RADIATION TRANSPORT AND SHIELDING INFORMATION, COMPUTER CODES, AND NUCLEAR DATA
FOR USE IN CTR NEUTRONICS RESEARCH AND DEVELOPMENT*

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Summary

The activities of the Radiation Shielding Information Center (RSIC) of the Oak Ridge National Laboratory are being utilized in support of fusion reactor technology. The major activities of RSIC include the operation of a computer-based information storage and retrieval system, the collection, packaging, and distribution of large computer codes, and the compilation and dissemination of processed and evaluated data libraries, with particular emphasis on neutron and gamma-ray cross-section data. The Center has acquired thirteen years of experience in serving fission reactor, weapons, and accelerator shielding research communities, and the extension of its technical base to fusion reactor research represents a logical progression. RSIC is currently working with fusion reactor researchers and contractors in computer code development to provide tested radiation transport and shielding codes and data library packages. Of significant interest to the CTR community are the 100 energy group neutron and 21 energy group gamma-ray coupled cross-section data package (DLC-37) for neutronics studies, a comprehensive 171 energy group neutron and 36 energy group gamma-ray coupled cross-section data base with retrieval programs, including resonance self-shielding, that are tailored to CTR application, and a data base for the generation of energy-dependent atomic displacement and gas production cross sections and heavy-particle-recoil spectra for estimating radiation damage to CTR structural components. Since 1964, the Center has been involved in the international exchange of information, encouraged and supported by both government and interagency agreements; and to achieve an equally viable and successful program in fusion research, the reciprocal exchange of CTR data and computing technology is encouraged and welcomed.

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1. INTRODUCTION

The Radiation Shielding Information Center (RSIC) [1] functions within the Neutron Physics Division of the Oak Ridge National Laboratory (ORNL), and it has long been engaged in shielding and radiation transport research. RSIC is a technical institute serving since 1963 the international scientific community in research and development concerning the design of shields to provide protection against the radiation that emanates from fission reactors, radioisotopes, nuclear weapons, and space. The Center collects, organizes, evaluates, packages, and disseminates shielding information to anyone whose research requires such information [2-4]. In general, this includes all information concerned with the transport of ionizing radiation and partial coverage of areas of radiation instrumentation and neutron thermalization.

RSIC material is distributed to more than 1500 persons, twenty percent of whom are in countries other than the United States. The shielding communities throughout the world are encouraged to exchange information and data, thereby enabling RSIC to become a more efficient technical institute and give ever expanding service to these communities.

RSIC is currently extending its established activities and expertise in shielding and related studies to the CTR community, particularly to the area of neutronics for fusion reactors and related systems. Some of these activities are summarized here.

2. THE ROLE OF RSIC IN THE CTR COMMUNITY

During the Fusion Reactor Technology International Working Session held in Oak Ridge in 1971, an announcement was made of RSIC as a source of CTR shielding information and data. As a result, by reviewing radiation transport literature and following current computer code development and programs for measuring, evaluating, and compiling cross sections, the scope of RSIC's activities has been extended to include the needs of fusion reactor researchers. Encouraged by CTR contractors, support has been given to the development of data processing codes to meet specific needs for fusion-related nuclear data. Examples include the collaboration with the University of Wisconsin in the development of the MACK computer code [5] for generating neutron energy deposition (kerma) coefficients from evaluated cross-section data available in ENDF format and with the Tokamak Experimental Power Reactor (EPR) neutronics study team through the addition of data to the DLC-37 coupled 100n-21 γ group cross-section library [6,7].

RSIC has a leading role in the development of a comprehensive 171n-36 γ group cross-section data base and retrieval programs, including resonance self-shielding, that are tailored to CTR application. The validation of this data base is being carried out at RSIC as well as other laboratories in the United States.

The interaction of CTR neutronics groups with RSIC has resulted in a flow of information, results, and data which are now being shared among these groups. As always, the Center relies on its user community to share ideas, codes, and data in the advancement of technology.

3. RSIC DATA ACTIVITIES

A large fraction of the activities of RSIC has been involved in disseminating data of various kinds, but particularly neutron and gamma-ray cross-section data. The solution of most radiation transport problems requires the use of large computer codes and their corresponding cross-section libraries, which treat the physics of neutron and gamma-ray interaction and production. The Center is involved in this general area by providing evaluated neutron and gamma-ray cross-section data in standard format, by packaging and distributing computer codes and associated cross-section and specialized data libraries, and by assisting in the compilation of benchmark problem data for testing computational methods, models, and data. Cross-section data that emphasize gamma-ray production and interaction and neutron cross sections in the energy range of interest in shielding are handled by RSIC prior to submission to the ENDF/B Library. For example, 28 cross-section evaluations for the ENDF/B-IV library were processed through RSIC. The Center also maintains and distributes the Defense Nuclear Agency cross-section library, which also serves as a source of evaluated data for ENDF/B. Also, a data library collection (DLC) has been developed which includes not only cross-section libraries but other nuclear data and radiation transport results. These data libraries serve as companions to the RSIC code collection and are in a format suitable for use with the more widely used radiation transport codes (i.e., ANISN, DOT, MORSE, etc.) [8,9,10].

4. DATA FOR CTR NEUTRONICS CALCULATIONS

Two new data libraries and one data package, presently being validated by several CTR contractors and by RSIC staff members, are particularly suited to CTR neutronics and related research. These are the DLC-37/EPR cross-section library [6,7] that was prepared for use in the Tokamak EPR neutronics calculations, the recoil data base, RECOIL [11], and the general purpose CTR Processed Multigroup Cross-Section Library (PMCSL) [12].

The DLC-37/EPR library is a coupled 100 energy group neutron and 21 energy group gamma-ray ANISN-formatted cross-section library for 40 elements of interest to the CTR community.

Selected modules of the AMPX [13] system were used to generate data sets from the latest ENDF/B-IV data. The fine group neutron energy structure used in the library is the GAM-II [14] 99 epithermal and fast groups, plus a thermal group. With the exception of the isotopes of tungsten, all of the data sets were generated for a P_3 order of Legendre expansion. For tungsten, a P_3 expansion of the cross section was obtained. The neutron and photon production cross sections were weighted with a $1/E$ function for $E_n > 5\text{keV}$ and with a Maxwellian distribution peaked at 800°K for $E_n \leq 5\text{keV}$. All resonance nuclides were treated as infinitely dilute. The photon interactions were flat-weighted.

Also included in the library are neutron cross sections for calculating tritium production in ^6Li and ^7Li and tritium and helium production from neutron reactions with ^{10}B and ^{11}B . Neutron and gamma-ray kerma factors are also included for most of the elements. The DLC-37/EPR library has been used exclusively in the neutronics calculations for the Tokamak fusion reactor studies being carried out at ORNL.

The heavy charged-particle recoil data base, RECOIL, and complementary analysis programs have been created to assist thermonuclear researchers in studying, evaluating, and correlating radiation damage effects in different neutron environments. This data base is useful in providing a means for estimating radiation damage in fusion devices, particularly since no experimentally determined neutron spectra are presently available. Most of the elements of interest in radiation damage studies and all neutron reactions of any significance for these elements have been processed, using ENDF/B-IV cross-section data. Gas production and atomic displacement rates in structural materials in fusion reactors are readily estimated with calculated CTR neutron spectra. RECOIL will also provide the heavy charged-particle recoil spectra for those particles produced following neutron collisions. The base may be used for neutrons having energies between thermal and 20 MeV. The group structure for neutrons with energies below 14.91 MeV is the GAM-II 99 group structure, plus a thermal group.

The program for the development, validation, and distribution of the general purpose Processed Multigroup Cross Section Library (PMCSL) is currently being undertaken by RSIC. The Center is coordinating the effort to establish PMCSL based on the needs and recommendations of CTR contractors. The 171n-36γ energy group structure was defined with boundaries that match other widely used group structures. The neutron energy region between thermal and 17.33 MeV was divided into six regions, and different weighting functions were assumed in each region. These include a Maxwellian thermal spectrum, a fusion spectrum, and a D-T fusion neutron spectrum with 1/E slowing-down regions joining these regions. Flat-weighting was used for the gamma-ray energy groups. All of the cross sections are expressed in a P_3 Legendre expansion. The computer code MINX [15] was used to generate the multigroup neutron cross sections that include self-shielding factors and the AMPX system was used to produce multigroup secondary gamma-ray production cross sections, multiplicities, and multigroup photon cross sections. The system is nearly completed and is currently being validated prior to general release.

The materials included in the three libraries are listed in Table I.

Table I. Materials Included and Proposed for Use in the CTR Data Libraries

Material	MAT ^a	DLC-37	RECOIL	PMCSL	Material	MAT ^a	DLC-37	RECOIL	PMCSL
H-1	1269	X		X	Cu	1295	X		X ^b
H-2	1120			X ^c	Zr	1284	X	X	
H-3	1169				Nb-93	1189	X ^d	X	X
He-4	1270	X ^c			Mo	1207	X	X	X
Li-6	1271	X	X ^e	X	Ag-107	1138			
Li-7	1272	X	X ^e	X	Ag-109	1139			
Be-9	1289	X	X ^e	X	Cd	1281			
B-10	1273	X	X ^e	X	Su	7039	X		
B-11	1160	X ^c	X ^e	X ^c	Eu-151	1290			
C-12	1274	X	X	X	Eu-152	1291			
N-14	1275	X	X ^e	X	Eu-153	1292			
O-16	1276	X	X ^e	X	Eu-154	1293			
F	1277	X		X ^b	Ta-181	1285		X	
Na-23	1156	X		X	W-182	1128	X ^c	X	
Mg	1280	X	X	X	W-183	1129	X ^c	X	
Al-27	1193	X	X	X	W-184	1130	X ^c	X	
Si	1194	X	X	X	W-186	1131	X ^c	X	
P	7019 ^f	X			Pb	1288	X	X	X
S	7020 ^f	X			Th-232	1296			
K	1150	X		X	U-233	1260			
Ca	1195	X		X	U-234	1043			X ^c
Ti	1286	X	X		U-235	1261	X		X
V	1196	X	X	X ^b	U-236	1163			X ^c
Cr	1191	X	X	X	U-238	1262	X		X
Mn-55	1197	X	X	X	Pu-238	1050			X ^c
Fe	1192	X	X	X	Pu-239	1264			X
Co-59	1199	X	X		Pu-240	1265			X
Ni	1190	X	X	X	Pu-241	1266			X ^c
Cu-63	1085 ^g				Pu-242	1161			X ^c
Cu-65	1086 ^g				Am-241	1056			X ^c

^aENDF/B-IV data unless otherwise noted.^bNo photon production data - available on ENDF/B-IV but not yet processed.^cNo photon production data - not available on ENDF/B-IV.^dBoth ENDF/B-III and ENDF/B-IV in DLC-37 library.^eIncluded in data base since these are components in many alloys used in CTR devices.^fLivermore Evaluated Data Library.^gENDF/B-III.

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