Activities of the Radiation Shielding Information Center and a Report on Codes/Data for High Energy Radiation Transport

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From the very early days in its history RSIC has been involved with high energy radiation transport. The National Aeronautics and Space Administration was an early sponsor of RSIC until the completion of the Apollo Moon Exploration Program. In addition, the intranuclear cascade work of Bertini at Oak Ridge National Laboratory provided valuable resources which were made available through RSIC. Over the years, RSIC has had interactions with many of the developers of high energy radiation transport computing technology and data libraries and has been able to collect and disseminate this technology. The current status of this technology will be reviewed and prospects for new advancements will be examined.

INTRODUCTION

Technology for radiation transport is available from the Radiation Shielding Information Center (RSIC) at Oak Ridge National Laboratory. Radiation transport practitioners at accelerator facilities have utilized the technology available from RSIC for many years and have contributed technology as well. The relationship is strong and mutually beneficial. RSIC, its relationship with the radiation transport community, and the technology for high energy analyses are reviewed in the following sections.

RADIATION SHIELDING INFORMATION CENTER (RSIC)

RSIC is embedded in the Engineering Physics and Mathematics Division at Oak Ridge National Laboratory. That Division is noted for its role as a leader in the development of radiation transport technology throughout the years. It is very beneficial for RSIC to be located within such an organization so that staff members have close proximity to these major developments and the transfer of such technology is enhanced by a climate of close cooperation.

In practice, RSIC is an information analysis center following the concepts suggested by Alvin Weinberg in 1963 [1]. It is staffed by scientists, engineers, computer specialists, and support personnel. While being physically located at ORNL, it is embedded in the national research and

*Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

development of its sponsors and interacts dynamically with contributors and users. Computing technology in its area of coverage has always been treated as valid technical information subject to critical examination and continuing improvement through usage.

The radiation transport needs of several communities are served by RSIC. It was founded in 1962 by the U. S. Atomic Energy Commission to provide support for its reactor research programs. The Defense Nuclear Agency joined in sponsorship in 1964 and the National Aeronautics and Space Administration (NASA) a little later as the Apollo Program grew. Over the years the scope of RSIC has broadened to include radiation transport from nuclear weapons, radioisotopes, accelerators, fusion reactors, nuclear waste, and both natural and man-made radiation in space. Current sponsors include the U. S. Department of Energy (Nuclear Energy, Fusion, Defense Programs, Environment, Safety and Health, Environmental Restoration and Waste Management), and the Defense Nuclear Agency.

In-depth coverage is provided for many radiation transport topics including:

Atmospheric dispersion and environmental dose

Criticality safety

Radiation production and sources

Radiation protection and shielding

Radiation detectors and measurements

Shield, storage and shipping cask design

Radiation waste management

Radiological safety and assessment

RSIC serves as the focus of radiation transport activities. Staff members answer technical inquiries about radiation transport problems. They package and disseminate pertinent computing technology and appropriate data libraries. Radiation transport literature is reviewed, indexed, and placed in a data base for subsequent search and retrieval upon demand. Bibliographies and review reports are published and seminar-workshops on computing methods and code systems are conducted. All activity is reported to the radiation transport community via a monthly RSIC Newsletter. Special activities, primarily in the area of processed data library generation, are also undertaken by the staff in response to community and sponsor needs.

Valuable technology products are packaged and disseminated by RSIC. The Computer Code Collection (CCC) [2] contains over 600 radiation transport calculational systems. The collection of codes peripheral to the actual transport calculation, the Peripheral Shielding Routines (PSR) [3], contains over 300 entries. The Data Library Collection (DLC) [4], has over 160 packages. The literature data base (SARIS) [5] contains over 19,400 citations. The RSIC Newsletter is mailed to about 2300 registrants from all over the world.

A new user may find that an RSIC staff member will be a collaborator throughout various stages of a project. A problem posed by letter or phone may be discussed for advice on method of solution (a literature search may be performed). The requestor can be provided with appropriate computer codes and data libraries applicable to the task and given guidance on the interpretation of preliminary results. User experience often results in improvements to method or data. These updates to the technology as well as results of the research are often fed back into the RSIC collections.

RSIC also collaborates and exchanges technology with other organizations, both domestic and international. Domestic institutions include the Energy Science and Technology Software Center, the National Nuclear Data Center (BNL), the U. S. Cross Section Evaluation Working Group (CSEWG), Radiation Protection and Shielding Standards (ANS-6), and Mathematics and Computing Standards (ANS-10).

INTERNATIONAL COLLABORATION

International organizations with which RSIC collaborates include the OECD Nuclear Energy Agency Data Bank (NEA DB), the Japanese Nuclear Energy Data Center (NEDAC), and the International Atomic Energy Agency Nuclear Data Section (NDS).

RSIC engages in international information exchange via bilateral and international agency exchange agreements negotiated by its sponsors. Where no agreement exists, RSIC is advised by its financial sponsors through contract monitors or special organizational units established to deal with such matters.

In general, RSIC is authorized to engage in international exchange on a **reciprocal** exchange basis.

HIGH ENERGY RADIATION TRANSPORT

RSIC has a long history of involvement with high energy radiation transport. We were led into this area through our early sponsorship from NASA in the late 1960s. As the successful Apollo moon landing program wound down, all of the major development laboratories placed their software in RSIC. That technology has been somewhat dormant over the intervening years but many have recently requested it because of new activities such as the Strategic Defense Initiative (SDI) and, more recently, the Space Exploration Initiative (SEI).

The development of the intranuclear cascade work by Bertini [6] and others at ORNL at about the same time as the Apollo program was another factor. The related data and computing technology were subsequently placed in RSIC and have seen steady use over the years. The development of the ETRAN code by Berger and Seltzer [7] and its inclusion in RSIC was also significant. There have been many extensions to the electron/photon cascade methodology over the years and complex geometry versions such as ITS [8] are in common use. The contribution of the EGS system by Nelson, Hirayama, and Rogers [9] was also significant, and many others could be cited.

Over the years RSIC has tried, with some success, to keep abreast of the field of high energy radiation transport by encouraging developers to contribute their technology. To learn what is available, an RSIC user will be given a "Capsule Review" [10], which provides a brief summary of all RSIC "Packages". It contains an alphabetic index by package name and has a separate section for CCCs, PSRs, and DLCs. Each section has a KEYWORD index to help a user select a package of interest. KEYWORDS which are likely to be most relevant for finding CCCs suitable for high energy radiation transport are listed in Table 1. A selected list from the CCC is given in Table 2. These have been grouped into somewhat arbitrary categories of Fusion; Bremsstrahlung, range, and stopping power; Heavy ions, beam transport; Electron-Photon cascade; Intranuclear cascade; and Space Radiation.

Table 1. Capsule Review Keywords to Identify CCCs for High Energy Radiation Transport

BEAM TRANSPORT
BREMSSTRAHLUNG
CHARGED PARTICLES
COSMIC RAYS
ELECTROMAGNETIC CASCADE
ELECTRON TRANSPORT
ENERGY DEPOSITION
EXTRANUCLEAR CASCADE
CTR
HADRON
HEAVY IONS
HIGH ENERGY
INTRANUCLEAR CASCADE
MESON
NUCLEAR MODELS
NUCLEON
PROTON
RADIATION DAMAGE
SPACE RADIATION

KEYWORDS which are likely to be most relevant in identifying PSRs and DLCs for high energy radiation transport are listed in Table 3. Selected lists from the PSR and DLC collections are shown in Table 4. These are grouped into categories Intranuclear cascade; Charged particle; and Neutron, photon multigroup cross sections (for DLCs); and Atomic collisions, damage, energy loss, dose; and Nuclear model (for PSRs).

Tables 5 and 6 provide a summary of the packages most often disseminated in the past three years to give the user a feel for the popularity and relative usage of these codes and data libraries. Table 7 summarizes the attributes of the various packages in terms of Application, Particle type, Energy range, Geometry, and Method. The contributors of the various packages are listed in Table A1.

Table 2. Packages from the RSIC Computer Code Collection for High Energy Radiation Transport

Fusion	Bremsstrahlung, Range, Stopping Power	Heavy Ions, Beam Transport
CCC-339/AKTIV	CCC-31/BREMRAD	CCC-244/TRANSPORT
CCC-349/MEDUSA- PIJ	CCC-50/LRSPC	CCC-249/HIC-1
CCC-410/THIDA-2	CCC-201/STRAGL	CCC-275/E-DEP-1
CCC-505/MEDUSA-IB	CCC-228/SPAR	CCC-537/TRIPOS
Electron-Photon Cascade	**Intranuclear Cascade**	**Space Radiation**
CCC-107/ETRAN	CCC-156/MECC-7	CCC-116/TRECO
CCC-117/BETA II	CCC-160/PICA	CCC-118/SIGMA II
CCC-119/ELBA	CCC-161/NMTC	CCC-148/SPARES
CCC-155/ELTRAN	CCC-178/HETC	CCC-157/MEVDP
CCC-176/CASCADE	CCC-207/FLUKA-TRANKA	CCC-205/TRAPP
CCC-197/USRHYD	CCC-265/CASIM	CCC-329/MODEL
CCC-331/EGS4	CCC-443/REAC	CCC-358/SOFIP
CCC-361/SANDYL	CCC-496/HETC-KFA	CCC-379/SHIELDOSE
CCC-430/EDMULT 2.1		
CCC-467/ITS		
CCC-544/CEPXS/ONELD		

Table 3. Capsule Review Keywords to Identify PSRs and DLCs for High Energy Radiation Transport

Keywords found in PSRs
CHARGED PARTICLE CROSS SECTION PROCESSING
DISPLACEMENT CROSS SECTIONS
KERMA
NUCLEAR MODELS
PROTON DOSE
RANGE, CHARGED PARTICLE
RADIATION DAMAGE
Keywords found in DLCs
CHARGED PARTICLE CROSS SECTIONS
CTR NEUTRONICS CROSS SECTIONS
DAMAGE CROSS SECTIONS
INTRANUCLEAR CASCADE
KERMA FACTORS

SUMMARY

The role of RSIC in supplying high energy radiation transport depends on the willingness of the user community to share the developments made in the field. There are several code systems that we are seeking at the present time including the latest versions of HETC/CALOR/MORSE from ORNL, REAC3 from HEDL, LAHET from LANL, FLUNEV from DESY, GEANT and FLUKA from CERN, updates for ITS and EGS from SNL and SLAC, respectively, and high energy cross section libraries being developed at various locations. RSIC users can help in this process by alerting us to developments which are not in RSIC. A section for doing so is provided on the RSIC Registration Form.

Table 4. Packages from the RSIC Peripheral Shielding Routine and Data Library Collection Related to High Energy Radiation Transport

Intranuclear Cascade, Charged Particle	Neutron, Photon Multigroup Cross Sections	Atomic Collisions, Damage, Energy Loss, Dose	Nuclear Model
DLC-1/LEP	DLC-55/RECOIL	PSR-47/ENLOSS	PSR-3/ELIESE
DLC-3/MEP	DLC-58/HELLO	PSR-195/REPC	PSR-10/EVAP
DLC-22/FLEP	DLC-84/MENSLIB	PSR-137/MARLOWE	PSR-125/GNASH
DLC-106/ECPL	DLC-87/HILO	PSR-257/ACAT	PSR-152/HAUSER*5
	DLC-119/HILO86	PSR-261/MICAP	PSR-158/SAMMY
	DLC-128/LAHIMACK	PSR-263/SPECTER-ANL	PSR-166/PREANG
			PSR-219/ERINNI
			PSR-224/PREM
			PSR-226/PRECO-D2
			PSR-227/ECIS-88
			PSR-235/DWUCK
			PSR-298/TNG1
			PSR-302/COMNUC3B

Table 5. High Energy Radiation Transport Packages from the RSIC CCC Collection That Were Sent Most Often in Recent Years

Fusion	Bremsstrahlung, Range, Stopping Power	Heavy Ions, Beam Transport
CCC-410/THIDA-2 (4)	CCC-228/SPAR (9)	CCC-275/E-DEP-1 (7)
CCC-339/AKTIV (2)	CCC-31/BREMRAD	CCC-537/TRIPOS (6)
CCC-505/MEDUSA-IB	CCC-50/LRSPC	CCC-244/TRANSPORT
	CCC-201/STRAGL	
Electron-Photon Cascade	**Intranuclear Cascade**	**Space Radiation**
CCC-467/ITS (153)	CCC-178/HETC (20)	CCC-379/SHIELDOSE (21)
CCC-331/EGS4 (37)	CCC-160/PICA (12)	CCC-157/MEVDP (4)
CCC-544/CEPXS/ONELD (18)	CCC-496/HETC-KFA (11)	CCC-329/MODEL
CCC-361/SANDYL	CCC-443/REAC	CCC-353/SOFIP
CCC-107/ETRAN	CCC-156/MECC-7	CCC-116/TRECO
CCC-117/BETA II	CCC-161/NMTC	CCC-118/SIGMA II
CCC-176/CASCADE	CCC-265/CASIM	CCC-148/SPARES
CCC-430/EDMULT 2.1		

Table 6. High Energy Radiation Transport Packages from the RSIC PSR and DLC Collections That Were Sent Most Often in Recent Years

Intranuclear Cascade, Charged Particle	Neutron, Photon Multigroup Cross Sections	Atomic Collisions, Damage, Energy Loss, Dose	Nuclear Model
DLC-106/ECPL (2)	DLC-119/HILO86 (8)	PSR-137/MARLOWE (21)	PSR-125/GNASH (21)
	DLC-128/LAHIMACK (6)	PSR-263/SPECTER-ANL(7)	PSR-10/EVAP (4)
	DLC-55/RECOIL	PSR-261/MICAP (4)	PSR-3/ELIESE (3)
	DLC-58/HELLO	PSR-257/ACAT	PSR-152/HAUSER*5
	DLC-87/HILO	PSR-47/ENLOSS	PSR-226/PRECO-D2
			PSR-235/DWUCK
			PSR-227/ECIS-88

Table 7. Attributes of RSIC Code Packages and Data Libraries in Terms of Application, Particle type, Energy range, Geometry, and Method (page 7)

Code name	Particle types	Energy range	Geometry	Method
FUSION				
CCC-339/AKTIV	Neutrons, photons	≤ 20 MeV	Aribitrary	Radioactive buildup and decay
CCC-349/MEDUSA-PIJ	Laser	Fusion	Spherical	1-D Lagrangian hydrodynamics and collision probability
CCC-410/THIDA-2	Neutrons, photons	≤ 20 MeV	Complex	Matrix exponential, discrete ordinates, Monte Carlo
CCC-505/MEDUSA-IB	Ion beam	Fusion	Spherical	1-D Lagrangian hydrodynamics and collision probability
BREMSSTRAHLUNG, RANGE, STOPPING POWER				
CCC-31/BREMRAD	Electron, photon	≤ 2 MeV		Bethe-Heitler (external), Knipp-Uhlenbeck (internal)
CCC-50/LRSPC	Protons	1 MeV – 100 GeV		Bethe-Bloch
CCC-201/STRAGL	Heavier than electrons	None		
CCC-228/SPAR	Many	< Few hundred GeV		
HEAVY IONS, BEAM TRANSPORT				
CCC-244/TRANSPORT		GeV range	Beam	Matrix multiplication
CCC-249/HIC-1	Heavy ions	≥50 MeV/nucleon		Monte Carlo
CCC-275/E-DEP-1 (Version P5.00)	Heavy ions			
CCC-537/TRIPOS	Ions	< 10 keV	Multilayer	Monte Carlo

Table 7. Attributes of RSIC Code Packages and Data Libraries in Terms of Application, Particle type, Energy range, Geometry, and Method (page 8)

Code name	Particle types	Energy range	Geometry	Method
ELECTRON-PHOTON CASCADE				
CCC-107/ETRAN	Electron, photon	10 MeV	Plane slabs	Monte Carlo
CCC-117/BETA-II	Electron, bremsstrahlung		Complex	Monte Carlo
CCC-119/ELBA	Electron, bremsstrahlung	< 10 MeV	Plane slab	Straight ahead
CCC-155/ELTRAN	Electron	K shell to few MeV	Multilayer slab	Quasi-Monte Carlo
CCC-176/CASCADE	Electrons, photons	1 GeV	Slab	Monte Carlo
CCC-197/USRHYD	Electron, X-ray	keV range	Multilayer slab	Monte Carlo
CCC-331/EGS4	Electron, photon	< few thousand GeV	Complex	Monte Carlo
CCC-361/SANDYL	Electron, photon	1 keV – 1000 MeV	Complex	Monte Carlo
CCC-430/EDMULT 2.1	Electrons	0.1 – 20 MeV	Layered slabs	Semiempirical
CCC-467/ITS	Electron, photon	1 keV – 1 GeV	Complex	Monte Carlo
CCC-544/CEPXS/ONELD	Electron, photon	1 keV – 100 MeV	One-Dimension	Discrete ordinates, linear discontinuous spatial differencing
INTRANUCLEAR CASCADE				
CCC-156/MECC-7	Neutron, proton, pion	100 – 2,500 MeV		Intranuclear cascade
CCC-160/PICA	Photon	30 – 400 MeV		Intranuclear cascade
CCC-161/NMTC	Nucleons, muons, and pions	<3.56 GeV; <2.5 GeV	Complex	Monte Carlo
CCC-178/HETC	Nucleons, mesons	≤3 GeV	Complex	Monte Carlo
CCC-207/FLUKA-TRANKA	Nucleons, mesons	E > 50 MeV	Cylindrical	Monte Carlo

Table 7. Attributes of RSIC Code Packages and Data Libraries in Terms of Application, Particle type, Energy range, Geometry, and Method (page 9)

Code name	Particle types	Energy range	Geometry	Method
CCC-265/CASIM	Neutron, proton, pion	20–1000 GeV/c	Complex	Monte Carlo, intranuclear cascade
CCC-443/REAC	Neutron, charged	≤ 40 MeV	Arbitrary	Simplified transmutation and decay
CCC-496/HETC-KFA	Nucleons, mesons, light ions	≤ 3 GeV	Complex	Monte Carlo
SPACE RADIATION				
CCC-116/TRECO	Van Allen	<600 p, < 7 MeV e	Orbital	
CCC-118/SIGMA II	Various	< 10 MeV	complex	Numerical integration of dose kernels
CCC-148/SPARES	Many	< 10 MeV	Multilayer	Monte Carlo, straight ahead
CCC-157/MEVDP	Various	Range given by empirical function of E	Complex	Path length areal densities
CCC-205/TRAPP	Alpha, proton	≤ 3 GeV	Spherical shell	Straight line
CCC-329/MODEL	Electrons, protons	Van Allen		
CCC-358/SOFIP	Proton, electron	Van Allen		
CCC-379/SHIELDOSE	Proton, electron	2–5000 MeV p, 0.02–20 MeV e.	One dimensional	Approximate, based on precalculated results
INTRANUCLEAR CASCADE, CHARGED PARTICLES				
DLC-1/LEP	Nucleons, mesons	25–400 MeV		Analysis of LECC history tapes
DLC-3/MEP	Nucleons, mesons	0.5 to 3 GeV		Analysis of MECC history tapes

Table 7. Attributes of RSIC Code Packages and Data Libraries in Terms of Application, Particle type, Energy range, Geometry, and Method (page 10)

Code name	Particle types	Energy range	Geometry	Method
DLC-22/FLEP Based on DLC-1, -3	Nucleons, mesons	25–400 MeV		NCDATA interpolates FLEP for intermediate energies and targets
DLC-106/ECPL82	10 types	< 20 MeV		
NEUTRON, PHOTON MULTIGROUP CROSS SECTIONS				
DLC-55/RECOIL	Neutrons	< 20 MeV		
DLC-58/HELLO	Neutrons, photons	≤60 MeV		Multigroup, discrete ordinates format, P_5
DLC-84/MENSLIB	Neutron	≤ 60 MeV		Multigroup, discrete ordinates format, P_5
DLC-87/HILO	Neutrons, photons	≤ 400 MeV		Multigroup, discrete ordinates format, P_5
DLC-119/HILO86	Neutron, photon	< 400 MeV		Multigroup, discrete ordinates format, P_5
DLC-128/LAHIMACK	Neutron, photon	< 800 MeV		Multigroup, discrete ordinates format, P_3
ATOMIC COLLISIONS, DAMAGE, ENERGY LOSS, DOSE				
PSR-47/ENLOSS	Many			Bethe equation
PSR-195/REPC	Protons		Convex	Buildup factor
PSR-137/MARLOWE	Many			Binary collision approximation
PSR-257/ACAT	Many			Binary collision approximation
PSR-261/MICAP	Neutron, photon	< 20 MeV	Complex	Monte Carlo

Table 7. Attributes of RSIC Code Packages and Data Libraries in Terms of Application, Particle type, Energy range, Geometry, and Method (page 11)

Code name	Particle types	Energy range	Geometry	Method
PSR-263/SPECTER-ANL	Neutron			Damage functions based on folding input spectra
NUCLEAR MODEL				
PSR-3/ELIESE-3	Neutrons, protons, alpha	< 40 MeV		Optical model, Hauser-Feshbach
PSR-10/EVAP-4	Many			Weisskopf
PSR-125/GNASH	Many	< 40 MeV		Hauser-Feshbach with pre-equilibrium correction
PSR-152/HAUSER	Many	< 60 MeV		Hauser-Fechbach, pre-equilibrium
PSR-158/SAMMY	Neutron			Fits based on Bayes' Theorem
PSR-166/PREANG	Many	10−50 MeV		Exciton model
PSR-219/ERINNI	Many			Optical model
PSR-224/PREM	Many			
PSR-226/PRECO-D2	Many	< 300 MeV		Exciton model
PSR-227/ECIS-88	Many			
PSR-235/DWUCK	Many	< 100 MeV		Distorted wave born approximation, coupled channel

ACKNOWLEDGEMENT

The author is grateful to Dr. T. Gabriel of ORNL, for inviting me to participate.

The efforts of all RSIC staff members in helping me prepare this paper are appreciated, in particular Alice Rice and Sheila Taylor for their efforts in preparing the manuscript and presentation materials.

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