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A Cable SGEMP Tutorial:
Running CEPXS, CEPTRE and EMPHASIS/CABANA to Evaluate the Electrical Response of a Cable

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Abstract

This tutorial is aimed at guiding a user through the process of performing a cable SGEMP simulation. The tutorial starts with processing a differential photon spectrum obtained from a Monte Carlo code such as ITS into a discrete (multi-group) spectrum used in CEPXS and CEPTRE. Guidance is given in the creation of a finite element mesh of the cable geometry. The set-up of a CEPTRE simulation is detailed. Users are instructed in evaluating the quality of the CEPTRE radiation transport results. The post-processing of CEPTRE results using Exostrip is detailed. And finally, an EMPHASIS/CABANA simulation is detailed including the interpretation of the output.

Acknowledgment

The authors would like to acknowledge the valuable discussions in developing this document with Wesley Fan and Clif Drumm. We also would like to acknowledge the valuable contributions of the CEPTRE project manager, Len Lorence, and the EMPHASIS project manager, Mark Kiefer

Contents

Acknowledgment **4**

Contents **5**

List of Figures **7**

List of Tables **9**

1 Introduction **11**

2 Overview of Cable SGEMP Simulation Process **13**

3 Generating the Radiation Transport Cross-Section Data **17**
3.1 What is a Cross-Section? 17
3.2 Converting a Differential Spectra to a Multi-Group Spectra 18
3.2.1 To Use Differential Spectra Energy Bins as Energy Groups 21
3.2.2 To Use Fewer Energy Groups than Energy Bins 24
3.3 Running CEPXS 29
User Exercise: Set-Up CEPXS Input and CEPTRE Source 31

4 Creating a Finite Element Mesh of the Cable **35**
4.1 Things to Remember During Mesh Generation 36

5 Creating a CEPTRE Input File **39**
Step 1: Add QA Comments 41
Step 2: Add Number of Energy Groups, Materials and Particle Types 42
Step 3: Add Solver Options 43
Step 4: Specify Quadrature and Legendre Order 44
Step 5: Add External Source Description 45
Step 6: Request CABANA Input 47
Step 7: Assign Materials to Element Blocks 48
Step 8: Add Execution Control Keywords 49
Step 9: Add Output Control Keywords 50
Step 10: Add Aztec Solver Options 51
5.1 Complete CEPTRE Input File 52
5.2 Running CEPTRE 54
User Exercise: Set-Up CEPTRE Input File 57

6 Set-Up An EXOSTRIP Input File **63**
User Exercise: Set-Up EXOSTRIP Input File 66

7 Creating a CABANA Input File **69**
Step 1: Add QA Comments . . . 71
Step 2: Add Time and Time History Keywords . . . 72
Step 3: Add SPICE Control Keywords . . . 73
Step 4: Add Cable Section Keywords . . . 74
Step 5: Load CEPTRE Data . . . 75
Step 6: Add Cable Topology . . . 76
Step 7: Add Framework Related Keywords . . . 77
Step 8: Define the Material Model . . . 78
Step 9: Add Execution and Output Control Keywords . . . 79
Step 10: Add Linear Solver Keywords . . . 80
7.1 Complete CABANA Input File . . . 81
7.2 Running CABANA . . . 83
User Exercise: Set-Up CABANA Input File . . . 85

8 Summary **89**

9 Solutions to User Exercises **91**
Set-Up CEPXS Input and CEPTRE Source . . . 91
Set-Up CEPTRE Input File . . . 94
Set-Up EXOSTRIP Input File . . . 97
Set-Up CABANA Input File . . . 98

References **101**

A Electronic Files Distributed with Tutorial **103**

B CEPXS Example 1: aljac31.cepinp **105**

List of Figures

1.1 Direct-Drive Component of Cable SGEMP Simulations 11
2.1 Cable SGEMP Simulation Process 13
2.2 Simple Coaxial Cable 15
3.1 A Differential Bremsstrahlung Spectra 18
3.2 CEPXS INput Using 32 Group Normalized Spectra Energy Bins 22
3.3 Example of External Surface Source Description for CEPTRE 24
3.4 Collapse 32 Energy Group Input Spectra to 16 Groups 25
3.5 Example of 32 Group Spectra Reduced to 16 Groups 27
3.6 CEPXS Input File for 16 Photon Energy Groups 28
3.7 Output to Screen from `runCepxs` script 29
4.1 Representing a Coaxial Cable in Finite Element Model 35
4.2 Finite Element Mesh of Simple Coaxial Cable 37
4.3 Mesh Refinement at Al Shield/Teflon Dielectric Interface 38
4.4 Mesh Refinement at Teflon Dielectric/Center Conductor Interface 38
5.1 Geometry Model for Simple Coaxial Cable 39
5.2 Add QA Comments 41
5.3 Add Number of Energy Groups, Materials and Particle Types 42
5.4 Add Solver Options 43
5.5 Specify Quadrature and Legendre Order 44
5.6 Add External Source Description 45
5.7 Contens of `aljac31g.source` File 46
5.8 Request CABANA Input 47
5.9 Assign CEPXS Materials to Element Blocks 48
5.10 Add Execution Control Keywords 49
5.11 Add Output Control Keywords 50
5.12 Add Aztec Solver Options 51
5.13 Brief Synopsis of Output to Screen During CEPTRE Run 55
5.14 Example of CEPTRE Calculation Summary 56
6.1 Exostrip Input for Simple Coaxial Cable 63
6.2 Example of EXOSTRIP Output to Screen 65
7.1 Cable Geometry Model for CABANA 70
7.2 Add QA Comments 71
7.3 Add Time and Time History Keywords 72
7.4 Add SPICE Control Keywords 73
7.5 Add Cable Section Keywords 74
7.6 Load CEPTRE Data 75
7.7 Add Cable Topology (Boundary Conditions) 76
7.8 Add Nevada Framework Related Keywords 77
7.9 Define the Material Model 78
7.10 Add Execution and Output Control Keywords 79
7.11 Add Linear Solver Keywords 80
7.12 Brief Synopsis of Output to Screen During CABANA Run 84

B.13 CEPXS Photon Group Structure for 31 Group Input 106
B.14 CEPXS Electron Energy Group Structure 107

List of Tables

1 Steps In a Cable SGEMP Simulation 14
2 32 Energy Group Differential Bremsstrahlung Spectra 19
3 32 Group Photon Spectra Normalized to 1.0 for CEPTRE 23
4 32 Group Photon Spectra Normalized to 1.0 for CEPTRE 26
5 Minimum Mesh Sizes at Conductor / Dielectric Interfaces 36

1 Introduction

Strategic missile weapon systems are required to survive the radiation environment produced by nuclear detonations. This implies that the system must survive an incident x-ray source that will cause photo/Compton-emission of electrons from material surfaces and the deposition of charge and energy within system materials. These currents and charges result in the generation of **e**lectro**m**agnetic (EM) fields producing electrical currents on cable shields and on the conductors within cables, a phenomenon referred to as cable **S**ystem **G**enerated **E**lectro**m**agnetic **P**ulse (SGEMP) or cable SGEMP. The incident x-rays create EM fields in cables by two mechanisms:

1. Electron displacement within the dielectric, subsequently inducing current within nearby conductor regions.
2. Knock-on charge generated by photon-induced electrons created near the conductor/dielectric interface and transported into the dielectric.

SGEMP is observed as the EM fields drive charge off/on conductors and deposit charge and induce conductivity in dielectric materials within the outer cable shield which results in potentially large transient currents being induced on internal cable conductors. The radiation effects community also refers to Cable SGEMP as Direct Charge Injection, which is depicted in Figure 1.1.

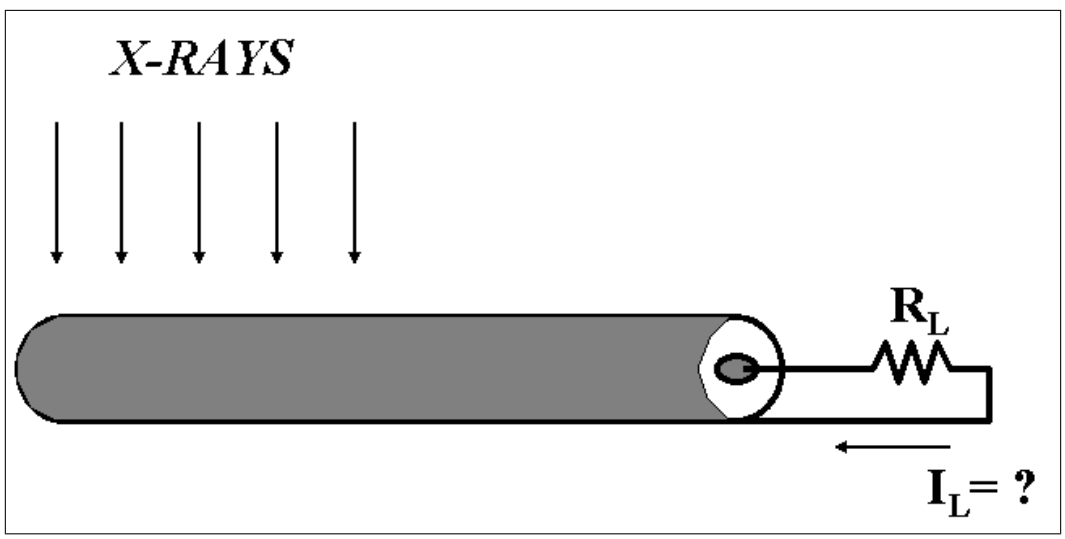


Figure 1.1: Direct-Drive Component of Cable SGEMP Simulations

Analyzing the electrical response of a cable consists of modeling two distinct types of physics:

1. Radiation transport through the cable
2. Quasi-electrostatic and circuit analysis

The computational capability developed at Sandia National Laboratories for cable SGEMP simulations consists of the two loosely coupled codes:

- CEPTRE (**C**oupled **E**lectron-**P**hoton **T**ransport for **R**adiation **E**ffects) for radiation transport
- EMPHASIS/CABANA (**CAB**le **ANA**lysis) for electrical response

Specifically, CEPTRE provides charge and energy deposition profiles along with the net electron current off the conductors, or knock-on charge, to the electrical response simulation code, CABANA. The electrical or SGEMP response of the cable is the sum of the knock-on charge calculated by CEPTRE and the induced charge determined by CABANA. Another desired result of the cable SGEMP simulation is the current delivered to the cable load(s) in Amps. Analysts can also request additional results from CABANA including potential, electric-field, charge-density and conductivity[1].

How to Use This Document

This document is intended to provide an introduction to the cable SGEMP simulation process to the novice analyst. Analysts with extensive experience with cable SGEMP calculations might find portions of this document too basic to be useful, but it should provide guidance in setting up the simulation that is useful to all. The tutorial will use a simple coaxial cable through out the document to provide the analysts with guidance through the process. The accompanying CD provides electronic versions of several files which readers should find useful (see Appendix A for a list of contents). Complete inputs for the simple coaxial cable are provided along with base outputs. A finite element mesh of a coaxial cable is provided that should yield good radiation transport results and help users as they generate their own finite element meshes.
As you go through this tutorial, have the following documents nearby for reference:

- **CEPXS Users Manual**[5] and keywords guide provided with distribution (keyCEPXS.pdf)
- **CEPTRE Version 1.1 Users Manual[3]**
- **CEPTRE PhysicsGuide**[2]
- **EMPHASIS/Nevada CABANA User Guide Version 1.1**[1]

All of these documents should have been provided with your distribution of the SGEMP package containing the codes: CEPXS, CEPTRE and EMPHASIS/CABANA.

2 Overview of Cable SGEMP Simulation Process

In actuality, performing a cable SGEMP simulation involves a handful of steps as depicted in Figure 2.1. This document will guide the analyst through these steps which Table 1 describes in more detail.

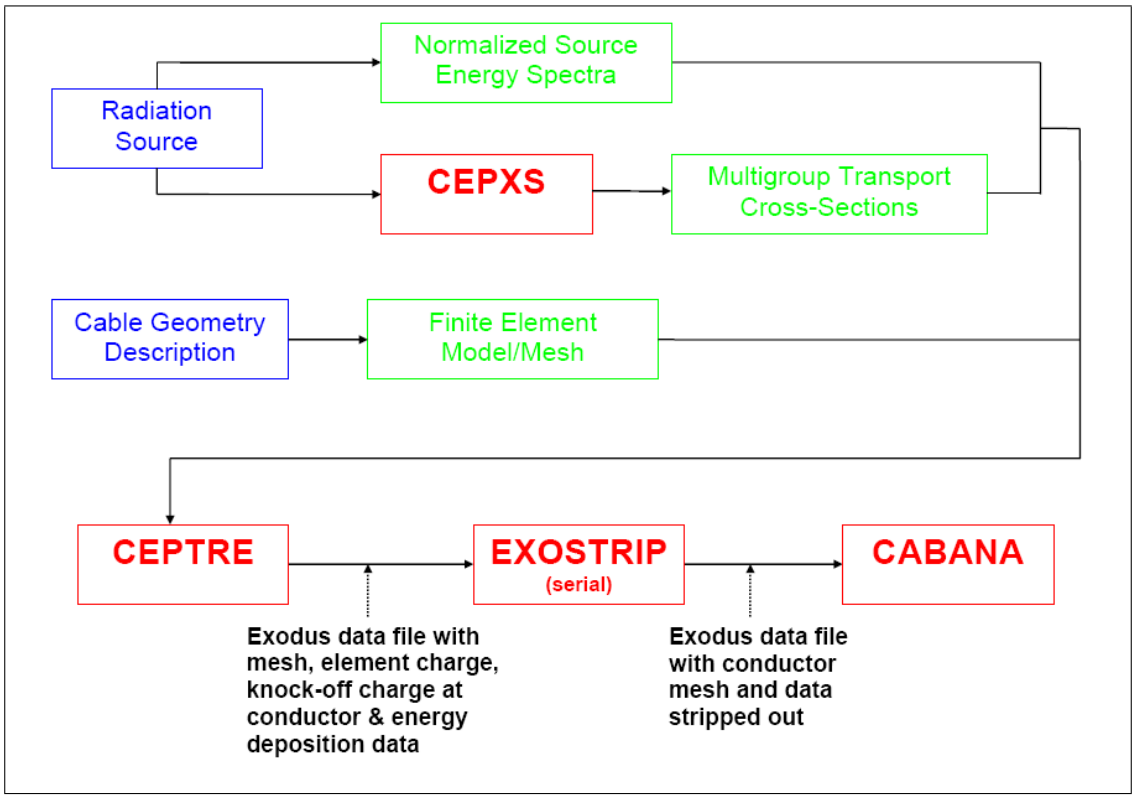


Figure 2.1: Cable SGEMP Simulation Process

The first step in the simulation process is setting up a discrete or multi-group energy spectra for the photon source. The source spectrum may be provided by measurements or Monte Carlo calculations, and may be given in a discrete or multi-group forms. Furthermore, this spectrum has to be converted to a multi-group structure suitable for both CEPXS and CEPTRE. The tutorial will show the analyst how to generate an input file for CEPXS, converting a differential spectra into a multi-group spectra, to obtain cross-section data for CEPTRE. Next, the tutorial will provide guidance for producing a finite element model of the cable geometry. The actual generation of the mesh using software such as CUBIT or ICEM is beyond the scope of this tutorial. The radiation transport simulation will then be detailed as analysts learn to set-up the input files for CEPTRE and run the radiation transport portion of the cable SGEMP simulation. The tutorial will then help the user set-up an EXOSTRIP input file to post-process the CEPTRE results before they are handed-off to EMPHASIS/CABANA. Finally, the reader will be guided in setting-up a CABANA simulation to yield the electrical response of the cable.

Table 1: Steps In a Cable SGEMP Simulation

Step	Description	Codes
1.	Generate multi-group cross-sections capturing incident photon source energy spectra for radiation transport.	CEPXS
2.	Generate a Finite Element model of the Cable geometry using QUAD8 elements.	CUBIT, ICEM
3.	Perform radiation transport simulation to determine charge and energy deposited in the dielectric layers of the cable and the net current from each of cable's internal conductors.	CEPTRE
4.	Post-process CEPTRE output using EXOSTRIP to remove conductor layers from results file.	EXOSTRIP
5.	Set-up the quasi-electrostatic and circuit analysis model and calculate the electrical response of the cable.	CABANA

To begin a cable SGEMP simulation the analyst starts with an incident photon source description, the cable geometry, and a quasi-electrostatic and circuit model to be analyzed by CABANA. The simple two-dimensional coaxial cable presented in Figure 2.2 provides the cable geometry used in this tutorial. This figure also depicts a simplified representation of a photon source incident at the top of the cable.

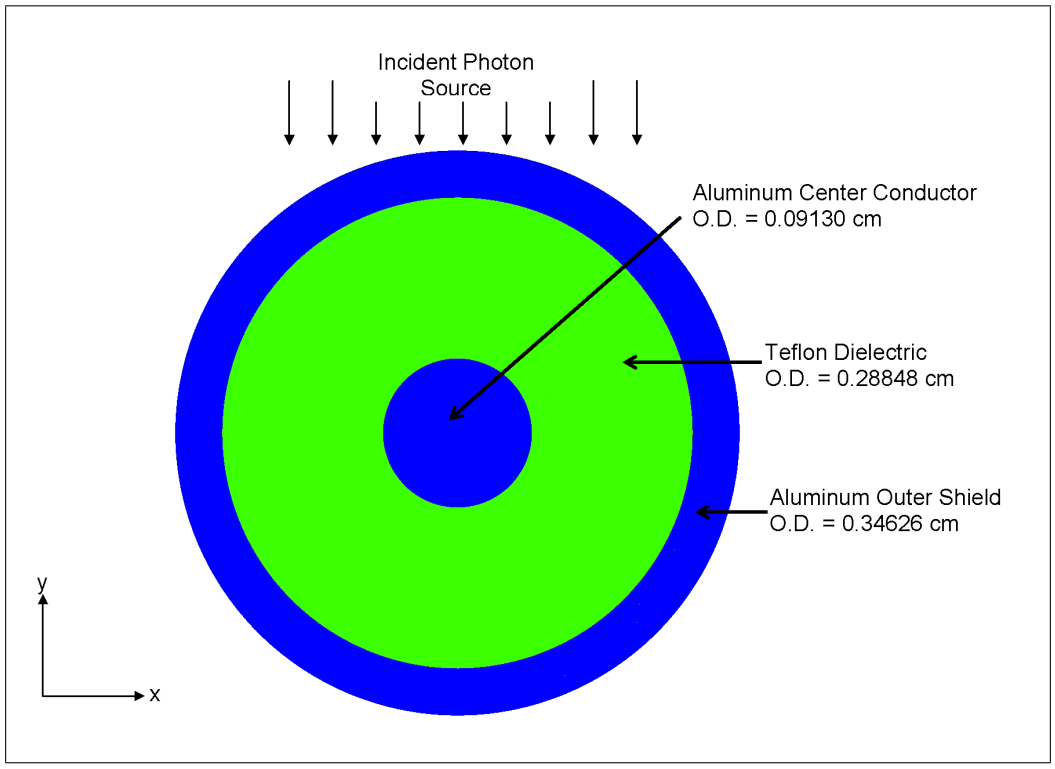


Figure 2.2: Simple Coaxial Cable

3 Generating the Radiation Transport Cross-Section Data

The first step is to generate the cross-section data for the radiation transport simulation. Essentially, the analyst is modeling the incident radiation source as a multi-group energy spectra normalized to unity. We start with the cross-section data, because analysts can use this to guide the finite element mesh generation and refinement at material interfaces.

3.1 What is a Cross-Section?

A cross-section is the probability of an electron or photon undergoing a certain type of interaction per unit path length of travel (cm^{-1}). Interaction cross-sections depend on both the particle energy and the material the particle is traversing. These cross-sections are essentially the method used to incorporate the "real physics" of electron and photon interactions in radiation transport codes. For cable SGEMP simulations employing CEPTRE, the cross-sections are generated using the CEPXS [5] code which is distributed as part of the code package.
CEPXS generates multi-group, Legendre coupled-electron photon cross-sections at energies ranging from 100 MeV to 1 keV[4]. CEPXS generates the following interaction and production cross-sections for electrons:

- Elastic scattering
- Inelastic collisional scattering
- Inelastic radiative scattering
- "Knock-on" electron production
- Radiative emission
- K-Shell impact ionization and relaxation

Photon interactions cross-sections generated by CEPXS include:

- Compton scattering and electron production
- Photoelectric absorption
- Photoelectron production
- Pair production

CEPTRE employs a multi-group approximation to treat the energy dependence of particle transport. The multi-group energy structure must be carefully selected to represent the source spectrum and the response function, and to optimize computational efficiency.

3.2 Converting a Differential Spectra to a Multi-Group Spectra

Throughout this section we will refer to the differential bremsstrahlung spectra depicted in Figure 3.1 with a peak energy of 164 keV. The actual spectra data in Photons/bin is presented in Table 2.

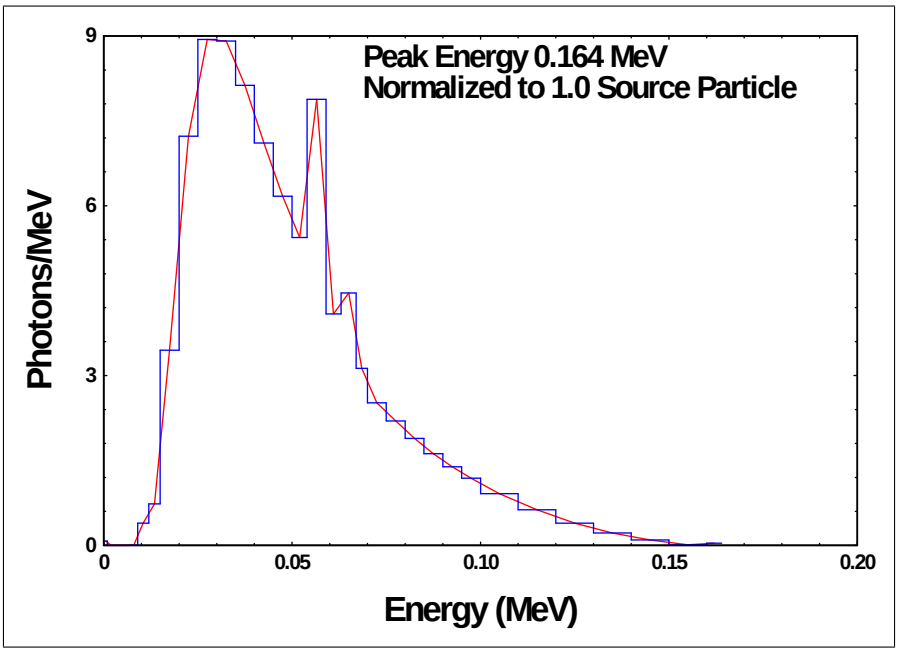


Figure 3.1: A Differential Bremsstrahlung Spectra

The differential photon spectra a user starts with is usually presented as one of the following:

1. The particle fluence, Φ, per unit energy.
2. The particle fluence, Φ, per energy bin.
3. The particle intensity, $I = \Phi \cdot E$, per unit energy.
4. The particle intensity, $I = \Phi \cdot E$, per bin.

Typically, to manipulate the differential spectra users should start with the spectra in terms of particle fluence per bin which is simply the number of photons in each bin. To convert the differential data from particle fluence per unit energy, Φ/MeV, to particle fluence per bin, Φ, simply multiply the particle fluence by the energy width of the bin as follows:

$$\begin{aligned} To\ Particle\ Fluence\ Per\ Bin \quad &: \\ \Phi\, photons \quad &= \left(\frac{\Phi}{MeV}\right)\frac{\Delta E\ MeV}{bin} \end{aligned} \tag{1}$$

Table 2: 32 Energy Group Differential Bremsstrahlung Spectra

Energy Bin	Upper Energy (MeV)	Lower Energy (MeV)	Photons/Bin
1	0.164	0.160	1.5560E-04
2	0.160	0.150	1.0800E-04
3	0.150	0.140	9.7200E-04
4	0.140	0.130	2.1900E-03
5	0.130	0.120	3.9500E-03
6	0.120	0.110	6.2900E-03
7	0.110	0.100	9.1500E-03
8	0.100	0.095	5.9500E-03
9	0.095	0.090	6.9500E-03
10	0.090	0.085	8.1000E-03
11	0.085	0.080	9.4500E-03
12	0.080	0.075	1.1000E-02
13	0.075	0.070	1.2600E-02
14	0.070	0.067	9.3900E-03
15	0.067	0.063	1.7840E-02
16	0.063	0.059	1.6360E-02
17	0.059	0.054	3.9400E-02
18	0.054	0.050	2.1760E-02
19	0.050	0.045	3.0850E-02
20	0.045	0.040	3.5550E-02
21	0.040	0.035	4.0650E-02
22	0.035	0.030	4.4550E-02
23	0.030	0.025	4.4700E-02
24	0.025	0.020	3.6150E-02
25	0.020	0.015	1.7250E-02
26	0.015	0.012	2.2020E-03
27	0.012	0.009	1.1790E-03
28	0.009	0.007	4.5000E-06
29	0.007	0.005	8.0800E-11
30	0.005	0.003	1.2720E-12
31	0.003	0.001	4.0800E-14
32	0.001	0.0	7.6400E-05

where

$$\begin{aligned} Energy\ Width \quad &: \\ \Delta E &= E_{upper} - E_{lower}\ MeV \end{aligned} \tag{2}$$

Example 1 *Given an energy bin with* $E_{upper} = 0.164 MeV$ *and* $E_{lower} = 0.160 MeV$ *with* $\Phi = 3.8900E - 02$ *photons per MeV, calculate the number of photons per bin.*

Solution 1

$$\begin{aligned} \Delta E &= (E_{upper} - E_{lower}) = 0.004 \quad MeV \\ \Phi &= \left(\frac{\Phi}{MeV}\right)\left(\frac{\Delta E}{bin}\right) = (3.8900E - 02) \times 0.004 = 1.5560E - 04 \quad photons \end{aligned}$$

If the differential spectra data is presented as particle fluence per bin, it can easily be converted to particle fluence per unit energy by dividing the particle fluence, Φ, by the energy bin width in MeV, ΔE, as shown in Equation 3.

$$\begin{aligned} To\ Particle\ Fluence\ Per\ MeV \quad &: \\ \frac{\Phi}{MeV} &= \left(\frac{\Phi}{bin}\right)\frac{bin}{\Delta E\ MeV} \end{aligned} \tag{3}$$

An example of converting the particle fluence per bin to particle fluence per energy is provided below.

Example 2 *Given an energy bin with* $E_{upper} = 0.164 MeV$ *and* $E_{lower} = 0.160 MeV$ *with* $1.5560E - 04$ *photons per bin, calculate the number of photons per MeV.*

Solution 2

$$\begin{aligned} \Delta E &= (E_{upper} - E_{lower}) = 0.004 \quad MeV \\ \left(\frac{\Phi}{MeV}\right) &= \left(\frac{\Phi}{bin}\right)\frac{1}{\Delta E} = (1.5560E - 04) \times \frac{1}{0.004} = 0.0389 \quad photons/MeV \end{aligned}$$

If the initial differential spectra is in terms of particle intensity, I, it needs to be converted to a particle fluence before it can be used to set-up the external source for the CEPTRE code. This is done by dividing the particle intensity in an energy bin by the average energy of that bin:

$$\begin{aligned} From\ Intensity\ to\ Particle\ Fluence \quad &: \\ \Phi\, photons &= \frac{I\ MeV}{E_{avg}\ MeV} \end{aligned} \tag{4}$$

where

$$\begin{aligned} Average\ Energy \quad &: \\ E_{avg} &= \frac{1}{2}\left(E_{upper} + E_{lower}\right) \end{aligned} \tag{5}$$

Example 3 *Given an energy bin with* $E_{upper} = 0.080\ MeV$ *and* $E_{lower} = 0.075\ MeV$ *and an intensity,* $I = 8.5250E-04$*, calculate the particle fluence,* Φ*.*

Solution 3

$$\begin{aligned} E_{avg} &= \frac{1}{2}\left(E_{upper} + E_{lower}\right) = 0.5(0.08 + 0.075) = 0.0775 \quad MeV \\ \Phi &= \frac{I}{E_{avg}} = \frac{8.5250E-04\ \ \gamma\text{-}MeV}{0.0775\ \ MeV} = 8.5250E-04 \quad photons \end{aligned}$$

Once the initial differential spectra is in terms of the number of photons per bin, the analyst must decide on the energy group structure to convert the differential spectra into for the multi-group radiation transport code CEPTRE. The group structure is used as input into CEPXS to generate the cross-section data and to set-up the surface source input file for a CEPTRE simulation. The simplest thing to do is to use the energy bins in the differential spectra; however, analysts may wish to reduce or increase the number of groups. When creating the multi-group photon energy group structure, users are encouraged to be mindful of the following:

1. Radiation transport accuracy is not highly dependent on number of photon energy groups.
2. CEPTRE solves of photon groups dominate the simulation run-time, so the more energy photon groups used the longer the run-time. In particular, higher energy photon groups tend to require the most run-time.

3.2.1 To Use Differential Spectra Energy Bins as Energy Groups

To use the energy bins in the differential spectra as the energy groups, simply perform the following steps :

1. If needed, convert differential spectra to particle fluence per unit bin (Number of Photons/Bin) using Eq. 1.
2. Determine the total number of photons in the spectra using:

$$N^{\gamma}_{total} = \sum_{i=1}^{N_{bins}} \Phi_i \qquad where \quad \Phi_i = \frac{\#\ Photons}{Bin} \tag{6}$$

3. Normalize the spectra to one incident photon by dividing the value for each energy group by the total number of photons

$$\begin{aligned} Normalized\ Photon\ Spectra\ in\ i^{th}\ Bin \quad &: \\ \Phi_i^{NORM} &= \frac{\Phi_i}{N^{\gamma}_{total}} \end{aligned}$$

Consider the differential energy spectra in Table 2 given in terms of particle fluence per unit bin (Photons/Bin), the total number of Photons in this spectra, N^{γ}_{total}, can be shown to be $4.3478E-01$. To obtain a normalized spectra we simply divide the number of photons in each bin by N^{γ}_{total}. The normalized spectra is presented in Table 3. Once, you have a normalized spectrum you can set up both the external surface source description for CEPTRE[3] and the CEPXS input file to generate the cross-sections.

Setting Up CEPXS Input File To set-up the CEPXS input file we need the average energy of the highest energy group in the spectra (refer to Tables 2 and 3) which is calculated as follows:

$$
\begin{aligned}
E_g^{AVG} &= \frac{1}{2}\left(E_g^{UP} + E_g^{LOW}\right) \quad where \;\; g = 1 \\
E_1^{AVG} &= \frac{1}{2}\left(E_1^{UP} + E_1^{LOW}\right) = \frac{1}{2}\left(0.164 + 0.160\right) = 0.162 \; MeV
\end{aligned}
$$

The average energy is used in the CEPXS input file with the keyword ENERGY as depicted in Figure 3.2. Note that the actual number of photon energy groups is 31 not 32 groups as depicted in Table 2. This is because the least energy group in the initial spectra ranges from $0.001 \; MeV$ to 0; however, the minimum energy available in CEPXS is $0.001 \; MeV$ and anything below this energy is discarded.

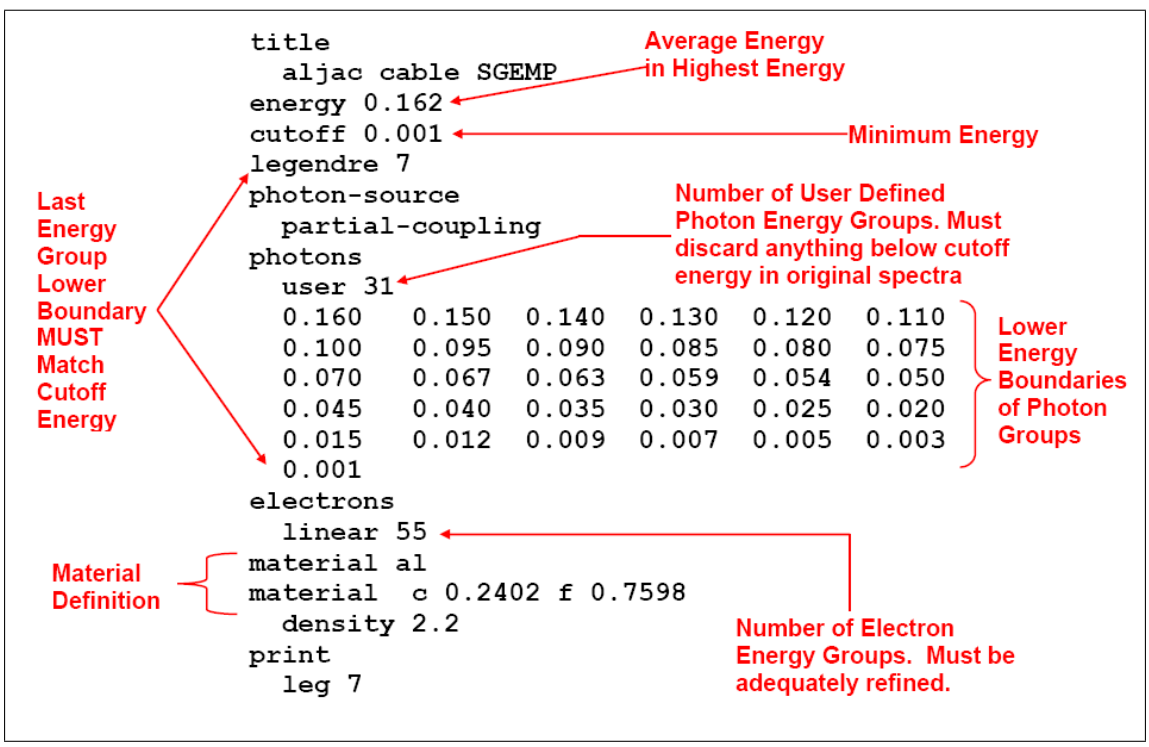


Figure 3.2: CEPXS INput Using 32 Group Normalized Spectra Energy Bins

Try to run CEPXS with this input file (provided on the accompanying CD as `aljac31.cepinp`) and study the output file cepout to examine the energy group

Table 3: 32 Group Photon Spectra Normalized to 1.0 for CEPTRE

Energy Bin	**Upper Energy (MeV)**	**Lower Energy (MeV)**	**Photons/Bin**	**Normalized Photons/Bin**
1	0.164	0.160	1.5560E-04	3.5788E-04
2	0.160	0.150	1.0800E-04	2.4840E-04
3	0.150	0.140	9.7200E-04	2.2356E-03
4	0.140	0.130	2.1900E-03	5.0371E-03
5	0.130	0.120	3.9500E-03	9.0851E-03
6	0.120	0.110	6.2900E-03	1.4467E-02
7	0.110	0.100	9.1500E-03	2.1045E-02
8	0.100	0.095	5.9500E-03	1.3685E-02
9	0.095	0.090	6.9500E-03	1.5985E-02
10	0.090	0.085	8.1000E-03	1.8630E-02
11	0.085	0.080	9.4500E-03	2.1735E-02
12	0.080	0.075	1.1000E-02	2.5300E-02
13	0.075	0.070	1.2600E-02	2.8980E-02
14	0.070	0.067	9.3900E-03	2.1597E-02
15	0.067	0.063	1.7840E-02	4.1032E-02
16	0.063	0.059	1.6360E-02	3.7628E-02
17	0.059	0.054	3.9400E-02	9.0621E-02
18	0.054	0.050	2.1760E-02	5.0049E-02
19	0.050	0.045	3.0850E-02	7.0956E-02
20	0.045	0.040	3.5550E-02	8.1766E-02
21	0.040	0.035	4.0650E-02	9.3496E-02
22	0.035	0.030	4.4550E-02	1.0247E-01
23	0.030	0.025	4.4700E-02	1.0281E-01
24	0.025	0.020	3.6150E-02	8.3146E-02
25	0.020	0.015	1.7250E-02	3.9675E-02
26	0.015	0.012	2.2020E-03	5.0647E-03
27	0.012	0.009	1.1790E-03	2.7117E-03
28	0.009	0.007	4.5000E-06	1.0350E-05
29	0.007	0.005	8.0800E-11	1.8584E-10
30	0.005	0.003	1.2720E-12	2.9256E-12
31	0.003	0.001	4.0800E-14	9.3841E-14
32	0.001	0.0	7.6400E-05	1.7572E-04
		TOTAL =	**4.3478E-01**	**1.0000**

structure for both photons and electrons. Appendix B shows the photon and electron energy group structure determine by CEPXS which would be in `aljac31.cepout`.

Setting Up CEPTRE Surface Source Description The normalized spectra values listed in Table 3 are used to set-up the surface source description for CEPTRE. Recall the simple coaxial cable depicted in Figure 2.2 (on page 15) in which the incident surface source is normally incident at the top of the cable flowing along the $-y$ direction, the surface source description for CEPTRE is presented in Figure 3.3.

```
BEGIN SURFACE SOURCE
  ID 1
  PLANE WAVE
  INCIDENT DIRECTION VECTOR 0. -1. 0.
  ENERGY SPECTRA
     1    3.58E-04
     2    2.48E-04
     3    2.24E-03
     4    5.04E-03
     5    9.09E-03
     6    1.45E-02
     7    2.10E-02
     8    1.37E-02
     9    1.60E-02
    10    1.86E-02
    11    2.17E-02
    12    2.53E-02
    13    2.90E-02
    14    2.16E-02
    15    4.10E-02
    16    3.76E-02
    17    9.06E-02
    18    5.01E-02
    19    7.10E-02
    20    8.18E-02
    21    9.35E-02
    22    1.02E-01
    23    1.03E-01
    24    8.32E-02
    25    3.97E-02
    26    5.07E-03
    27    2.71E-03
    28    1.04E-05
    29    1.86E-10
    30    2.93E-12
    31    9.39E-14
  END ENERGY SPECTRA
END
```

Tells CEPTRE this is the start of the source description

Normally Incident Plane Wave

Flowing in negative y direction

Energy Spectra of External Source Normalized to 1.0 Photon

Source description is completed

Figure 3.3: Example of External Surface Source Description for CEPTRE

3.2.2 To Use Fewer Energy Groups than Energy Bins

The easiest way to modify a differential energy spectra is to reduce the number of bins or energy groups where the new energy group boundaries fall on the energy bin

boundaries in the initial spectra. For example, consider Figure 3.4 which depicts the reduction of a 32 energy group spectra to a 16 energy group spectra. The new energy groups all have boundaries that existed in the original spectra.

ORIGINAL			NEW	
Upper Energy (MeV)	Lower Energy (MeV)	→	Upper Energy (MeV)	Lower Energy (MeV)
0.164 0.16	0.16 0.15	→	0.164	0.15
0.15 0.14	0.14 0.13	→	0.15	0.13
0.13 0.12	0.12 0.11	→	0.13	0.11
0.11 0.1	0.1 0.095	→	0.11	0.095
0.095 0.09	0.09 0.085	→	0.095	0.085
0.085 0.08	0.08 0.075	→	0.085	0.075
0.075 0.07	0.07 0.067	→	0.075	0.067
0.067 0.063	0.063 0.059	→	0.067	0.059
0.059 0.054	0.054 0.05	→	0.059	0.05
0.05 0.045	0.045 0.04	→	0.05	0.04
0.04 0.035	0.035 0.03	→	0.04	0.03
0.03 0.025	0.025 0.02	→	0.03	0.02
0.02 0.015	0.015 0.012	→	0.02	0.012
0.012 0.009	0.009 0.007	→	0.012	0.007
0.007 0.005	0.005 0.003	→	0.007	0.003
0.003 0.001	0.001 0	→	0.003	0.001

Figure 3.4: Collapse 32 Energy Group Input Spectra to 16 Groups

To reduce the number of energy bins from 32 down to 16 as depicted in Figure 3.4 we perform the following steps on the original spectra presented in Table 2:

1. Determine the new energy boundaries. For example, the new energy group 1 collapses groups 1 and 2 yielding the following energy group boundaries:

$$\begin{aligned} E_{g=1}^{NEW\ upper} &= E_{g=1}^{upper} = 0.164\ MeV \\ E_{g=1}^{NEW\ lower} &= E_{g=2}^{lower} = 0.150\ MeV \end{aligned}$$

2. Determine the total number of photons in the new energy groups. When you use prexisting bin energy boundaries, you simply add the number of photons in each bin that you are collapsing in the new bin:

$$\begin{aligned} \Phi_{g=1}^{NEW} &= \Phi_{g=1} + \Phi_{g=2} \\ &= 1.5560E-04 + 1.0800E-04 \\ &= 2.6360E-04 \qquad photons \end{aligned}$$

Table 4: 32 Group Photon Spectra Normalized to 1.0 for CEPTRE

Energy Bin	Upper Energy (MeV)	Lower Energy (MeV)	Photons/Bin	Normalized Photons/Bin
1	0.164	0.150	2.6360E-04	6.0639E-04
2	0.150	0.130	3.1620E-03	7.2740E-03
3	0.130	0.110	1.0240E-02	2.3556E-02
4	0.110	0.095	1.5100E-02	3.4737E-02
5	0.095	0.085	1.5050E-02	3.4621E-02
6	0.085	0.075	2.0450E-02	4.7044E-02
7	0.075	0.067	2.1990E-02	5.0586E-02
8	0.067	0.059	3.4200E-02	7.8675E-02
9	0.059	0.050	6.1160E-02	1.4069E-01
10	0.050	0.040	6.6400E-02	1.5275E-01
11	0.040	0.030	8.5200E-02	1.9600E-01
12	0.030	0.020	8.0850E-02	1.8599E-01
13	0.020	0.012	1.9452E-02	4.4748E-02
14	0.012	0.007	1.1835E-03	2.7226E-03
15	0.007	0.003	8.2072E-11	1.8880E-10
16	0.003	0.001	4.0800E-14	9.3858E-14
		TOTAL =	**4.3470E-01**	**1.0000**

3. Normalized the new photon spectra values to 1.0 by determining the total number of photons in the new bins, this should be the same as before unless you changed the cutoff energy, and dividing through the number in each bin:

$$
\begin{aligned}
N_{total}^{\gamma,NEW} &= \sum_{i=1}^{N_{bins}^{NEW}} \Phi_i^{NEW} \\
\Phi_i^{NORM} &= \frac{\Phi_i^{NEW}}{N_{total}^{\gamma,NEW}}
\end{aligned}
$$

Applying these steps to the original spectra in Table 2 to reduce the number of groups to the 16 groups depicted in Figure 3.4 yields the new spectra presented in Table 4. Figure 3.5 depicts the results of reducing the 32 group differential spectra into a 16 group spectra in which the boundaries of new energy groups match with existing ones in the original differential spectra.

Setting Up the CEPXS Input File Creating a CEPXS input file with the energy group structure presented in Table 4 yields the file shown in Figure 3.6:

Setting Up the CEPTRE Surface Source Description Once again we consider the simple coaxial cable with the normally incident photon source flowing down in the $-y$

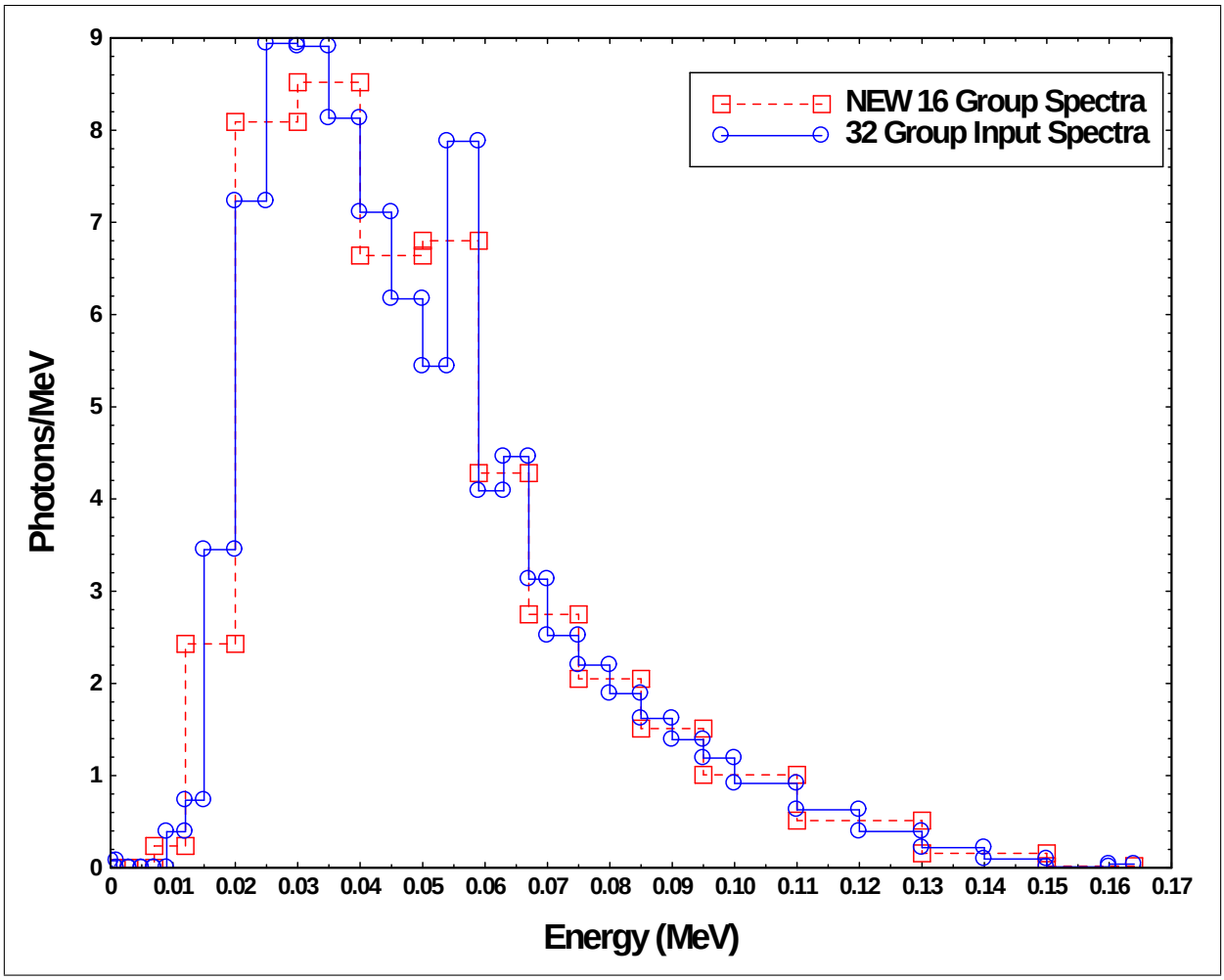


Figure 3.5: Example of 32 Group Spectra Reduced to 16 Groups

```
title
  aljac cable SGEMP - 16 photon groups
energy 0.157
cutoff 0.001
legendre 7
photon-source
  partial-coupling
photons
  user 16
  0.150   0.130  0.110
  0.095   0.085  0.075
  0.067   0.059  0.050
  0.040   0.030  0.020
  0.012   0.007  0.003
  0.001
electrons
  linear 55
material al
material  c 0.2402 f 0.7598
  density 2.2
print
  leg 7
```

Figure 3.6: CEPXS Input File for 16 Photon Energy Groups

direction as shown in Figure 2.2. Using the normalized spectra for the 16 energy groups given in Table 4 the correct surface source description for CEPTRE is found in Figure **??**.

3.3 Running CEPXS

CEPXS can be run using script ***runCepxs*** provided with you code distribution package which also translates the CEPXS cross-sections into the netcdf format required by CEPTRE. .For a CEPXS input file named `aljac31.cepinp`, execute the following command to run CEPXS using the ***runCepxs*** script:

```
$ ./runCepxs aljac31
```

The output to the screen should look like that shown in Figure 3.7. The ***runCepxs*** also runs the translator, bxs2nc, needed to get the CEPXS cross-sections into the proper format for CEPTRE[3]. The resulting cross-section data libray for CEPTRE will have the extension "`.xslib`" (e.g. `aljac31.xslib`). This file is a netcdf binary file, the output file with the extension "`.cepout`" is an ASCI text file you can examine easily.

```
$  ./runCepxs aljac31g
Checking for aljac31g.cepinp input file in /home/jlpowel/xsData/aljac/31g
Creating symbolic links to executables and data files in
/home/jlpowel/xsData/aljac/31g
 ...Running CEPXS

                     CCCC   EEEEE   PPPP    X   X    SSSS
                    C       E       P   P    X X    S
                    C       EEEE    PPPP      X      SSS
                    C       E       P        X X        S
                     CCCC   EEEEE   P       X   X   SSSS
              A COUPLED ELECTRON/PHOTON X-SECTION GENERATION CODE
 VERSION: 7.1.1
 DATE: APRIL 10, 2006
   aljac cable SGEMP

 EXECUTION DATE    4- 9- 7      CEPXS START TIME   11:30:13
 INPUT/GRID GENERATION SUCCESSFUL
 PROCESSING X-SECTIONS FOR MATERIAL AL
 PROCESSING X-SECTIONS FOR MATERIAL UNKNOW
 PERFORMING FINAL CHECKS

 X-SECTIONS SUCCESSFULLY GENERATED

  TOTAL CPU TIME (SEC) =            1
 ...Translating bxslib to NETCDF format
 --------
  bxs2nc
 --------
 ...Renaming Output files
...Cleaning up
```

Figure 3.7: Output to Screen from `runCepxs` script

To run both CEPXS and bxs2nc without the script perform the following steps:

1. Create softlinks to CEPXS executable and data files to current directory:

```
$ ln -s $CEPXS_BIN/xcepxs .
$ ln -s $CEPXS_DATA/elec2p1.dat .
$ ln -s $CEPXS_DATA/elec3.dat .
$ ln -s $CEPXS_DATA/n14neutphot.dat .
$ ln -s $CEPXS_DATA/phot2p1.dat .
$ ln -s $CEPXS_DATA/phot3.dat .
```

where `$CEPXS_BIN` is the directory where the CEPXS and bxs2nc executables have been installed and `$CEPXS_DATA` is the directory where the data files have been placed.

2. Copy the input file aljac31.cepinp to cepinp:

```
$ cp -p aljac31.cepinp cepinp
```

3. Run CEPXS:

```
$ ./xcepxs
```

4. Run translator, bxs2nc:

```
$./bxs2nc bxslib
```

5. Rename files:

```
$ mv cepout aljac31.cepout
$ mv bxslib aljac31.bxslib
$ mv bxslib.nc aljac31.xslib
$ mv egroup aljac31.egroup
$ mv pgroup aljac31.pgroup
```

Next is a user exercise to allow you to practice creating the CEPXS input file and CEPTRE Source description file.

User Exercise: Set-Up CEPXS Input and CEPTRE Source Description

Now it is your turn to set up a CEPXS input file and a CEPTRE surface source description.

1. We start by normalizing the 10 group photon spectra shown below, go ahead and fill in table with the normalized photon spectrum.

Fill in the table below with the correct values.

Energy Bin #	Upper Energy (MeV)	Lower Energy (MeV)	Number of Photons/Bin	NORMALIZED Photons/Bin
1	0.178	0.140	4.3423E-03	
2	0.140	0.100	2.7280E-02	
3	0.100	0.085	2.2650E-02	
4	0.085	0.070	3.3550E-02	
5	0.070	0.059	4.3690E-02	
6	0.059	0.045	9.1230E-02	
7	0.045	0.030	1.1345E-01	
8	0.030	0.015	9.6800E-02	
9	0.016	0.007	4.6408E-03	
10	0.007	0.001	4.7747E-07	
	TOTAL Number of Photons =			

2. Next, set-up the CEPXS input file by filling out the missing values in the file below.

```
title
  a 10 photon group cepinp file
energy  _____________
cutoff 0.001
legendre 7
photon-source
  partial-coupling
photons
  user 10

  _______________  _______________

  _______________  _______________

  _______________  _______________

  _______________  _______________
                   0.001
  _______________
electrons
  linear 55
material al
material  c 0.2402 f 0.7598
  density 2.2
print
  leg 7
```

3. Fill in the surface source description for CEPTRE in the following file:

```
BEGIN SURFACE SOURCE
  ID 1
  PLANE WAVE
  INCIDENT DIRECTION VECTOR 0. -1. 0.
  ENERGY SPECTRA
    1
    2
    3
    4
    5
    6
    7
    8
    9
    10
  END ENERGY SPECTRA
END
```

Check your work in Section 9 on page 94. Now, you are ready to set-up CEPXS input files and CEPTRE source descriptions on your own.

4 Creating a Finite Element Mesh of the Cable

Next, the user must create a finite element mesh of the cable geometry using unstructured finite elements. Detailing exactly how this is done is beyond the scope of this tutorial. Analysts must obtain training on using a finite element mesh generator of their choice on their own. The finite element model of the problem geometry must be described in the EXODUSII file format[6]. Two tools that can generate meshes directly in this format are CUBIT and ICEM. Both have been used to generate finite element models of cables successfully.

To obtain accurate cable SGEMP solutions, both CEPTRE and EMPHASIS/CABANA require the use of 2nd order quadrilaterals elements (QUAD8). In CEPTRE these higher order elements are required to accurately calculate the charge deposition and dose enhancement profiles at material interfaces. For CABANA, the higher order elements are required to obtain sufficient accuracy in the electric field computation[1]. The external boundaries and interfaces between material regions of the cable must be described as EXODUSII sidesets. Figure 4.1 illustrates how different regions of the simple coaxial cable, originally presented in Figure 2.2, should be represented in your finite element model.

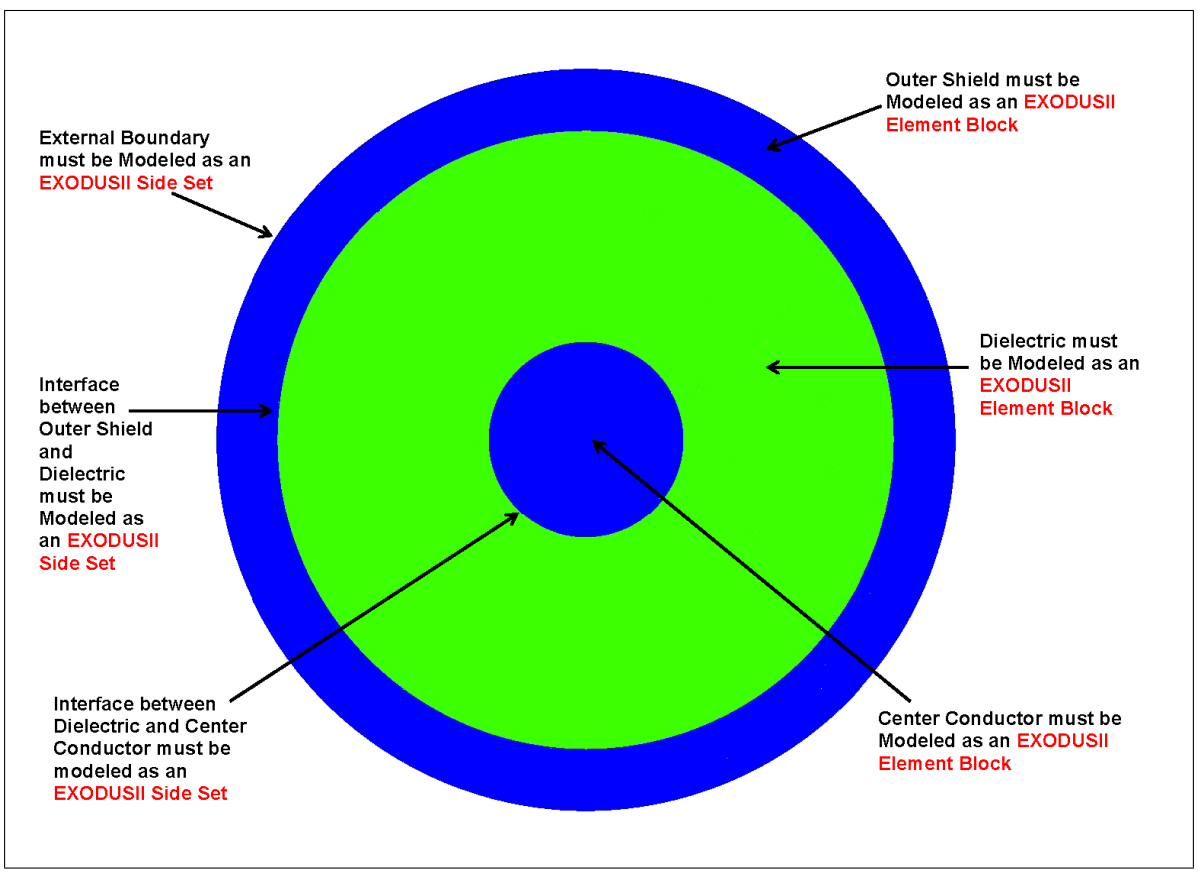


Figure 4.1: Representing a Coaxial Cable in Finite Element Model

Table 5: Minimum Mesh Sizes at Conductor / Dielectric Interfaces

Interface Type	Minimum Mesh Size	Typical Conductor
High-Z conductor/Dielectric	$0.50\ \mu m$	Silver $(Z = 47)$
Moderate-Z Conductor/Dielectric	$1.0\ \mu m$	Copper $(Z = 29)$

As you generate the finite element model of your cables be aware that accurate coupled electron-photon transport calculations require refinement at material interfaces. Poor results will be obtained if a mesh is not accurately refined at these interfaces. To complicate matters, the mesh refinement needed is dictated by the external source energy spectrum for any given problem and the atomic number (Z) of the materials. A good rule of thumb is to refine the mesh approximately $40\ \mu m$ deep in dielectric material regions and $20\ \mu m$ in conductor material regions. Table 5 gives mimum mesh sizes that are usually appropriate for moderate-Z conductor/dielectric (i.e. Cu/Teflon) and high-Z conductor/dielectric (i.e. Ag/Teflon) interfaces. Often more than one simulation needs to be run with ever more refined finite element meshes until the user is satisfied that the radiation transport results have converged. Users can evaluate the quality of CEPTRE results by looking at the energy and charge conservation ratios that are written at the end of the simulation.

Users should resist the urge to highly refine the entire mesh in hopes of avoiding the need to run more than a single simulation for a problem. Extremely long run times will result if mesh refinement is performed imprudently. It is also likely that highly refined meshes will not run due to memory limitations on computers.

A adequately refined mesh of the simple coaxial cable used throughout this document is portrayed in Figure 4.2. This is a QUAD8 Mesh with 3 element blocks and 3 side sets (1 at the external boundary and 2 at the material interfaces). The refinement between the outer Al shield and the Teflon dielectric is presented in Figure 4.3 where the minimum element size is approximately $0.15\ \mu m$ thick. Similarly, Figure 4.4 shows the refinement at the material interface between the Teflon dielectric and the center Al conductor where the thinnest element is approximately $0.32\ \mu m$ thick.

4.1 Things to Remember During Mesh Generation

As you generate the finite element mesh of your cable, keep in mind the following required characteristics of your mesh:

1. The finite element mesh **MUST BE** in the EXODUSII format
    - External boundaries **MUST BE** described as EXODUSII sidesets
    - Interfaces between material regions of the cable **MUST BE** described as EXODUSII sidesets

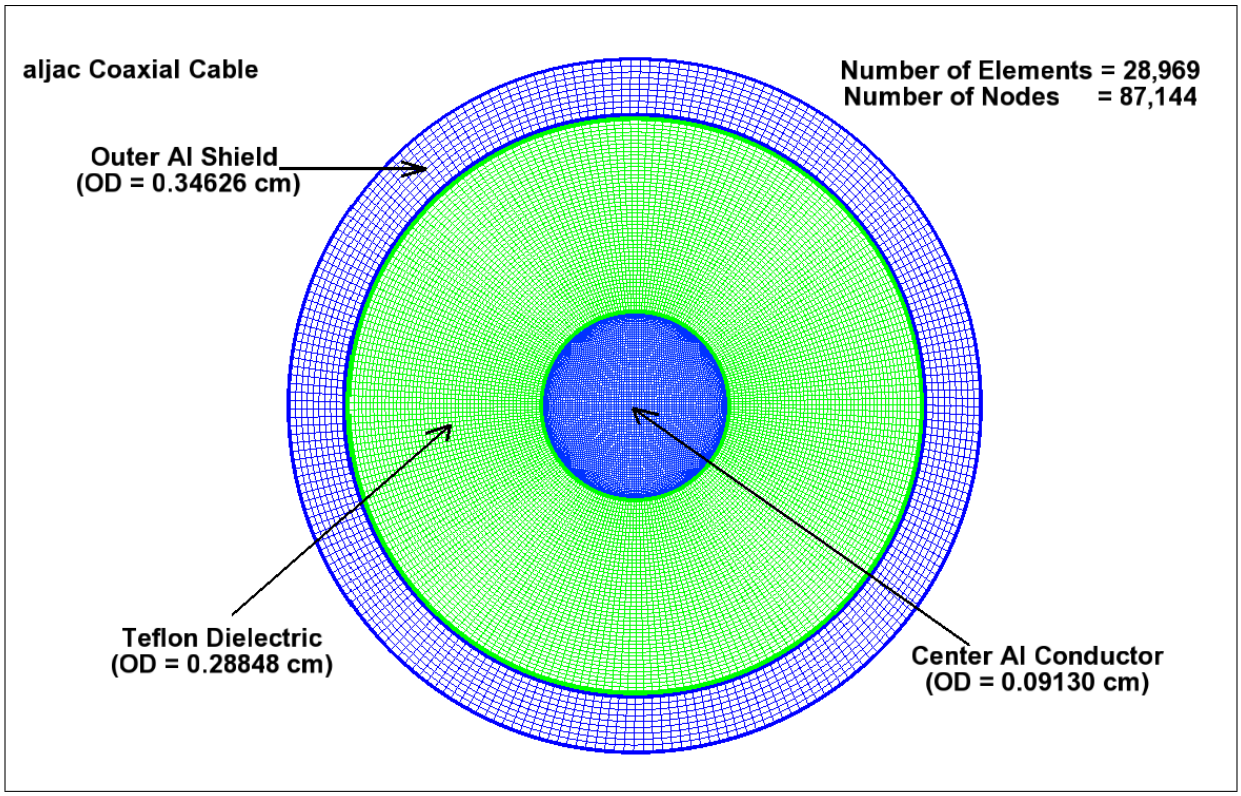


Figure 4.2: Finite Element Mesh of Simple Coaxial Cable

2. An accurate solution **REQUIRES** the use of 2nd order quadrilateral elements (e.g. QUAD8)

   - To accurately calculate the charge deposition and dose enhancement profiles at material interfaces in CEPTRE
   - To obtain sufficient accuracy in the electric field computation in EMPHASIS/CABANA

3. An accurate coupled electron-photon transport calculations **REQUIRES** refinement at material interfaces

   - Refine the mesh approximately $40\ \mu m$ deep in dielectric material regions
   - Refine the mesh approximately $20\ \mu m$ in conductor material regions
   - Minimum elements at meterial interfaces should be sub-micon ($< 1\ \mu m$)
   - ONELD can be used to examine the energy/charge profiles near the interface to determine the minimal mesh-size and how quickly one can enlarge the mesh-size to reduce the element count.

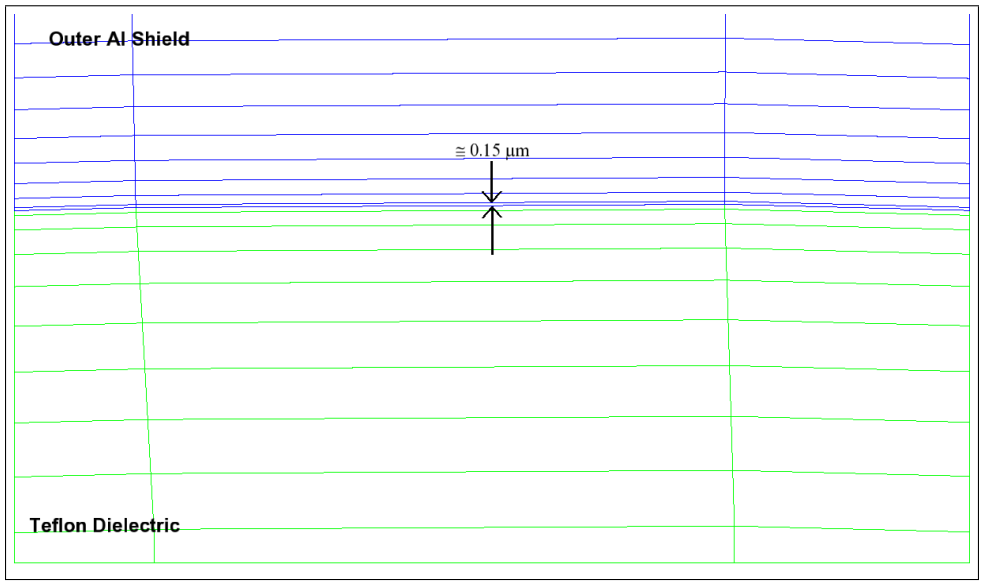


Figure 4.3: Mesh Refinement at Al Shield/Teflon Dielectric Interface

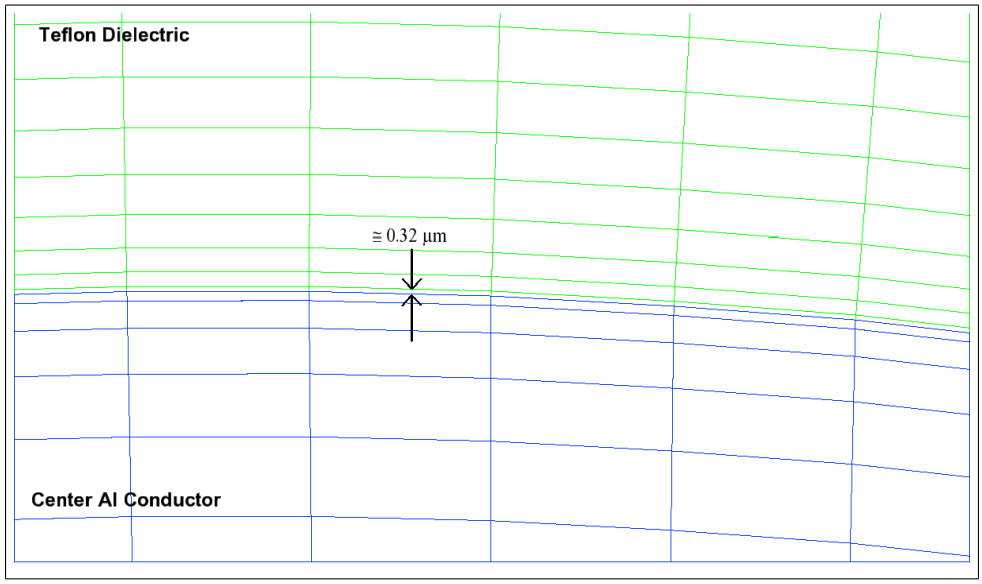
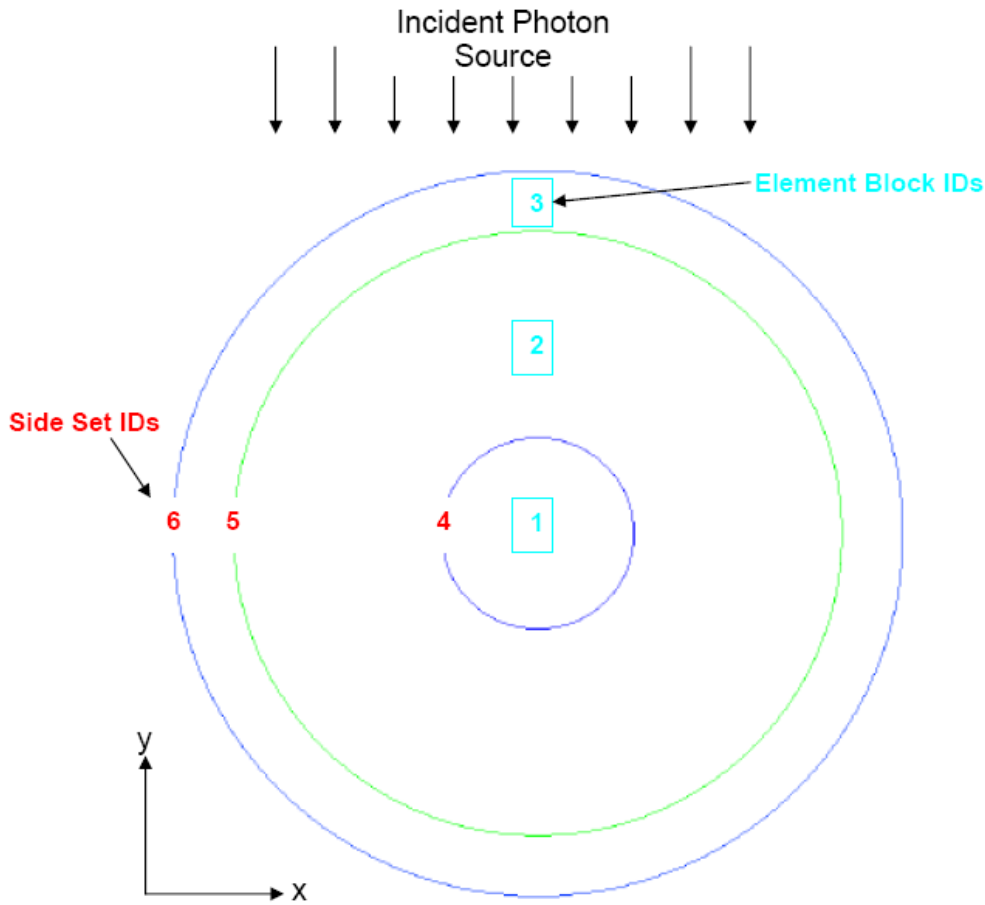


Figure 4.4: Mesh Refinement at Teflon Dielectric/Center Conductor Interface

5 Creating a CEPTRE Input File

This section will guide the reader in setting up the CEPTRE input file for the simple coaxial cable used throughout this document. The details of the geometry model of this cable needed to set-up the CEPTRE input is presented in Figure 5.1 below.



Element Block ID	Material	Bounding Side Sets
1	Aluminum (conductor)	4
2	Teflon (dielectric)	4, 5
3	Aluminum (shield)	5, 6

Figure 5.1: Geometry Model for Simple Coaxial Cable

CEPTRE uses the element-block IDs to assign material and side set IDs to assign boundary condition and to tally the knock-on charge. We will create a CEPTRE input file for this cable using the following information regarding the radiation transport simulation:

1. Name (runid): `aljac`
2. Photon source, normally incident at the "top" of the cable

3. Energy Group Structure: 31 Photon Groups and 55 Electron Groups
4. S_8 Quadrature, P_5 Legendre Order
5. Materials: Aluminum and Teflon
6. Geometry/Finite Element Mesh Model
   - 3 Element Blocks
   - 3 Side Sets
   - 1 internal conductor
7. Solver Information
   - Block Diagonal Preconditioner for Photon Solve
   - Use Solver Tolerance = $1.0E-08$
   - Uncollided Flux Solve with SAAF equation
   - Full Transport Solve with EOPF equation

As we go through this exercise the reader should have a copy of the CEPTRE User's Manual[3] handy for reference. This manual provides detailed explanations of all of the keywords used by CEPTRE

Step 1: Add QA Comments

First, place a few QA comments at the beginning of the input file to document the simulation as shown in the figure below:

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac
$Title:            aljac coax cable base case
$Owner:            Jennifer Powell
$
$Description:
$  Simple coax cable
$  S8, P5
$  31 Photon Energy Groups
$  55 Electron Energy Groups
$
$----------------------END_QA-----------------------
```

Figure 5.2: Add QA Comments

Note to User: QA comments are completely discretionary, put something that makes sense to you. The only thing you MUST have is a "$" at the beginning of each line.

Step 2: Add Number of Energy Groups, Materials and Particle Types

Next, add a title and the basic description of the CEPTRE simulation in terms of the number of energy groups, particles and materials to be used with the following keywords[3]:

```
TITLE
   CEPTRE: aljac coaxial cable base case

NUMBER ENERGY GROUPS 86

NUMBER PARTICLE TYPES 2

NUMBER MATERIALS 2
```

With these keywords, the CEPTRE input file `aljac.inp` now looks like:

```
…
TITLE
  CEPTRE: aljac coax cable base case

$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$
…
END
$ end physics options
```

Figure 5.3: Add Number of Energy Groups, Materials and Particle Types

Step 3: Add Solver Options

Next, we typically specify the solver options as detailed in the CEPTRE Users Manual[3]. Recall from page 39 that for this simulation we want to use the SAAF equation for the uncollided flux solve to handle the normally incident photon source, this is specificed with the keyword: `SOLVE UNCOLLIDED FLUX, SAAF`. To specifiy the EOPF for the full transport solve, use the keyword: `SOLVE COLLIDED FLUX, EOPF`.

To improve the solver efficiency, we want to employ the block diagonal preconditioner in the full transport (or block) solve for both photons and electrons, this is done by employing the `BLOCK SOLVE OPTIONS` keyword as follows:

```
BLOCK SOLVE OPTIONS
   PRECONDITIONER, BLOCK DIAGONAL
END
```

With these solver options, the CEPTRE input file, `aljac.inp` becomes:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
…
END
$ end physics options
```

Figure 5.4: Add Solver Options

Step 4: Specify Quadrature and Legendre Order

The quadrature quadrature and legendre order are specified with the keywords `SN SET`, `PHOTON QUADRATURE SET` and `ELECTRON QUADRATURE SET` which gives

```
SN SET  1 , SN  8 , P  7 , END
PHOTON QUADRATURE SET 1
ELECTRON QUADRATURE SET 1
```

And the CEPTRE input file becomes:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
SN SET 1, SN 8, P 5, END
PHOTON QUADRATURE SET 1
ELECTRON QUADRATURE SET 1
…
END
$ end physics options
```

Figure 5.5: Specify Quadrature and Legendre Order

Step 5: Add External Source Description

The keywords we employ here are `SURFACE SOURCE`, `INCLUDE` and `SURFACE SOURCE BC`. The CEPTRE input file now becomes:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE "aljac31g.source"
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
…
END
$ end physics options
```

Figure 5.6: Add External Source Description

The surface source description is provided by the keywords `BEGIN SURFACE SOURCE` which is included in the CEPTRE input file here using `INCLUDE "ALJAC31G.SOURCE"`. The file, `aljac31g.source`, contains describes the same source presented earlier in 3.3 on pg. 24.

```
$ aljac31g.source
BEGIN SURFACE SOURCE
   ID 1
   PLANE WAVE
   INCIDENT DIRECTION VECTOR 0. -1. 0.
   ENERGY SPECTRA
      1          3.58E-04
      2          2.48E-04
      3          2.24E-03
      4          5.04E-03
      5          9.09E-03
      6          1.45E-02
      7          2.10E-02
      8          1.37E-02
      9          1.60E-02
      10         1.86E-02
      11         2.17E-02
      12         2.53E-02
      13         2.90E-02
      14         2.16E-02
      15         4.10E-02
      16         3.76E-02
      17         9.06E-02
      18         5.01E-02
      19         7.10E-02
      20         8.18E-02
      21         9.35E-02
      22         1.02E-01
      23         1.03E-01
      24         8.32E-02
      25         3.97E-02
      26         5.07E-03
      27         2.71E-03
      28         1.04E-05
      29         1.86E-10
      30         2.93E-12
      31         9.39E-14
   END ENERGY SPECTRA
END
$
EXIT
```

Figure 5.7: Contens of `aljac31g.source` File

Step 6: Request CABANA Input

Next we specify the input necessary to generate CABANA input using the keywords: CABANA INPUT, CONDUCTOR, and SOURCE NORMALIZATION. The only internal conductor is represented by side set 4 in Figure 5.1 on pg. 39. The CEPTRE input file becomes:**Note:** In this case, the response is normalized to 1 $photon/cm^2$. The actual

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE "aljac31g.source"
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
$  CABANA
   CABANA INPUT
   CONDUCTOR, sideset 4
   SOURCE NORMALIZATION 1.0
…
END
$ end physics options
```

Figure 5.8: Request CABANA Input

particle fluence (intensity/averaged photon energy) can be used here to scale to the actual fluence[3].

Step 7: Assign Materials to Element Blocks

Next, we add the keywords to fill the element blocks in the finite element mesh with materials in the CEPXS generated cross-section data file. The CEPXS ID numbers for the two materials are 1 for Aluminum and 2 forTeflon. So for the simple coaxial cable we are modeling here, the `ELEMENT BLOCK` keyword would be look like:

```
ELEMENT BLOCK  1 , MATERIAL  1 , NAME "ALUMINUM", CONDUCTOR, END
ELEMENT BLOCK  2 , MATERIAL  2 , NAME "TEFLON", DIELECTRIC, END
ELEMENT BLOCK  3 , MATERIAL  3 , NAME NAME "ALUMINUM", CONDUCTOR,
END
```

The CEPTRE input file becomes:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE "aljac31g.source"
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
$  CABANA
   CABANA INPUT
   CONDUCTOR, sideset 4
   SOURCE NORMALIZATION 1.0
$  fill elemen blocks with cepxs materials
   ELEMENT BLOCK 1, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
   ELEMENT BLOCK 2, MATERIAL 2, Name "Teflon", DIELECTRIC, END
   ELEMENT BLOCK 3, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
$
END
$ end physics options
```

Figure 5.9: Assign CEPXS Materials to Element Blocks

Step 8: Add Execution Control Keywords

Here we add in the keywords that are required by the framework to control the code execution (see the user's manual for more details[3]). The keywords in this section are `TERMINATION CYCLE 1` and `CRT: OFF`. This is the section of the input file where we would add in the keyword `READ RESTART DUMPS = -1` { `int` | `-1` }
if we were restarting a simulation. Adding these keywords to the input file yields:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE "aljac31g.source"
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
$  CABANA
   CABANA INPUT
   CONDUCTOR, sideset 4
   SOURCE NORMALIZATION 1.0
$  fill elemen blocks with cepxs materials
   ELEMENT BLOCK 1, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
   ELEMENT BLOCK 2, MATERIAL 2, Name "Teflon", DIELECTRIC, END
   ELEMENT BLOCK 3, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
$
END
$ end physics options

$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$$$

TERMINATION CYCLE 1
CRT:OFF
```

Figure 5.10: Add Execution Control Keywords

Step 9: Add Output Control Keywords

Now, we add the keywords that tell CEPTRE what output to write to the EXODUSII output file using the keywords `EMIT PLOT, CYCLE INTERVAL = 1` and `PLOT VARIABLES`. Since we are running a cable SGEMP simulation we want the charge and energy deposition written to the output file. The CEPTRE input file becomes:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE "aljac31g.source"
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
$  CABANA
   CABANA INPUT
   CONDUCTOR, sideset 4
   SOURCE NORMALIZATION 1.0
$  fill element blocks with cepxs materials
   ELEMENT BLOCK 1, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
   ELEMENT BLOCK 2, MATERIAL 2, Name "Teflon", DIELECTRIC, END
   ELEMENT BLOCK 3, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
$
END
$ end physics options

$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$$$

TERMINATION CYCLE 1
CRT:OFF

$$$$$$$$$$$$$$$$$$$ output control $$$$$$$$$$$$$$$$$$$$$$

Emit plot, cycle interval = 1
Plot variable
   No underscores
   Charge
   Energy deposition
End
```

Figure 5.11: Add Output Control Keywords

Step 10: Add Aztec Solver Options

Now, we add the Aztec solver options to control the tolerance, maximum number of iterations and output to the screen. The input file becomes:

```
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$$
CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE "aljac31g.source"
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
$  CABANA
   CABANA INPUT
   CONDUCTOR, sideset 4
   SOURCE NORMALIZATION 1.0
$  fill element blocks with cepxs materials
   ELEMENT BLOCK 1, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
   ELEMENT BLOCK 2, MATERIAL 2, Name "Teflon", DIELECTRIC, END
   ELEMENT BLOCK 3, MATERIAL 1, Name "Aluminum", CONDUCTOR, END
$
END
$ end physics options

$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$$$
TERMINATION CYCLE 1
CRT:OFF
$$$$$$$$$$$$$$$$$$$ output control $$$$$$$$$$$$$$$$$$$$$$
Emit plot, cycle interval = 1
Plot variable
   No underscores
   Charge
   Energy deposition
End
$$$$$$$$$$$$$$$$$$$ Aztec Options $$$$$$$$$$$$$$$$$$$$$$
$ standard CEPTRE options
Aztec
   Solver, CG
   Scaling, sym_diag
   Precond, none
   Maximum iterations, 20000
   Output, 1000
   Tol=1.e-8
End

EXIT
```

Figure 5.12: Add Aztec Solver Options

5.1 Complete CEPTRE Input File

Here is the complete CEPTRE input file generated in this section.

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac
$Title:            aljac coax cable base case
$Owner:            Jennifer Powell
$
$Description:
$  Simple coax cable
$  S8, P5
$  31 Photon Energy Groups
$  55 Electron Energy Groups
$
$----------------------END_QA------------------------

TITLE
  CEPTRE: aljac coax cable base case

$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS 86
   NUMBER MATERIALS 2
   NUMBER PARTICLE TYPES 2
$  solution flags
   SOLVE UNCOLLIDED FLUX, SAAF
   SOLVE COLLIDED FLUX, EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PRECONDITIONER, block diagonal
   END
$ quadrature set
   SN SET 1, SN 8, P 5, END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE ``aljac31g.source''
$ boundary condition specifications
   SURFACE SOURCE BC, 1, sideset 6
$  CABANA
   CABANA INPUT
```

```
   CONDUCTOR, sideset 4
   SOURCE NORMALIZATION 1.0
$  fill element blocks with cepxs materials
   ELEMENT BLOCK 1, MATERIAL 1, Name ``Aluminum'', CONDUCTOR, END
   ELEMENT BLOCK 2, MATERIAL 2, Name ``Teflon'', DIELECTRIC, END
   ELEMENT BLOCK 3, MATERIAL 1, Name ``Aluminum'', CONDUCTOR, END
$
END
$ end physics options

$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$$$
TERMINATION CYCLE 1
CRT:OFF
$$$$$$$$$$$$$$$$$$$ output control $$$$$$$$$$$$$$$$$$$$$$
Emit plot, cycle interval = 1
Plot variable
   No underscores
   Charge
   Energy deposition
End
$$$$$$$$$$$$$$$$$$$ Aztec Options $$$$$$$$$$$$$$$$$$$$$$
$ standard CEPTRE options
Aztec
   Solver, CG
   Scaling, sym_diag
   Precond, none
   Maximum iterations, 20000
   Output, 1000
   Tol=1.e-8
End

EXIT
```

5.2 Running CEPTRE

Run CEPTRE using the `Ceptre` script provided with your installation as follows:

```
$ export CEPTRE_EXE=path-to-ceptreExecutable/ceptreExeName
```

```
$ ./Ceptre -nprocs num_procs --x $CEPTRE_EXE -restartDir
/myScratch runid | tee runid.log
```

where `num_procs` is the number of processors, `path-to-ceptreExecutable/ceptreExeName` is the installation path and name of the Ceptre executable, the directory following `restartDir` is the directory to write the restart dumps and the job name is `runid`. Most likely you will place this line in a PBS or other batch queue job script. Typically, the CEPTRE code will be in an executable named along the lines "`sgemp_1.1_2D_gnu3_opt.x`". **Refer to your installation notes for help with running CEPTRE.**

For example, if we have a `runid=aljac` and we want to use 60 processors and write restart dumps to the directory `/scratch/aljac` we would do the following:

```
$ export
CEPTRE_EXE=/usr/local/Sgemp1.1/bin/sgemp_1.1_2D_gnu3_opt.x
```

```
$ ./Ceptre -nprocs 60 -x $CEPTRE_EXE -restartdir=/scratch/aljac
aljac | tee aljac.log
```

Once the simulation has completed you can evaluate the quality of results by looking in the `runid.log` or `runid.out` files at the energy and charge conservation ratios. Energy and charge conservation ratios of 0.95 or higher are desired.

```
Starting CEPTRE calculation...
*
*    Calculation will be performed on ICC-liberty (i686)
*    running Linux release 2.4.21-27.0.2.ELSFSsmp version #1 SMP
Fri Jan 28 14:22:15 MST 2005
*
*    The executable for this problem will be
*    /usr/local/Sgemp1.1/bin/sgemp_1.1_2D_icc_opt.x
*
*    CEPTRE will be run in DEFAULT mode with the command:
*
*      mpiexec -n 60
/usr/local/Sgemp1.1/bin/sgemp_1.1_2D_icc_opt.x
-c -p 60 -r 1 -f 1 -o 1 -R /home/jlpowel/aljac/ -D
/scratch/aljac/ -S . -g par -L /home/jlpowel/aljac aljac
*
*
*
*    Starting CEPTRE calculation for aljac
*         at Fri Feb  2 14:32:32 MST 2007
*
*
*
Genesis Suffix (-g)= par
Number of Raids (-r)= 1
Root dir (-R)= /home/jlpowel/aljac
Sub dir (-S)= .
Raid Offset (-o)= 1
Number of Files to Write Concurrently (-f)= 1
Current dir (-L)= /home/jlpowel/aljac
Restart Dump dir (-D)= /scratch/aljac
File prefix= aljac
Number of processors (-p)= 60

                 CCCCC  EEEEEEE PPPPPP  TTTTTT  RRRRRR  EEEEEEE
                CC   CC EE      PP   PP   TT    RR   RR EE
                CC      EE      PP   PP   TT    RR   RR EE
                CC      EEEEE   PPPPPP    TT    RRRRRR  EEEEE
                CC      EE      PP        TT    RRRRR   EE
                CC   CC EE      PP        TT    RR  RR  EE
                 CCCCC  EEEEEEE PP        TT    RR   RR EEEEEEE

*****************************************************************
*****************************************************************
…
User time: 7.780 cpu sec + System time: 263.010 cpu sec, Elapsed
time: 31:43:09.02 [Approx]
Problem aljac


*   CEPTRE exiting with status: 0
*
*
*    Completed CEPTRE calculation for aljac
*         at Sat Feb  3 22:15:41 MST 2007
```

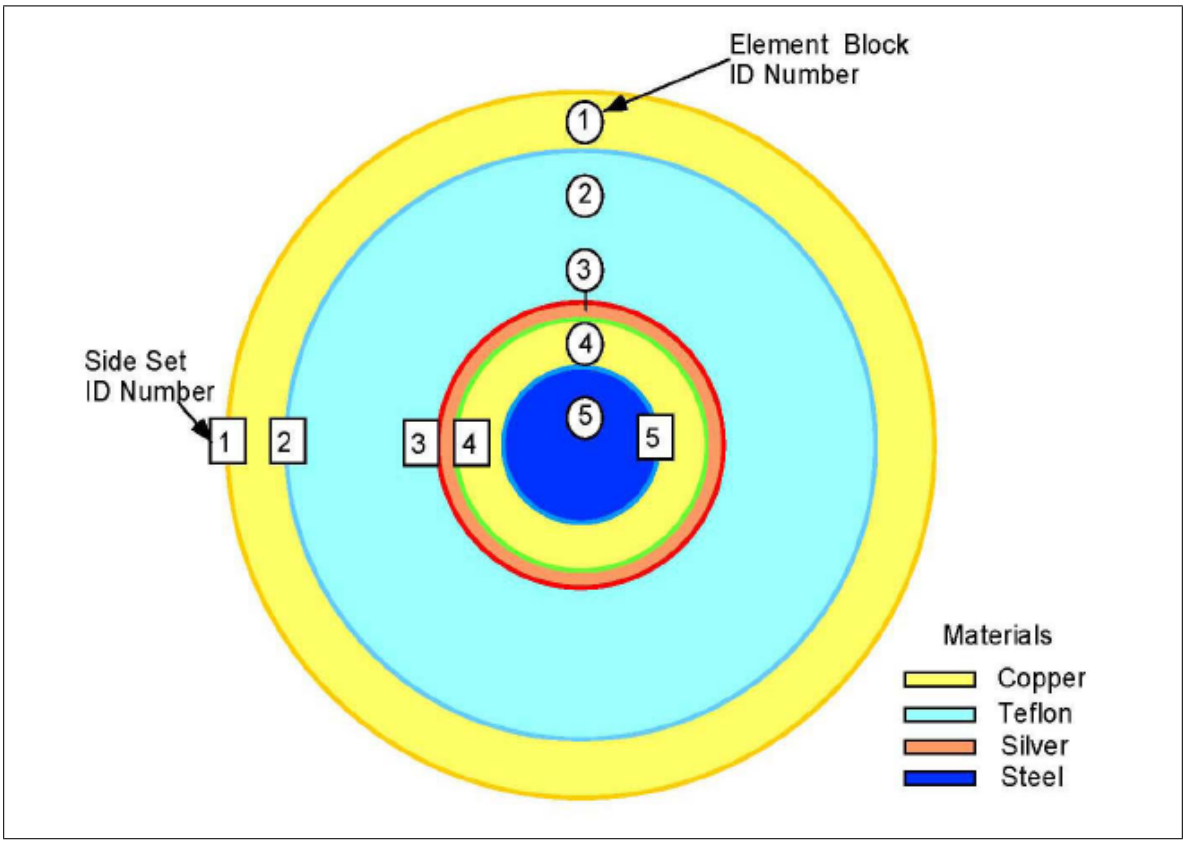
Figure 5.13: Brief Synopsis of Output to Screen During CEPTRE Run

```
*******************************************************************************

 CEPTRE CALCULATION SUMMARY INFORMATION: aljac

------ ELEMENT BLOCK SUMMARY -----------------------------------------------------

                     Optional                    Element
 Element  CEPXS      User          Material      Block
 Block    Material   Specified     Density       Area          Material
 ID       ID         Name          (g/cm^3)      (cm^2)        Type
 -------  --------   -----------   ------------  ------------  ----------------
 1        1          "Aluminum"    2.7           0.0065435     CONDUCTOR
 2        2          "Teflon"      2.2           0.058784      DIELECTRIC (NONCONDUCTOR)
 3        1          "Aluminum"    2.7           0.028789      CONDUCTOR

------ END ELEMENT BLOCK SUMMARY-------------------------------------------------


------ CHARGE CONSERVATION SUMMARY -----------------------------------------------

                      Continuity          Charge-Deposition   CHARGE
 Element  CEPXS       Equation            Cross-Section       CONSERVATION
 Block    Material    CHARGE (q_NL)       CHARGE (q_XS)       RATIO
 ID       ID          (C/m)               (C/m)               ABS(q_NL/q_XS)
 -------  --------    ------------------  ------------------  --------------------
 1        1           5.965044468e-22     6.057271308e-22     9.847741936e-01
 2        2           -2.629925125e-21    -2.651066585e-21    9.920253002e-01
 3        1           5.819649886e-21     5.856377269e-21     9.937286515e-01

------ END CHARGE CONSERVATION SUMMARY -------------------------------------------


------ ENERGY CONSERVATION SUMMARY -----------------------------------------------

                      Continuity          Energy-Deposition   ENERGY
 Element  CEPXS       Equation            Cross-Section       CONSERVATION
 Block    Material    ENERGY (Edep_NL)    ENERGY (Edep_XS)    RATIO
 ID       ID          (rad)               (rad)               ABS(Edep_NL/Edep_XS)
 -------  --------    ------------------  ------------------  --------------------
 1        1           1.447674625e-12     1.505768086e-12     9.614193840e-01
 2        2           3.696732718e-12     3.725962562e-12     9.921550892e-01
 3        1           7.035637605e-12     7.321055476e-12     9.610141089e-01

------ END ENERGY CONSERVATION SUMMARY -------------------------------------------


 END CEPTRE CALCULATION SUMMARY INFORMATION
 *******************************************************************************
```

Figure 5.14: Example of CEPTRE Calculation Summary

User Exercise: Set-Up CEPTRE Input File

Given the coaxial cable depicted below and the problem specifications that follow, set up a CEPTRE Input file. Use the user's guide to help you.



Here are the problem specifications:

1. Photon source, normally incident at the "bottom" of the cable
   - Use 16 Energy Group Spectra in Table 4 on pg. 26.
   - Provide the description in a file named "16gSpectra.data"
2. Energy Group Structure: 16 Photon Groups and 40 Electron Groups
3. S_4 Quadrature, P_3 Legendre Order
4. CEPXS Material IDs: Copper - 1, Teflon - 2, Silver - 3, and Steel - 4
5. Geometry/Finite Element Mesh Model
   - 5 Element Blocks
   - 5 Side Sets

- 1 internal conductor (Side Set #3)

6. Solver Information

   - Block Diagonal Preconditioner for Photon Solve with Tolerance $1.0E-04$
   - Use Solver Tolerance = $1.0E-08$
   - Uncollided Flux Solve with SAAF equation
   - Full Transport Solve with EOPF equation

7. CABANA Input

   - Source Normalization $1.0E14$

1. Fill in the missing information in the CEPTRE input file below:

```
CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS
   NUMBER MATERIALS
   NUMBER PARTICLE TYPES
$  solution flags
   SOLVE UNCOLLIDED FLUX,
   SOLVE COLLIDED FLUX,
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PHOTONS
     AZTEC SET,
     PRECONDITIONER,
   END
$ quadrature set
   SN SET 1,  SN       ,  P     ,  END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE  "                          "
$ boundary condition specifications
   SURFACE SOURCE BC, 1,  sideset
$  CABANA
   CABANA INPUT
   CONDUCTOR,   sideset
   SOURCE NORMALIZATION
$  fill element blocks with cepxs materials
ELEMENT BLOCK 1,  MATERIAL    ,   Name "            ",           ,  END
ELEMENT BLOCK 2,  MATERIAL    ,   Name "            ",           ,  END
ELEMENT BLOCK 3,  MATERIAL    ,   Name "            ",           ,  END
ELEMENT BLOCK 4,  MATERIAL    ,   Name "            ",           ,  END
ELEMENT BLOCK 5,  MATERIAL    ,   Name "            ",           ,  END
$
END
```

2. Fill in the Aztec Solver information missing in the CEPTRE input file below

```
$$$$$$$$$$$$$$$$$$ Aztec Options $$$$$$$$$$$$$$$$$$$$
$ standard CEPTRE options
Aztec
   Solver,
   Scaling,                sym_diag
   Precond,                none
   Maximum iterations,
   Output,                 1000
   Tolerance=              1.e-
End

$ for Block Diagonal Solver
Aztec
   Solver,                 CG
   Scaling,                sym_diag
   Precond,                none
   Maximum iterations,
   Output,                 1000
   Tolerance=              1.e-
End
```

3. Fill in the source description information in the file 16gSpectra.dat below:

```
BEGIN SURFACE SOURCE
  ID 1
  PLANE WAVE
  INCIDENT DIRECTION VECTOR _____
  ENERGY SPECTRA
     1    6.0639E-04
     2    7.2740E-03
     3
     4
     5
     6
     7
     8
     9
     10
     11
     12
     13
     14
     15
     16   9.3858E-14
  END ENERGY SPECTRA
END
```

Check your answers starting on pg. 97.

6 Set-Up An EXOSTRIP Input File

Once the CEPTRE radiation transport simulation is complete and the analyst has determined the results are suitable to send to CABANA to evaluate the cable's electrical response, the next step is to post-process the CEPTRE results using EXOSTRIP (see Appendix C of the EMPHASIS/CABANA Manual[1]). EXOSTRIP is designed to remove the cable conductor element blocks from a CEPTRE Exodus output file. EXOSTRIP also removes all node sets and side sets that are not associated with the dielectric material in the cable.

EXOSTRIP is fairly simple to use and simply requires setting up an input file that looks like that provided in Figure 6.1. The analyst simply specifies the element blocks, side sets and node sets that need to be removed from the CEPTRE Exodus output file. Figure 6.1 is the input necessary to properly strip the CEPTRE input file for the mesh presented in Figure 5.1 on pg. 39.

```
$
$ simple Coaxial Cable Exostrip
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$debug mode, LOCATION, FILE, EXODUS

title
  EXOSTRIP: aljac cable

$$$$$$$$$$$$$$$$$$$$ physics options $$$$$$$$$$$$$$$$$$$$

EXOSTRIP
  strip exodus, block 1, block 3,
                nodeset 4, nodeset 5, nodeset 6,
                sideset 6, end

END

$$$$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$

termination cycle = 1

$emit plot, cycle interval = 1

exit
```

Figure 6.1: Exostrip Input for Simple Coaxial Cable

Prior to running EXOSTRIP, the CEPTRE Exodus output file must be renamed to match the name of the EXOSTRIP input file with a "`.gen`" extension. For example, if the exostrip input file in Figure 6.1 is named `aljac_exostrip.inp`, then you would

perform the following steps to run EXOSTRIP:

4. Create the EXOSTRIP input file as depicted in Figure 6.1 and give it the name `aljac_exostrip.inp`. Remember to strip out *ALL* conductor element blocks, and all node sets and side sets not directly associated with the dielectric.

5. Copy or create a link to the CEPTRE Exodus output file to `aljac.exo` in the current directory:
   ```
   $ ln -s ../ceptre/aljac.exo aljac_exostrip.gen
   ```

6. Run EXOSTRIP using the ***Exostrip*** script provided with your installation:
   ```
   $ ./Exostrip aljac_exostrip
   ```

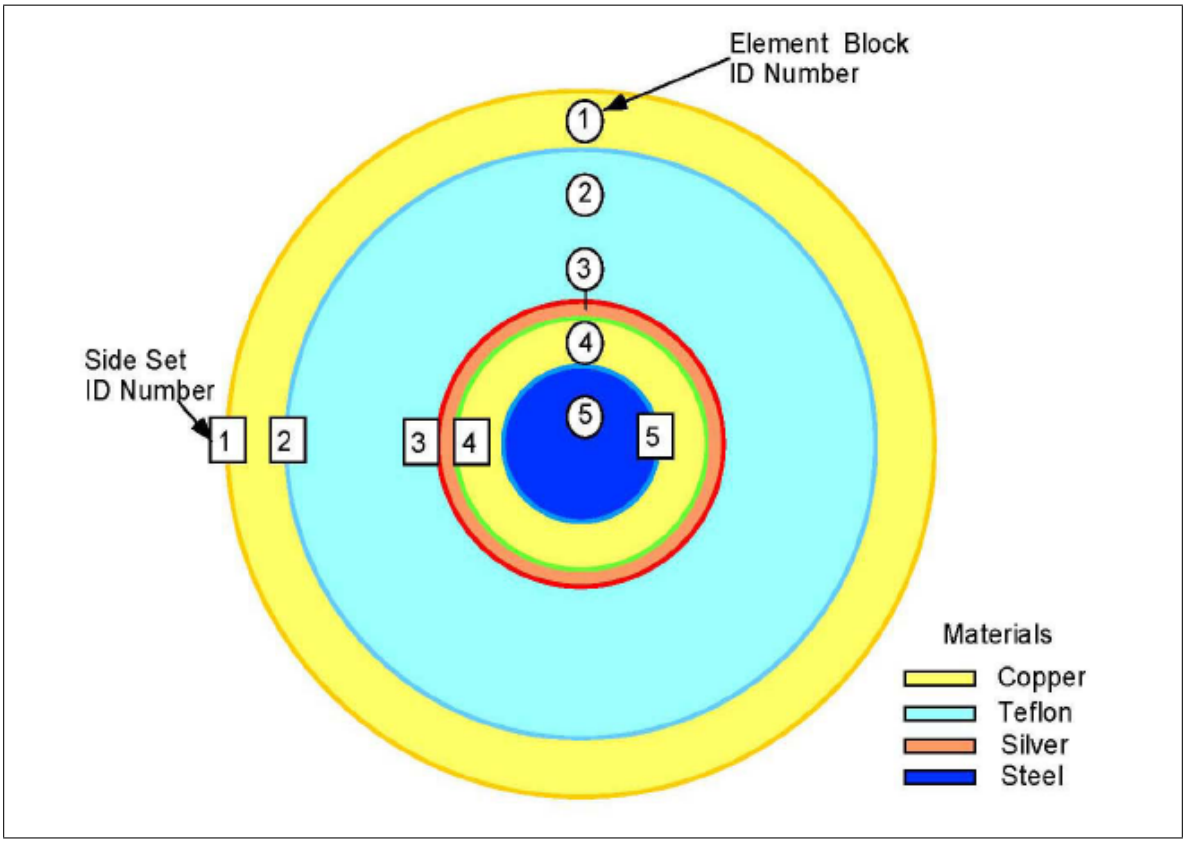
The output you should see to the screen will look like that depicted in Figure 6.2. Remember, that EXOSTRIP is a serial code and should be run with a single processor.

```
File prefix= aljac_exostrip

        EEEEEEE XX   XX  OOOOO   SSSSSS TTTTTT  RRRRRR    IIII  PPPPPP
        EE       XX XX  OO   OO SS        TT    RR   RR    II   PP   PP
        EE        XXX   OO   OO SS        TT    RR   RR    II   PP   PP
        EEEEE     XXX   OO   OO  SSSSS    TT    RRRRRR     II   PPPPPP
        EE        XXX   OO   OO      SS   TT    RRRRR      II   PP
        EE       XX XX  OO   OO      SS   TT    RR  RR     II   PP
        EEEEEEE XX   XX  OOOOO  SSSSSS    TT    RR   RR   IIII  PP


*****************************************************************************
*****************************************************************
        Code Version:     sgemp2D
        Release:          4.6
        Platform/OS:      Linux GCC
        Dimensionality:   2D
        MP Library:       MPI
        Build Date:       07/02/01_11:02:18
        Build Directory:  /projects/ceptre/ICC/sgemp_release_1_1/Wed-
31Jan07/intel/alegra/Build_1.1_2D_icc_opt
*******************************************************************
*******************************************************************
.
.
.

STRIPPED Exodus record written for Region 0 at time (0) = 0
User time: 0.000 cpu sec + System time: 0.020 cpu sec, Elapsed time: 0:07.32
[Approx]
Problem aljac_exostrip FINISHED


*   EXOSTRIP exiting with status: 0
*
*
*    Completed EXOSTRIP calculation for aljac_exostrip
*         at Wed Feb  7 09:28:56 MST 2007
*
*
*******************************************************************
 ...EXOSTRIP Done
```

Figure 6.2: Example of EXOSTRIP Output to Screen

User Exercise: Set-Up EXOSTRIP Input File

Consider the coaxial cable depicted below:



Fill in the EXOSTRIP input file on the following page.

```
$
$ simple Coaxial Cable Exostrip Exercise
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$debug mode, LOCATION, FILE, EXODUS

title
  EXOSTRIP: cable

$$$$$$$$$$$$$$$$ physics options $$$$$$$$$$$$$$$$$$

EXOSTRIP
  strip exodus,
     block ______, block ______, block ______, block ______,

     sideset ______, sideset ______, sideset ______,
  end
END

$$$$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$

termination cycle = 1

$emit plot, cycle interval = 1

exit
```

7 Creating a CABANA Input File

In this section we will set up a CABANA input file to solve the electrical portion of the cable SGEMP simulation. The user should refer to the EMPHASIS/CABANA users manual[1] for help in this section. The CABANA model specifications are:

1. Triangle pulse shape with a risetime = $1.0e-09$ seconds. Initial time step $1.e-10$ seconds. Termination time = 30 nanoseconds
2. One section of Cable that is 1.0 m in length all exposed to the radiation
3. Build the Spice model
4. Load the transport charge density, dose and conductor current.
5. On the internal conductor:
   - Initial potential = 0.0 V
   - Input of the SPICE model resistance = $1.0e08$ ohms
   - Load end of the SPICE model resistance = 50 ohms
6. On the cable shield:
   - Potential = 0.0 V
7. Use a gradual startup factor of 1.0 and a maximum time step ratio of 1.2
8. The dielectric material model uses RIC with a relative permittivity (ε)=2.0, a relative permeability (μ)=1.0, an initial or dark conductivity (σ_0) = 0.0, and for the RIC model set the coefficient, K, equal to $3.26e-06$ and the exponent (e) = 0.95
9. Request screen, plot and hisplt dumps every cycle. Request potential, electric_field and charge_density be written to the output.

The cable model with side set and element block IDs is depicted in Figure 7.1.

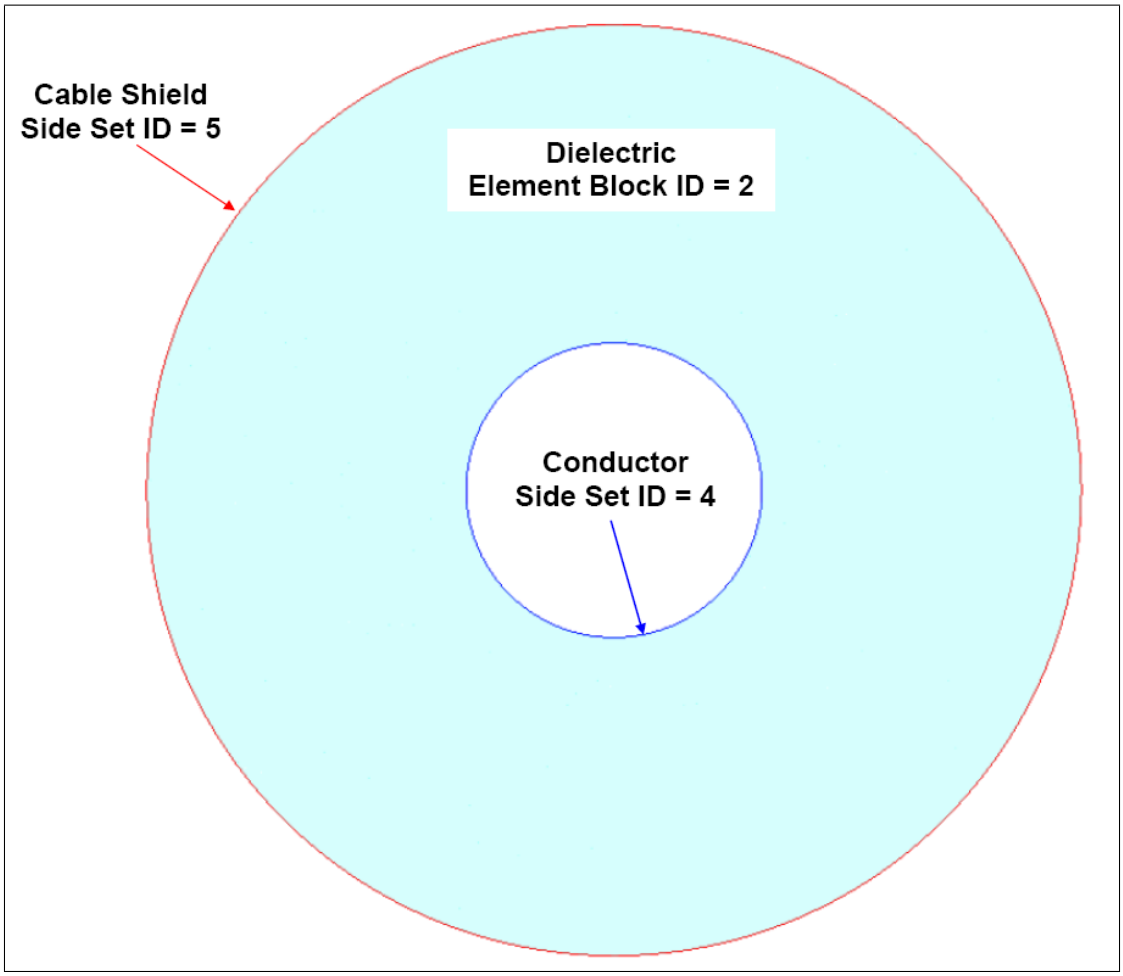


Figure 7.1: Cable Geometry Model for CABANA

Step 1: Add QA Comments

First add a brief QA comment to describe the electrical model:

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac_cabana
$Title:            aljac CABANA base case
$Owner:            Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA------------------------
```

Figure 7.2: Add QA Comments

Note to User: QA comments are completely discretionary, put something that makes sense to you. The only thing you MUST have is a "$" at the beginning of each line.

Step 2: Add Time and Time History Keywords

The time and time history keywords consist of `PULSE SHAPE` and `INITIAL TIME STEP` described in detail in the users manual[1]. Adding these keywords in the `CABLE SGEMP` section of the input file using the problem specifications given on pg. 69 yields the following:

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac_cabana
$Title:            aljac CABANA base case
$Owner:            Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA-----------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
END
```

Figure 7.3: Add Time and Time History Keywords

Step 3: Add SPICE Control Keywords

For this simulation, CABANA will create a lumped-parameter SPICE deck and write it to a file with the `.in` extension. The keyword to do this is simply `SPICE MODEL, BUILD` and the input file becomes:

```
$-------------------BEGIN_QA-------------------------
$RUNID:             aljac_cabana
$Title:             aljac CABANA base case
$Owner:             Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA------------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
  $ spice control
  spice model, build

END
```

Figure 7.4: Add SPICE Control Keywords

Step 4: Add Cable Section Keywords

For this problem, a single cable section 1.0 m long is being exposed to the radiation source. We use the CABANA keywords `NUMBER SECTIONS` and `SECTION PARAMS` to describe this and the input file becomes:

```
$-------------------BEGIN_QA------------------------
$RUNID:             aljac_cabana
$Title:             aljac CABANA base case
$Owner:             Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA-----------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
  $ spice control
  spice model, build
  $ cable sections
  number sections, 1, end
  section params, sec 1, len 1.0, exp, yes

END
```

Figure 7.5: Add Cable Section Keywords

Step 5: Load CEPTRE Data

Here we instruct CABANA to read the charge density, energy deposition and conductor current from a CEPTRE generated Exodus file. The keywords used to do this are `LOAD TRANSPORT CHARGE DENSITY`, `LOAD DOSE` and `LOAD CONDUCTOR CURRENT`. With these keywords, the input file becomes:

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac_cabana
$Title:            aljac CABANA base case
$Owner:            Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA-----------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
  $ spice control
  spice model, build
  $ cable sections
  number sections, 1, end
  section params, sec 1, len 1.0, exp, yes
$  load CEPTRE data
  load transport charge density, yes
  load dose, yes
  load conductor current, yes
END
```

Figure 7.6: Load CEPTRE Data

Step 6: Add Cable Boundary Conditions

Next we specify the conductor and shield as described on pg. 69. From Figure **??** it is clear that the cable shield is defined by side set 5 while the internal cable conductor is defined by side set 4. Using the CABANA `CONDUCTOR` and `SHIELD` keywords, the input file becomes:

```
$-------------------BEGIN_QA-------------------------
$RUNID:             aljac_cabana
$Title:             aljac CABANA base case
$Owner:             Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA------------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
  $ spice control
  spice model, build
  $ cable sections
  number sections, 1, end
  section params, sec 1, len 1.0, exp, yes
$  load CEPTRE data
  load transport charge density, yes
  load dose, yes
  load conductor current, yes
$  cable topology
  conductor, sideset 4, potential 0.,rinpt 1.e8, rload 50.
  shield, sideset 5, potential 0.
END
```

Figure 7.7: Add Cable Topology (Boundary Conditions)

Step 7: Add Nevada Framework Related Keywords

The assignment of materials to the dielectric and the specification of a gradual startup factor and maximum time step ratio are Nevada framework related keywords that must be included within the `CABLE SGEMP` keyword block[1]. For this simulation, we assign material 1 to the dielectric element block and use the startup factor and maximum time step ratio specified on pg. 69 using the keywords `BLOCK`, `GRADUAL STARTUP FACTOR` and `MAIMUM TIME STEP RATIO`. The CABANA input file becomes:

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac_cabana
$Title:            aljac CABANA base case
$Owner:            Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA------------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
  $ spice control
  spice model, build
  $ cable sections
  number sections, 1, end
  section params, sec 1, len 1.0, exp, yes
$  load CEPTRE data
  load transport charge density, yes
  load dose, yes
  load conductor current, yes
$  cable topology
  conductor, sideset 4, potential 0.,rinpt 1.e8, rload 50.
  shield, sideset 5, potential 0.
$  framework related keywords
  block 2
    material 1
  end

  gradual startup factor 1.0
  maximum time step ratio 1.2
END
```

Figure 7.8: Add Nevada Framework Related Keywords

Step 8: Define the Material Model

Next, we will define the material and the RIC Electrical material model using the Nevada framework keywords `MATERIAL` and `MODEL` and the parameters specified on pg. 69. These specifications are done outside of the `CABLE SGEMP` physics keyword blocks. The CABANA input file becomes:

```
$-------------------BEGIN_QA-------------------------
$…
$----------------------END_QA------------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  …
  $ spice control
  …
  $ cable sections
  …
$  load CEPTRE data
  …
$  cable topology
  …
$  framework related keywords
  …
END
$$$$$$$$$$$$$$$$$$$ Materials $$$$$$$$$$$$$$$$$$$$$

Material 1
  Model 1
end

Model 1 RIC Electrical
  eps     2.0
  mu      1.0
  sigma0 0.0
  coefficient 3.23e-6
  exponent 0.95
end
```

Figure 7.9: Define the Material Model

Step 9: Add Execution and Output Control Keywords

Next, we need to specify the CABANA simulation termination time and output variables. These specifications are done with the keywords `TERMINATION TIME` and `PLOT VARIABLE`. The `CRT:OFF` keyword insures that CABANA can be run in the background. We also need to instruct CABANA when to print status information to the screen using the `EMIT SCREEN` keyword. Also, we must instruct CABANA when to write the requested output variables to the Exodus output file and when to write the global variables to the hisplt file using the keywords `EMIT PLOT` and `EMIT HISPLT`. The CABANA input file becomes:

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  …
END
$$$$$$$$$$$$$$$$$$$$ Materials $$$$$$$$$$$$$$$$$$$$$$

Material 1
  Model 1
end

Model 1 RIC Electrical
  eps    2.0
  mu     1.0
  sigma0 0.0
  coefficient 3.23e-6
  exponent 0.95
end

$$$$$$$$$$$$$$$$$$ Execution Control $$$$$$$$$$$$$$$$$$$

termination time = 3.0e-08
CRT:OFF

$$$$$$$$$$$$$$$$$$$$$ Output Control $$$$$$$$$$$$$$$$$$$

emit screen, cycle interval = 1
emit plot, cycle interval = 1
emit hisplt, cycle interval = 1
plot variable
  potential
  electric_field
  charge_density
end
```

Figure 7.10: Add Execution and Output Control Keywords

Step 10: Add Linear Solver Keywords

Next, we need to add the linear solver keywords using the `AZTEC` keyword block. The typical values for CABANA are depicted in the Figure below. Users should consult the CABANA users manual for more guidance[1]. After these keywords the input file is closed with `EXIT`.

```
…
$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  …
END
$$$$$$$$$$$$$$$$$$$$ Materials $$$$$$$$$$$$$$$$$$$$$$

  …

$$$$$$$$$$$$$$$$$ Execution Control $$$$$$$$$$$$$$$$$$

termination time = 3.0e-08
CRT:OFF

$$$$$$$$$$$$$$$$$$$$ Output Control $$$$$$$$$$$$$$$$$$

emit screen, cycle interval = 1
emit plot, cycle interval = 1
emit hisplt, cycle interval = 1
plot variable
  potential
  electric_field
  charge_density
end

$$$$$$$$$$$$$$$$$$$$ Linear Solver $$$$$$$$$$$$$$$$$$$

aztec
  solver,   cg
  precond,  none
  scaling,  sym_diag
  output,   none
  tol      = 1.e-9
  polynomial order, 1
  max iterations, 5000
end

units, si

EXIT
```

Figure 7.11: Add Linear Solver Keywords

7.1 Complete CABANA Input File

Here is the complete CABANA input file created by steps 1 through 10 detailed earlier.

```
$-------------------BEGIN_QA-------------------------
$RUNID:            aljac_cabana
$Title:            aljac CABANA base case
$Owner:            Jennifer Powell
$
$Description:
$  Triangular pulse with 1.0e-9 risetime
$  Rinpt = 1.0E08 ohms, Rload = 50.0 ohms
$
$----------------------END_QA------------------------
TITLE
  CABANA: aljac base case

$$$$$$$$$$$$$$$$ Physics Options $$$$$$$$$$$$$$$$$$$$$$

CABLE SGEMP
  $ time / time history
  Pulse shape, triangle, risetime 1.e-9, end
  Initial time step, 1.e-10, end
  $ spice control
  spice model, build
  $ cable sections
  number sections, 1, end
  section params, sec 1, len 1.0, exp, yes
$  load CEPTRE data
  load transport charge density, yes
  load dose, yes
  load conductor current, yes
$  cable topology or boundary conditions
  conductor, sideset 4, potential 1.,rinpt 1.e8, rload 50.
  shield, sideset 5, potential 0.
$  Nevada framework related keywords
  block 2
    material 1
  end

  gradual startup factor 1.0
  maximum time step ratio 1.2
END

$$$$$$$$$$$$$$$$$$$$ Materials $$$$$$$$$$$$$$$$$$$$$$
```

```
Material 1
  Model 1
end

Model 1 RIC Electrical
  eps    2.0
  mu     1.0
  sigma0 0.0
  coefficient 3.23e-6
  exponent 0.95
end

$$$$$$$$$$$$$$$$ Execution Control $$$$$$$$$$$$$$$$$$

termination time = 3.0e-08
CRT:OFF

$$$$$$$$$$$$$$$$$$$ Output Control $$$$$$$$$$$$$$$$$$$

emit screen, cycle interval = 1
emit plot, cycle interval = 1
emit hisplt, cycle interval = 1
plot variable
  potential
  electric_field
  charge_density
end

$$$$$$$$$$$$$$$$$$$ Linear Solver $$$$$$$$$$$$$$$$$$$

aztec
  solver,   cg
  precond,  none
  scaling,  sym_diag
  output,   none
  tol      = 1.e-9
  polynomial order, 1
  max iterations, 5000
end

units, si

EXIT
```

7.2 Running CABANA

Run CABANA using the `Emphasis` or `Sgemp` script provided with your installation as follows:

```
$ export SGEMP_EXE=path-to-executable/exeName
```

```
$ ./Emphasis -nprocs num_procs --x $SGEMP_EXE runid | tee
runid.log
```

or

```
$ ./Sgemp -nprocs num_procs --x $SGEMP_EXE runid | tee runid.log
```

where `num_procs` is the number of processors, `path-to-executable/exeName` is the installation path and name of the Emphasis executable and the job name is `runid`. Most likely you will place this line in a PBS or other batch queue job script. Typically, the EMPHASIS/CABANA code will be in an executable named along the lines "`sgemp_1.1_2D_gnu3_opt.x`". **Refer to your installation notes for help with running CABANA.**

For example, if we have a `runid=aljac` and we want to use 20 processors we would do the following:

```
$ export
SGEMP_EXE=/usr/local/Sgemp1.1/bin/sgemp_1.1_2D_gnu3_opt.x
```

```
$ ./Emphasis -nprocs 20 -x $SGEMP_EXE aljac | tee aljac.log
```

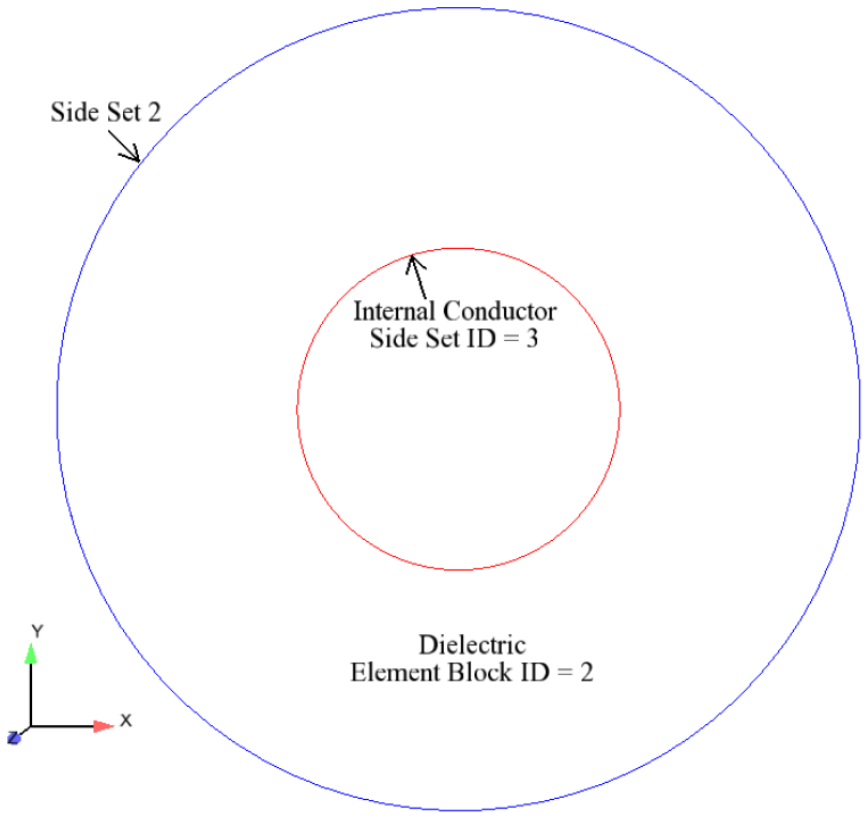
When your CABANA run completes successfully it will write out the FINAL LOAD CHARGE which is the electrical response of the cable. The time history of the load currents can be found in the `runid.his` file under the name "LOAD-CURRENT," and the time integral of the LOAD-CURRENT should equal the FINAL LOAD CHARGE. The distribution should provide you with a utility called "shiv" which will allow you to view the hisplt file, `runid.his`, using the following syntax: `"shiv runid.his"`

```
Starting CABANA calculation...
*
* Calculation will be performed on ICC-liberty (i686)
* running Linux release 2.4.21-27.0.2.ELSFSsmp version #1 SMP Fri Jan 28 14:22:15 MST 2005
*
*    The executable for this problem will be
*    /usr/local/Sgemp1.1/bin/sgemp_1.1_2D_icc_opt.x
*
*    CABANA will be run in DEFAULT mode with the command:
*
*      mpiexec -n 20
/usr/local/Sgemp1.1/bin/sgempIntel/alegra/bin/sgemp_1.1_2D_icc_opt.x -c -p 20 -r 1 -f 1 -o
1 -R /home/jlpowel/aljac/cabana/ -S . -g par -L /home/jlpowel/aljac/cabana aljac_cabana
*
*
*
*    Starting CABANA calculation for aljac_cabana
*         at Wed Feb  7 09:29:00 MST 2007
*
*
Genesis Suffix (-g)= par
Number of Raids (-r)= 1
Root dir (-R)= /home/jlpowel/aljac/cabana/
Sub dir (-S)= .
Raid Offset (-o)= 1
Number of Files to Write Concurrently (-f)= 1
Current dir (-L)= /home/jlpowel/ aljac/cabana
File prefix= aljac_cabana
Number of processors (-p)= 20
Debug Mode: CABANA

        EEEEEEE M     M PPPPPP  HH   HH  AAAAA   SSSSSS   IIII   SSSSSS
        EE      MM   MM PP   PP HH   HH AA   AA SS         II   SS
        EE      MMM MMM PP   PP HH   HH AA   AA SS         II   SS
        EEEEE   MM M MM PPPPPP  HHHHHHH AAAAAAA  SSSSS     II    SSSSS
        EE      MM   MM PP      HH   HH AA   AA      SS    II        SS
        EE      MM   MM PP      HH   HH AA   AA      SS    II        SS
        EEEEEEE MM   MM PP      HH   HH AA   AA SSSSSS    IIII  SSSSSS

                 CCCCC   AAAAA  BBBBBB   AAAAA  N    NN  AAAAA
                CC   CC AA   AA BB   BB AA   AA NN   NN AA   AA
                CC      AA   AA BB   BB AA   AA NNN  NN AA   AA
                CC      AAAAAAA BBBBBB  AAAAAAA NN N NN AAAAAAA
                CC      AA   AA BB   BB AA   AA NN  NNN AA   AA
                CC   CC AA   AA BB   BB AA   AA NN   NN AA   AA
                 CCCCC  AA   AA BBBBBB  AA   AA NN    N AA   AA
*******************************************************************************
*******************************************************************************
…
Final Conductor Load Charges:
Conductor 4 Load Charge= -1.09323e-23

User time: 0.320 cpu sec + System time: 4.500 cpu sec, Elapsed time: 3:52.15 [Approx]
Problem aljac_cabana FINISHED


*   CABANA exiting with status: 0
*
*
*    Completed CABANA calculation for aljac_cabana
*         at Wed Feb  7 09:32:52 MST 2007
```

Figure 7.12: Brief Synopsis of Output to Screen During CABANA Run

User Exercise: Set-Up CABANA Input File

Here we will create a CABANA input file for the stripped cable depicted in Figure **??**.



The CABANA simulation details are given below:

1. Triangle pulse shape with a risetime = $1.0e-09$ seconds. Initial time step $1.e-10$ seconds. Termination time = 50 nanoseconds
2. One section of Cable that is 0.5 m in length all exposed to the radiation
3. Build the Spice model
4. Load the transport charge density, dose and conductor current.
5. On the internal conductor:
   - Initial potential = 1.0 V
   - Input of the SPICE model resistance = $1.0e08$ ohms
   - Load end of the SPICE model resistance = 50 ohms

6. On the cable shield:
    - Potential = 0.0 V
7. Use a gradual startup factor of 1.0 and a maximum time step ratio of 1.2
8. The dielectric material model uses RIC with a relative permittivity (ε)=2.2, a relative permeability (μ)=1.0, an initial or dark conductivity (σ_0) = 0.0, and for the RIC model set the coefficient, K, equal to $3.23e-06$ and the exponent (e) = 0.95
9. Request screen, plot and hisplt dumps every cycle. Request potential, electric_field and charge_density be written to the output.

Fill in the CABANA input file presented on the next two pages.

```
$-----------------------------------BEGIN_QA---------------------------
$ RUNID:    rg402
$-----------------------------------END_QA---------------------------

$ debug mode, cabana
title
  CABANA: Coaxial cable with quad8 mesh
$$$$$$$$$$$$$$$$$$$$ physics options $$$$$$$$$$$$$$$$$$$$
CABLE SGEMP
$  time/time history
  pulse shape, ____________, risetime ____________, end
  initial time step, _______________, end
$ spice control
  spice model, ________________
$  cable sections
  number sections, 1, end
  section params, sec 1, len _______, exp, yes
$ load CEPTRE data
  load transport charge density, _________
  load dose, yes
  load conductor current, yes
$  cable topology or boundary conditions
  conductor, sideset___, potential _____, rinpt _______, rload ________
  shield, sideset ___, potential _________

  block 2
    material 1
  end

  gradual startup factor 1.0
  maximum time step ratio 1.2
end
$ Aztec solver
aztec
  solver,   cg
  precond,  none
  scaling,  sym_diag
  output,   none
  tol      = 1.e-9
  polynomial order, 1
  max iterations, 5000
end

units, si
```

```
$$$$$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$

termination time = __________

$$$$$$$$$$$$$$$$$$$$ material models $$$$$$$$$$$$$$$$$$$$

emit screen, cycle interval = 1
emit plot, cycle interval = 1
emit hisplt, cycle interval = 1
plot variable
  ____________________
  ____________________
  ____________________
end

$$$$$$$$$$$$$$$$$$$$ material models $$$$$$$$$$$$$$$$$$$$

Material 1
  Model 1
end

Model 1 RIC Electrical
  eps _________________
  mu  _________________
  sigma0 _______________
  coefficient ___________
  exponent ______________
end

crt: off
exit
```

8 Summary

Performing cable SGEMP simulations is not a simple task. The physics that the codes are modeling are complex and the cable SGEMP simulation process involves a number of steps. The first step is the conversion of the photon source energy spectra into a multi-group form suitable for both CEPTRE and CEPXS. Next, CEPXS is run to generate cross-section data for CEPTRE. A finite element mesh of the cable geometry must be produced with refinement at material interfaces. Then CEPTRE is run to determine the charge and energy deposited in the dielectric layers of the cable as well as the net current from each internal conductor. The CEPTRE output is post-processed by EXOSTRIP to remove conductor layers before running the quasi-electrostatic and circuit model in CABANA.

This tutorial should give you a foundation for working each part of the process; however, it is not all-inclusive. Much of what analysts learn in running these types of simulations is obtained by simply going through the process and discussing results with other analysts.

9 Solutions to User Exercises

Set-Up CEPXS Input and CEPTRE Source

Here is the solution to the user exercise found on page 31.

The correct energy spectra data is:

Energy Bin #	Upper Energy (MeV)	Lower Energy (MeV)	Number of Photons/Bin	NORMALIZED Photons/Bin
1	0.178	0.140	4.3423E-03	9.9222E-03
2	0.140	0.100	2.7280E-02	6.2335E-02
3	0.100	0.085	2.2650E-02	5.1756E-02
4	0.085	0.070	3.3550E-02	7.6662E-02
5	0.070	0.059	4.3690E-02	9.9832E-02
6	0.059	0.045	9.1230E-02	2.0846E-01
7	0.045	0.030	1.1345E-01	2.5924E-01
8	0.030	0.015	9.6800E-02	2.2119E-01
9	0.016	0.007	4.6408E-03	1.0604E-02
10	0.007	0.001	4.7747E-07	1.0910E-06
	TOTAL Number of Photons =		4.3763E-01	1.0000E+00

The correct CEPXS input file is:

```
title
  a 10 photon group cepinp file
energy   0.1589
cutoff 0.001
legendre 7
photon-source
  partial-coupling
photons
  user 10
  0.140        0.100
  0.085        0.070
  0.059        0.045
  0.030        0.015
  0.007        0.001
electrons
  linear 55
material al
material  c 0.2402 f 0.7598
  density 2.2
print
  leg 7
```

The CEPTRE surface source description answer is:

```
BEGIN SURFACE SOURCE
  ID 1
  PLANE WAVE
  INCIDENT DIRECTION VECTOR 0. -1. 0.
  ENERGY SPECTRA
    1    9.9222E-03
    2    6.2335E-02
    3    5.1756E-02
    4    7.6662E-02
    5    9.9832E-02
    6    2.0846E-01
    7    2.5924E-01
    8    2.2119E-01
    9    1.0604E-02
    10   1.0910E-06
  END ENERGY SPECTRA
END
```

Set-Up CEPTRE Input File

Here is the solution to the user exercise presented on pg. 57. The filled in CEPTRE input file looks like:

```
CEPTRE
$  problem definition
   NUMBER ENERGY GROUPS   76
   NUMBER MATERIALS       4
   NUMBER PARTICLE TYPES  2
$  solution flags
   SOLVE UNCOLLIDED FLUX,  SAAF
   SOLVE COLLIDED FLUX,   EOPF
$  efficiency improvements/solve options
   BLOCK SOLVE OPTIONS
     PHOTONS
     AZTEC SET,        1
     PRECONDITIONER,  Block diagonal
   END
$ quadrature set
   SN SET 1,   SN  4     ,   P  3   ,  END
   PHOTON QUADRATURE SET 1
   ELECTRON QUADRATURE SET 1
$ source info
   SURFACE SOURCE
   INCLUDE  "16gSpectra.data"
$ boundary condition specifications
   SURFACE SOURCE BC, 1,  Sideset 1
$  CABANA
   CABANA INPUT
   CONDUCTOR,   sideset 3
   SOURCE NORMALIZATION    1.0E14
$  fill element blocks with cepxs materials
ELEMENT BLOCK 1,  MATERIAL 1 ,    Name " Copper",   Conductor,    END
ELEMENT BLOCK 2,  MATERIAL 2  ,   Name " Teflon",   Dielectric,   END
ELEMENT BLOCK 3,  MATERIAL 3  ,   Name " Silver",   Conductor,    END
ELEMENT BLOCK 4,  MATERIAL 1  ,   Name " Copper",   Conductor,    END
ELEMENT BLOCK 5,  MATERIAL 4  ,   Name " Steel",    Conductor,    END
$
END
```

The correct aztec solver options are:

```
$$$$$$$$$$$$$$$$$$ Aztec Options $$$$$$$$$$$$$$$$$$$$$$
$ standard CEPTRE options
Aztec
   Solver,                CG
   Scaling,               sym_diag
   Precond,               none
   Maximum iterations,    20000
   Output,                1000
   Tolerance=             1.e-08
End

$ for Block Diagonal Solver
Aztec
   Solver,                CG
   Scaling,               sym_diag
   Precond,               none
   Maximum iterations,    10000
   Output,                1000
   Tolerance=             1.e-04
End
```

The correct surface source description is:

```
BEGIN SURFACE SOURCE
  ID 1
  PLANE WAVE
  INCIDENT DIRECTION VECTOR 0.    1.    0.
  ENERGY SPECTRA
     1    6.0639E-04
     2    7.2740E-03
     3    2.3556E-02
     4    3.4737E-02
     5    3.4621E-02
     6    4.7044E-02
     7    5.0586E-02
     8    7.8675E-02
     9    1.4069E-01
     10   1.5275E-01
     11   1.9600E-01
     12   1.8599E-01
     13   4.4748E-02
     14   2.7226E-03
     15   1.8880E-10
     16   9.3858E-14
  END ENERGY SPECTRA
END
```

Set-Up EXOSTRIP Input File

Here is the solution to the user exercise 6 presented on pg. 66. The filled in EXOSTRIP input file looks like:

```
$
$ simple Coaxial Cable Exostrip Exercise
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$debug mode, LOCATION, FILE, EXODUS

title
  EXOSTRIP: cable

$$$$$$$$$$$$$$$ physics options $$$$$$$$$$$$$$$$$$

EXOSTRIP
  strip exodus,
     block     1, block     3, block     4, block     5,

     sideset     1, sideset     4, sideset     5,
  end
END

$$$$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$

termination cycle = 1

$emit plot, cycle interval = 1

exit
```

Set-Up CABANA Input File

The solution to the user exercise on pg. 85 is presented here.

```
$-----------------------------------BEGIN_QA---------------------------
$ RUNID:    rg402
$-----------------------------------END_QA-----------------------------

$ debug mode, cabana
title
  CABANA: Coaxial cable with quad8 mesh
$$$$$$$$$$$$$$$$$$$$ physics options $$$$$$$$$$$$$$$$$$$$
CABLE SGEMP
$  time/time history
  pulse shape,   triangle ,    risetime   1.0E-09  ,    end
  initial time step,   1.0e-10   , end
$ spice control
  spice model,  build
$  cable sections
  number sections, 1, end
  section params, sec 1, len  0.50  , exp, yes
$ load CEPTRE data
  load transport charge density,  yes
  load dose, yes
  load conductor current, yes
$  cable topology or boundary conditions
  conductor, sideset 3 , potential  1.0 , rinpt  1.0E08, rload  50.
  shield, sideset  2 , potential   0.0

  block 2
    material 1
  end

  gradual startup factor 1.0
  maximum time step ratio 1.2
end
$ Aztec solver
aztec
  solver,   cg
  precond,  none
  scaling,  sym_diag
  output,   none
  tol      = 1.e-9
  polynomial order, 1
  max iterations, 5000
end

units, si
```

```
$$$$$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$$$

termination time = 5.0e-08

$$$$$$$$$$$$$$$$$$$$ material models $$$$$$$$$$$$$$$$$$$$

emit screen, cycle interval = 1
emit plot, cycle interval = 1
emit hisplt, cycle interval = 1
plot variable
  potential
  electric field
  charge density
end

$$$$$$$$$$$$$$$$$$$$ material models $$$$$$$$$$$$$$$$$$$$

Material 1
  Model 1
end

Model 1 RIC Electrical
  eps 2.2
  mu 1.0
  sigma0 0.0
  coefficient 3.23E-6
  exponent 0.95
end

crt: off
exit
```

References

[1] C. D. Turner, W. J. Bohnhoff, and J. L. Powell. EMPHASIS/Nevada CABANA User Guide Version 1.1. Technical report SAND2006-1119, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, March 2006.

[2] J. L. Liscum-Powell, W. J. Bohnhoff, C. R. Drumm, W. C. Fan and S. D. Pautz. Ceptre version 1.0 physics and numerics guide. Technical report - IN PREPARATION SAND2007-XXXX, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, March 2007.

[3] J. L. Liscum-Powell, W. J. Bohnhoff, C. R. Drumm, W. C. Fan and S. D. Pautz. Ceptre version 1.1 User's manual. Technical report SAND2007-XXXX, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, March 2007.

[4] J. E. Morel L. J. Lorence, Jr. and G. D. Valdez. Physics guide to cepxs: A multigroup coupled electron-photon cross-section generating code version 1.0. Technical report SAND89-1685, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, October 1989.

[5] J. E. Morel L. J. Lorence, Jr. and G. D. Valdez. User's guide to cepxs/onedant: A one-dimensional coupled electron-photon discrete ordinates code package version 1.0. Technical report SAND89-1661, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, September 1989.

[6] L. A. Schoof and V.R. Yarberry. Exodus ii : a finite element data model. Technical report SAND92-2137, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, September 1996.

A Electronic Files Distributed with Tutorial

Here is a list of files and descriptions accompanying this tutorial.

If you did not receive the electronic distribution, please contact Jennifer Liscum-Powell by email at jlpowel@sandia.gov to request this information.

B CEPXS Example 1: aljac31.cepinp

The aljac31.cepinp file is listed below:

```
title
  aljac cable SGEMP
energy 0.162
cutoff 0.001
legendre 7
photon-source
  partial-coupling
photons
  user 31
  0.160   0.150  0.140  0.130  0.120  0.110
  0.100   0.095  0.090  0.085  0.080  0.075
  0.070   0.067  0.063  0.059  0.054  0.050
  0.045   0.040  0.035  0.030  0.025  0.020
  0.015   0.012  0.009  0.007  0.005  0.003
  0.001
electrons
  linear 55
material al
material  c 0.2402 f 0.7598
  density 2.2
print
  leg 7
```

The CEPXS output file, aljac31.cepout, should contain the photon energy group stucture depicted in Figure B.13 and the electron energy group structure depicted in Figure .

SUMMARY OF PHOTON GROUP STRUCTURE

GROUP	UPPER ENERGY (MEV)	AVERAGE ENERGY (MEV)	LOWER ENERGY (MEV)	INTERVAL	FRACTIONAL WIDTH
1	1.64000E-01	1.62000E-01	1.60000E-01	4.00000E-03	2.46914E-02
2	1.60000E-01	1.55000E-01	1.50000E-01	1.00000E-02	6.45161E-02
3	1.50000E-01	1.45000E-01	1.40000E-01	1.00000E-02	6.89655E-02
4	1.40000E-01	1.35000E-01	1.30000E-01	1.00000E-02	7.40741E-02
5	1.30000E-01	1.25000E-01	1.20000E-01	1.00000E-02	8.00000E-02
6	1.20000E-01	1.15000E-01	1.10000E-01	1.00000E-02	8.69565E-02
7	1.10000E-01	1.05000E-01	1.00000E-01	1.00000E-02	9.52381E-02
8	1.00000E-01	9.75000E-02	9.50000E-02	5.00000E-03	5.12821E-02
9	9.50000E-02	9.25000E-02	9.00000E-02	5.00000E-03	5.40541E-02
10	9.00000E-02	8.75000E-02	8.50000E-02	5.00000E-03	5.71429E-02
11	8.50000E-02	8.25000E-02	8.00000E-02	5.00000E-03	6.06061E-02
12	8.00000E-02	7.75000E-02	7.50000E-02	5.00000E-03	6.45161E-02
13	7.50000E-02	7.25000E-02	7.00000E-02	5.00000E-03	6.89655E-02
14	7.00000E-02	6.85000E-02	6.70000E-02	3.00000E-03	4.37956E-02
15	6.70000E-02	6.50000E-02	6.30000E-02	4.00000E-03	6.15385E-02
16	6.30000E-02	6.10000E-02	5.90000E-02	4.00000E-03	6.55738E-02
17	5.90000E-02	5.65000E-02	5.40000E-02	5.00000E-03	8.84956E-02
18	5.40000E-02	5.20000E-02	5.00000E-02	4.00000E-03	7.69231E-02
19	5.00000E-02	4.75000E-02	4.50000E-02	5.00000E-03	1.05263E-01
20	4.50000E-02	4.25000E-02	4.00000E-02	5.00000E-03	1.17647E-01
21	4.00000E-02	3.75000E-02	3.50000E-02	5.00000E-03	1.33333E-01
22	3.50000E-02	3.25000E-02	3.00000E-02	5.00000E-03	1.53846E-01
23	3.00000E-02	2.75000E-02	2.50000E-02	5.00000E-03	1.81818E-01
24	2.50000E-02	2.25000E-02	2.00000E-02	5.00000E-03	2.22222E-01
25	2.00000E-02	1.75000E-02	1.50000E-02	5.00000E-03	2.85714E-01
26	1.50000E-02	1.35000E-02	1.20000E-02	3.00000E-03	2.22222E-01
27	1.20000E-02	1.05000E-02	9.00000E-03	3.00000E-03	2.85714E-01
28	9.00000E-03	8.00000E-03	7.00000E-03	2.00000E-03	2.50000E-01
29	7.00000E-03	6.00000E-03	5.00000E-03	2.00000E-03	3.33333E-01
30	5.00000E-03	4.00000E-03	3.00000E-03	2.00000E-03	5.00000E-01
31	3.00000E-03	2.00000E-03	1.00000E-03	2.00000E-03	1.00000E+00

Figure B.13: CEPXS Photon Group Structure for 31 Group Input

SUMMARY OF ELECTRON GROUP STRUCTURE

GROUP	UPPER ENERGY (MEV)	AVERAGE ENERGY (MEV)	LOWER ENERGY (MEV)	INTERVAL	FRACTIONAL WIDTH
1	1.64000E-01	1.62518E-01	1.61036E-01	2.96364E-03	1.82357E-02
2	1.61036E-01	1.59555E-01	1.58073E-01	2.96364E-03	1.85744E-02
3	1.58073E-01	1.56591E-01	1.55109E-01	2.96364E-03	1.89260E-02
4	1.55109E-01	1.53627E-01	1.52145E-01	2.96364E-03	1.92911E-02
5	1.52145E-01	1.50664E-01	1.49182E-01	2.96364E-03	1.96705E-02
6	1.49182E-01	1.47700E-01	1.46218E-01	2.96364E-03	2.00652E-02
7	1.46218E-01	1.44736E-01	1.43255E-01	2.96364E-03	2.04761E-02
8	1.43255E-01	1.41773E-01	1.40291E-01	2.96364E-03	2.09041E-02
9	1.40291E-01	1.38809E-01	1.37327E-01	2.96364E-03	2.13504E-02
10	1.37327E-01	1.35845E-01	1.34364E-01	2.96364E-03	2.18162E-02
11	1.34364E-01	1.32882E-01	1.31400E-01	2.96364E-03	2.23028E-02
12	1.31400E-01	1.29918E-01	1.28436E-01	2.96364E-03	2.28116E-02
13	1.28436E-01	1.26955E-01	1.25473E-01	2.96364E-03	2.33441E-02
14	1.25473E-01	1.23991E-01	1.22509E-01	2.96364E-03	2.39020E-02
15	1.22509E-01	1.21027E-01	1.19545E-01	2.96364E-03	2.44873E-02
16	1.19545E-01	1.18064E-01	1.16582E-01	2.96364E-03	2.51020E-02
17	1.16582E-01	1.15100E-01	1.13618E-01	2.96364E-03	2.57484E-02
18	1.13618E-01	1.12136E-01	1.10655E-01	2.96364E-03	2.64289E-02
19	1.10655E-01	1.09173E-01	1.07691E-01	2.96364E-03	2.71463E-02
20	1.07691E-01	1.06209E-01	1.04727E-01	2.96364E-03	2.79038E-02
21	1.04727E-01	1.03245E-01	1.01764E-01	2.96364E-03	2.87048E-02
22	1.01764E-01	1.00282E-01	9.88000E-02	2.96364E-03	2.95531E-02
23	9.88000E-02	9.73182E-02	9.58364E-02	2.96364E-03	3.04531E-02
24	9.58364E-02	9.43545E-02	9.28727E-02	2.96364E-03	3.14096E-02
25	9.28727E-02	9.13909E-02	8.99091E-02	2.96364E-03	3.24281E-02
26	8.99091E-02	8.84273E-02	8.69455E-02	2.96364E-03	3.35150E-02
27	8.69455E-02	8.54636E-02	8.39818E-02	2.96364E-03	3.46772E-02
28	8.39818E-02	8.25000E-02	8.10182E-02	2.96364E-03	3.59229E-02
29	8.10182E-02	7.95364E-02	7.80545E-02	2.96364E-03	3.72614E-02
30	7.80545E-02	7.65727E-02	7.50909E-02	2.96364E-03	3.87035E-02
31	7.50909E-02	7.36091E-02	7.21273E-02	2.96364E-03	4.02618E-02
32	7.21273E-02	7.06455E-02	6.91636E-02	2.96364E-03	4.19508E-02
33	6.91636E-02	6.76818E-02	6.62000E-02	2.96364E-03	4.37878E-02
34	6.62000E-02	6.47182E-02	6.32364E-02	2.96364E-03	4.57929E-02
35	6.32364E-02	6.17545E-02	6.02727E-02	2.96364E-03	4.79906E-02
36	6.02727E-02	5.87909E-02	5.73091E-02	2.96364E-03	5.04098E-02
37	5.73091E-02	5.58273E-02	5.43455E-02	2.96364E-03	5.30858E-02
38	5.43455E-02	5.28636E-02	5.13818E-02	2.96364E-03	5.60619E-02
39	5.13818E-02	4.99000E-02	4.84182E-02	2.96364E-03	5.93915E-02
40	4.84182E-02	4.69364E-02	4.54545E-02	2.96364E-03	6.31416E-02
41	4.54545E-02	4.39727E-02	4.24909E-02	2.96364E-03	6.73971E-02
42	4.24909E-02	4.10091E-02	3.95273E-02	2.96364E-03	7.22678E-02
43	3.95273E-02	3.80455E-02	3.65636E-02	2.96364E-03	7.78973E-02
44	3.65636E-02	3.50818E-02	3.36000E-02	2.96364E-03	8.44778E-02
45	3.36000E-02	3.21182E-02	3.06364E-02	2.96364E-03	9.22729E-02
46	3.06364E-02	2.91545E-02	2.76727E-02	2.96364E-03	1.01653E-01
47	2.76727E-02	2.61909E-02	2.47091E-02	2.96364E-03	1.13155E-01
48	2.47091E-02	2.32273E-02	2.17455E-02	2.96364E-03	1.27593E-01
49	2.17455E-02	2.02636E-02	1.87818E-02	2.96364E-03	1.46254E-01
50	1.87818E-02	1.73000E-02	1.58182E-02	2.96364E-03	1.71308E-01
51	1.58182E-02	1.43364E-02	1.28545E-02	2.96364E-03	2.06722E-01
52	1.28545E-02	1.13727E-02	9.89091E-03	2.96364E-03	2.60592E-01
53	9.89091E-03	8.40909E-03	6.92727E-03	2.96364E-03	3.52432E-01
54	6.92727E-03	5.44545E-03	3.96364E-03	2.96364E-03	5.44240E-01
55	3.96364E-03	2.48182E-03	1.00000E-03	2.96364E-03	1.19414E+00

Figure B.14: CEPXS Electron Energy Group Structure

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