVES

The CSRL-V AMPX master and pointwise cross-section libraries are available on magnetic tape from the Radiation Shielding Information Center in a package identified as DLC-095/CSRL-V.[a] Documentation for the library is given in Ref. 1.

CSRL-V eigenvalue results for the thermal reactor benchmarks were slightly lower than ENDF/B-V based results reported by others. Possible reasons for the differences are being investigated.

ENDF/B-V Special Purpose Dosimetry, Activation, and Gas Production Files are being processed for CSRL-V. Photon-production and photon-interaction libraries are in the planning stage.

[a] Inquiries should be addressed to Radiation Shielding Information Center, P. O. Box X, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

REFERENCES

1. W. E. Ford, III, B. R. Diggs, L. M. Petrie, C. C. Webster, and R. M. Westfall, "CSRL-V: Processed ENDF/B-V 227-Neutron-Group and Pointwise Cross-Section Libraries for Criticality Safety, Reactor and Shielding Studies," ORNL/CSD/TM-160 (NUREG/CR-2306) (in press).

2. W. E. Ford, III, R. M. Westfall, B. R. Diggs, C. C. Webster, and J. R. Knight, "CSRL-V: An ENDF/B-V 227-Group Cross-Section Library for Criticality Safety Studies," Trans. Am. Nucl. Soc., 34, 331 (1980).

3. N. M. Greene, W. E. Ford, III, et al., "AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries from ENDF/B," ORNL/TM-3706 (March 1976).

4. "SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, SCALE System Criticality Safety Analysis Modules CSAS1 and CSAS2," ORNL/NUREG/CSD-2 (NUREG/CR-0200), Vol. 1-3 (August 1980, Revised October 1981).

5. L. M. Petrie and N. F. Cross, "KENO IV An Improved Monte Carlo Criticality Program," ORNL-4938 (November 1975).

6. W. W. Engle, Jr., "A Users Manual for ANISN, A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," K-1693, Union Carbide Corporation, Nuclear Division (March 1967).

7. N. M. Greene and C. W. Craven, Jr., "XSDRN: A Discrete Ordinates Spectral Averaging Code," ORNL/TM-2500 (July 1969).

8. D. R. Vondy, T. B. Fowler, and G. W. Cunningham, "VENTURE: A Code Block for Solving Multigroup Neutronics Problems Applying the Finite-Difference Diffusion-Theory Approximation to Neutron Transport, Version II," ORNL-5062/R1 (November 1977).

9. W. A. Rhoades and F. R. Mynatt, "The DOT-III Two-Dimensional Transport Code," ORNL/TM-4280 (1973).

10. E. A. Straker et al., "The MORSE Code - A Multigroup Neutron and Gamma-Ray Monte Carlo Transport Code," ORNL/TM-4585 (1970).

11. "AMPX-II Modular Code System for Generating Coupled Multigroup Neutron - Gamma-Ray Cross-Section Libraries from Data in ENDF Format," Radiation Shielding Information Center documentation for PSR-63, Oak Ridge National Laboratory (November 1978).

12. W. E. Ford, III, R. M. Westfall and C. C. Webster, "A 218-Neutron-Group Master Cross-Section Library for Criticality Safety Studies," Trans. Am. Nucl. Soc., 22, 290 (1975).

13. W. E. Ford, III, C. C. Webster and R. M. Westfall, "A 218-Group Neutron Cross-Section Library in the AMPX Master Interface Format for Criticality Safety Studies," ORNL/CSD/TM-4 (July 1976).

14. "CSRL A 218-Group Neutron Cross-Section Reference Library in the AMPX Master Interface Format for Criticality Safety Studies," Radiation Shielding Information Center documentation for DLC-43, Oak Ridge National Laboratory (March 1978).

15. R. Kinsey, Ed., "ENDF/B Summary Documentation," BNL-NCS-17541 (ENDF-201), 3rd ed., Brookhaven National Laboratory (1979).

16. R. J. Howerton, "The Lawrence Livermore Laboratory Evaluated Nuclear Data Library (ENDL) Translated into the ENDF/B Format," UCID-16727 (March 1975).

17. "LENDL Livermore Evaluated Neutron and Secondary Gamma-Ray Production Cross-Section Library in ENDF/B-IV Format," Radiation Shielding Information Center documentation for DLC-34, Oak Ridge National Laboratory (January 1980).

18. R. E. MacFarlane, R. J. Barrett, D. W. Muir and R. M. Boicourt, "The NJOY Nuclear Data Processing System: User's Manual," LA-7584-M (December 1978).

19. "NJOY A Code System for Producing Pointwise and Multigroup Neutron and Photon Cross Sections from ENDF/B-IV and -V Evaluated Nuclear Data," Radiation Shielding Information Center documentation for PSR-118, contributed by Los Alamos Scientific Laboratory (March 1979).

20. L. W. Nordheim, "The Theory of Resonance Absorption," Proceedings of Symposia in Applied Mathematics, Vol. XI, p. 58, G. Birkhoff and E. P. Wigner, Eds., American Mathematical Soc. (1961).

21. I. I. Bondarenko, M. N. Nikolaev, L. P. Abagyan, and N. O. Bazazyants, "Group Constants for Nuclear Reactor Calculations," published by Consultants Bureau, New York (1964).

22. "Cross Section Evaluation Working Group Benchmark Specifications," BNL 19302 (ENDF-202) (March 1974).

23. T. C. Engelder, R. H. Clark, M. N. Baldwin, E. J. DeRoche, G. T. Fairburn and J. W. Hallam, "Measurement and Analysis of Uniform Lattices of Slightly Enriched UO_2 Moderated by D_2O-H_2O Mixtures," BAW-1273, Ca-7 (November 1963).

24. C. R. Weisbin, R. D. McKnight, J. D. Hardy, Jr., R. W. Roussin, R. E. Schenter and B. Magurno, "Benchmark Testing of ENDF/B-V," (to be published in 1982).

25. J. K. Fox, L. W. Gilley, R. Gwin and J. T. Thomas, "Critical Parameters of Uranium Solutions in Simple Geometry," Neutron Physics Division Annual Progress Report, ORNL-2609, p. 42 (September 1, 1958).

26. J. T. Thomas, J. K. Fox and D. Callihan, "A Direct Comparison of Some Nuclear Properties of U-233 and U-235," Nucl. Sci. Engr. 1, 20 (1956).

27. D. W. Magnuson, "Measurement and Calculation of the Prompt-Neutron Decay Constant and Effective Buckling as a Function of Size for Homogeneous Uranium Solutions," Neutron Physics Division Annual Progress Report for Period Ending August 1, 1963, ORNL-3499, Vol. 1, p. 57 (October 21, 1963).

28. R. Gwin and D. W. Magnuson, "The Measurement of Eta and Other Nuclear Properties of U^{233} and U^{235} in Critical Aqueous Solutions," Nuc. Sci. Engr. 12, 364 (1962).

29. G. E. Hansen and W. H. Roach, "Six and Sixteen Group Cross Sections for Fast and Intermediate Critical Assemblies," LAMS-2543 (1961).