***Program EPICP: Electron Photon Interaction Code:
Photon Test Module***

(Version 94.2)

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Introduction

The computer code EPICP performs Monte Carlo photon transport calculations in a simple one zone cylindrical detector. Results include deposition within the detector, transmission, reflection and lateral leakage from the detector, as well as events and energy deposition as a function of the depth into the detector.

EPICP is part of the EPIC (Electron Photon Interaction Code) system. EPICP is designed to perform both normal transport calculations and diagnostic calculations involving only photons, with the objective of developing optimum algorithms for later use in EPIC.

The EPIC system includes other modules that are designed to develop optimum algorithms for later use in EPIC; this includes electron and positron transport (EPICE), neutron transport (EPICN), charged particle transport (EPICC), geometry (EPICG), source sampling (EPICS). This is a modular system that once optimized can be linked together to consider a wide variety of particles, geometries, sources, etc.

By design EPICP only considers photon transport. In particular it does not consider electron transport so that later EPICP and EPICE can be used to quantitatively evaluate the importance of electron transport when starting from photon sources. In this report I will merely mention where we expect the results to significantly differ from those obtained considering only photon transport from that obtained using coupled electron-photon transport.

Code Documentation

This code is designed to be self documenting, in the sense that the latest documentation is included as comment lines at the beginning of the code. Periodically printed documentation is published, such as this report, consisting mostly of a copy of the comment lines from the code. The user should be aware that the comment lines within the code are continually updated to reflect the most recent status of the code. These comments provide the most recent documentation for the code and may supersede published documentation, such as this report. Therefore, the user should always read the documentation within the actual code.

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The remainder of this report consists of an explanation of definitions used by this code, example results and a listing of the documentation that appears at the beginning of the code. I recommend that you now read all of this documentation from the code, which appears later in this report, and only then return to this point to see example results.

Detector Response and Leakage

In order to correctly interpret the results produced by this code the user must understand the definitions of detector response and leakage used by this code. Starting from each source photon the code tracks this photon and all photons that it may produce (through pair production, fluorescence, etc.) until they have all "disappeared", i.e., either leak or are absorbed. For each source photon this is defined to be one history. The detector response is then defined as one count, corresponding to the total energy deposited in the detector during the entire history. Since this code only tracks photons, it is assumed that everything happens at the speed of light and rather than responding separately to each event that occurs within the detector, the detector will add all of the energy deposited by all events during a history and score a single count corresponding to the total energy deposited during the entire history.

For example, consider the typical history of a 10 MeV photon incident on the detector. Assume the initial photon undergoes pair production. The result will be a deposition of the incident energy of the photon minus the energy of two 0.511 MeV photons produced when the positron annihilates, but the history isn't finished yet. Each of the 0.511 MeV photons is then separately tracked. Each may undergo more collisions and deposit all or a portion of their energy, or they may leak from the detector. Let's consider the energy deposited for three cases: 1) both 0.511 MeV photons are absorbed in the detector = all 10 MeV of the incident photon is deposited, 2) one 0.511 MeV photon leaks = about 9.5 MeV is deposited, 3) both 0.511 MeV photons leak = about 9 MeV is deposited. In each of these cases the total amount of energy deposited is recorded as a single event, so that these three cases correspond to three different energy depositions of about 10, 9.5 or 9 MeV.

In contrast this code defines transmission, reflection and lateral leakage for each event separately. In the above example the leakage for the three cases is: 1) no leakage, since everything was absorbed in the detector, 2) one 0.511 MeV photon leaked, 3) two 0.511 MeV photons leaked. It is important for the user to understand the difference between how deposition and leakage are defined here. In case 3 the deposition will have a single score about 1 MeV below the source energy, whereas the leakage will have two scores at about 0.5 MeV - not one score at about 1 MeV. Therefore in contrast to deposition where there are three different depositions about 0, 0.5 or 1.0 MeV below the source energy, the leakage will only include either 0, 1 or 2 scores all at about 0.5 MeV.

When leakage occurs (transmission, reflection or lateral leakage) each event is scored as one count, without any consideration of the direction of leakage. This corresponds to scoring the first, not zeroth, angular moment of the photon distribution. To score the zeroth angular moment of the photon distribution each event should be weighted by the reciprocal of its direction cosine relative to the normal of the surface it crosses. Therefore the leakage as defined here corresponds to the source of photons that one would see leaking from the detector.

The definition of deposition used here is designed to correspond to what we would really see when performing an experimental measurement; except that the effects of electron and positron transport and the actual response of the detector's electronics have not been included. As we incorporate more sophisticated models into the calculation this will allow

us to use the many published experimentally measured detector responses to benchmark our calculations.

The definition of leakage used here is designed to provide us with as much information as possible to understand what is physically happening. For example, in order to conserve energy all of the energy incident on the detector must either be deposited within the detector or leak from it. Therefore if this code defined leakage in exactly the same way it defines deposition we would end up with two completely complementary distributions that do not provide much more information than just one of these distributions. In contrast, with the definition of leakage used here we can obtain additional information about individual events. For example, for any given history since additional photons may be produced there can be leakage events corresponding to transmission, reflection and lateral leakage - all due to only one history. By scoring each of these separately we can obtain additional information. This may not correspond to anything that can actually be measured with a real detector (which would add together all events from each history), which is all right since this is not what the leakage as defined here is intended to be used for. Here the leakage is defined to provide us with more insight into what is physically happening.

Even though this code is primarily designed to perform detector response calculations in cylindrical geometry, it can also be used to calculate transmission and reflection in planar geometry. In this case, as defined here the leakage corresponds to what a normal photon calculation would define as the source of photons transmitted or reflected - let me stress that this is what a transport code would calculate, not what a detector measurement would indicate (as explained above). Therefore with the definition of leakage used here the results are directly comparable to those produced by other photon transport codes, allowing us the possibility to benchmark our results against those of other codes.

Methodical versus Random Sampling of Sources

This code's documentation discusses methodical versus random sampling of sources (as recommended above, please read the code documentation for an explanation of methodical sampling; here I will only demonstrate it). When performing Monte Carlo transport calculations we assume that we know the source and we will start from the source and use statistical sampling to define what happens to each particle sampled. If we know the source why should we statistically sample it? Rather than treating the source as a completely random variable, methodical sampling uses what we know about the source to speed convergence in our calculations.

The advantages of one method versus the other can be better illustrated graphically. Consider sampling a source that is uniform between 0 and 1 MeV. We will use 1000 scoring bins, uniformly spaced in energy (each bin is 1 keV wide), and sample 1 million photons. With random sampling we expect about 1000 photons per scoring bin. Assuming a one over the square root of the number of scores as an estimate of the uncertainty in the results, we would estimate an uncertainty of $\sim 3\%$. Figure 1 illustrates the results. Most results indeed cluster about 3% from the expected result, with some outlying to several times this; in the worst case 10.4%. Statistically this is what we expect, so there isn't any big surprise. The second half of figure 1 illustrates the results obtained methodically sampling and scoring exactly the same source. In this case there is virtually no uncertainty due to source sampling; a maximum of 0.2%, a factor of 50 less than the randomly sampled source. Again assuming the one over square root as an estimate of uncertainty, in order to reduce the uncertainty in the randomly sampled source to the same 0.2% as the methodically sampled source would require about 2,500 times as many histories = 2.5 billion rather than 1 million histories to achieve the same starting accuracy. Obviously the error in the results of any Monte Carlo calculation will be the error in sampling the source

Fig. 1

plus any additional error due to statistically sampling what happens in each history from that point on. Therefore if we can start on the right foot by sampling the source as accurately as possible using methodical sampling (minimize the initial error) we can reduce the overall error and speed convergence.

This can be used to greatly speed up Monte Carlo transport calculations. Generally users do not consider any problem with the source and assume that statistics only involve tracking particles after they have been "accurately" sampled from the source. However, from the above example we can see that this isn't true. If not accurately sampled the source itself can introduce large errors, e.g., in the above example using 1 million histories and randomly sampling the source the results cannot be more accurate than the initial error in the source sampling - over 10 %.

With the methodical source sampling used by this code we can speed convergence. This is particularly true in photon transport calculations, because photons never have very many collisions before they "disappear."; so that accurately modeling each and every event can have a significant impact on the outcome of each history. Naturally this applies all the way back to the initial energy they are assigned as sampled from the source, i.e., if photons initially get off on the wrong foot you cannot expect them to find their way back = the error in the results will be at least as large the error in sampling the source.

Here we only use methodical sampling to sample an energy spectrum; obviously the same technique can be used to methodically sample any given distribution.

Example Problem

As an example I will use a typical detector and a variety of program options to present results. Before actually performing any transport calculations I can first use the option to output the macroscopic cross sections for the detector that I will be discussing. It is highly recommended that users do the same thing for their applications so that they can actually see the cross sections involved, which makes it much easier to understand the calculated results. Figure 2 presents the total cross section for the composite detector material and each of its constituents, as well as the cross sections for each process, i.e., photoelectric, Compton, etc. From figure 2 we can see which constituents and processes are important in different energy ranges, and as well as where the photoelectric edges are located. If you are interested in specific energy ranges PLOTTAB can be used to produce additional plots, as illustrated in figure 3 of the 1 keV to 1 MeV energy range (see the comment lines from the program for reference to PLOTTAB and its availability).

The next thing to look at is the source distribution. Before performing any transport calculations we should be sure that we can accurately sample the source; it may come as a surprise to some people to discover that this isn't always possible.

The spectrum that I will use for this example is a bremsstrahlung spectrum filtered through cadmium. Figure 4 illustrates the results obtained using the program option to methodically sample 10 million histories from the source distribution. We can easily see that even using batches of 10 million histories each it is not possible to accurately methodically sample the lower energy portion of this spectrum, below about 12 keV. The second half of figure 4 illustrates that on the other hand methodical sampling does a fantastic job of the sampling the most important (highest probability) part of the spectrum.

To understand the difficulty below about 12 keV figure 5 illustrates both the differential and integral spectrum. From the plot of the integral we can see that methodical sampling starts exactly where we expect it to; for batches of 1.0×10^7 histories, sampling should start near an

Fig. 2

Fig. 3

Fig. 4

Fig. 5

integral probability of 1.0×10^{-7} . On the basis of the integral of the spectrum we can see that in order to force sampling to start from the beginning of the spectrum we would need batches of about 1.0×10^{24} histories, which obviously is not practical.

Before proceeding to the final calculation I first performed preliminary calculations in order to insure that ignoring the lower energy portion of the spectrum will not effect results. In order to do this we have to consider both the incident spectrum and the cross sections of the detector, i.e., the response will be proportional to the product of the two. In this case there are very few photons and very little energy in the lower energy portion of the spectrum. If we consider lower and lower energies we can see that the spectrum is decreasing much faster than the photoelectric cross section of our detector is increasing. Therefore the lower energy portion of the detector can be safely ignored. Note, that having plots of both the spectrum and cross sections available greatly simplified this judgment call; again, I highly recommend that users generate these plots before starting the actual transport calculations.

Hopefully this example will serve as a warning to users of this (or indeed other Monte Carlo codes) - do not assume that these codes can accurately sample any arbitrary source that you may be interested in. In the case of this code it is strongly recommended that before running your problems you first verify that your source can be accurately sampled, and if not decide what you can do about it. Very difficult problems can be divided into a number of separate energy ranges, run separately and the results added together later; this is how I verified that the low energy portion of my example spectrum is unimportant. The example spectrum that I am using is not a theoretical or artificial spectrum merely used here to scare users. It is a real spectrum encountered in real applications. So please do not assume that your spectrum can be accurately sampled by this, or any other Monte Carlo transport code - use the code option and check.

Now that these preliminary steps are completed let's move on to look at example results for transport calculations.

Example Input and Output Listing

Tables I and II present example input parameters and the corresponding output report. The format and physical description of the input parameters are defined in detail later in this report, which if you followed the above recommendation, you have already read. Here I will only discuss the output report and correspondence between the input parameters and what appears in the output report.

In this example, the detector is 13.1072 cm in radius and 0.0111 cm thick. The input spectrum is between 50 and 8.14 keV. Photons are tracked down to 10 eV. All of these parameters appear on the first line of input parameters and are interpreted in the output report.

This example will run 1000 batches of photons with each batch consisting of 1 million photons (a total of 1 billion photon histories if the program is allowed to run to completion). Output results will be in 100 bins equally spaced in energy between the spectrum maximum energy (50 keV) and the scoring minimum energy (10 eV). The energy dependent spectrum is input as a table. The source initial position will be a point on the centerline of the cylindrical detector (rather than uniform across the face of the detector). This will be a normal transport calculation (as opposed to one of the diagnostic calculations), using the cross sections in their original form as read from the photon data library (as opposed to using the same fixed energies to represent all elements). All of these parameters appear on the second line of input parameters and are interpreted in the output report.

Table I: Example Input Parameters

```

13.1072  1.110e-02 5.000e-02 8.140E-03 1.000E-05
    1000    1000000      100    3    0    0    0
      4.51
      53      1.0
      55      1.0
      81      1.2801e-2

```

(BLANK LINE=END COMPOSITION)

```

8.140D-03 1.835D-24
8.150D-03 2.397D-24
.
.
.

```

```

4.999D-02 4.071D-01
5.000D-02 3.716D-01

```

(BLANK LINE=END SPECTRUM)

```

*** NOTHING FROM THIS POINT ON WILL BE READ BY THE CODE.***
*** SO THAT YOU CAN STORE ADDITIONAL PROBLEMS HERE AND ***
*** COPY TO THE BEGINNING OF THIS FILE ANYTIME YOU WANT ***
*** TO USE THEM. ***

```

Electron-Photon Interaction Calculations (EPICP 94.2)

Detector Composition

Tabulated Input Spectrum

```
4186 4.9990E-02 4.0710E-01
4187 5.0000E-02 3.7160E-01
4187 Tabulated Points
```

For Each Batch 5 Lines of Output are Listed

- Sum - Events = Average Number of Events Inside the Detector
= Photo + Compton + Rayleigh + Pair
- Sum - Energy = Average Energy Deposition or Leakage
= The Sum of Everything Except Fluorescence
(Exactly 1.0 for Energy Conservation Check)

Convergence = Same results for successive Batches

Batches Events.(Inside the Detector).....Losses.(Leakage and Low Energy)

11	49.85 Seconds								
0.76775	0.73535	0.02772	0.00468	0.00000	0.33090	0.09375	0.50180	0.00000	0.00000
						0.09381	0.50176	0.00000	
1.00000	0.43323	0.00000	0.00030	0.00000	0.24289	0.08135	0.48512	0.00000	0.00000
						0.08141	0.48508	0.00000	

The detector has an overall density of 4.51 grams/cc. It is composed of the following atom fractions: 53-I, 1 atom, 55-Cs, 1 atom, 81-Tl, 0.012801 atoms. This composition is defined by lines three through six of the input parameters. The composition is terminated by a blank line (line seven of the input). This composition is interpreted in the output report, and from this report we can see that the program has defined the density of each constituent to maintain the input overall density and atom fractions.

The last portion of the input parameters is the tabulated energy dependent input spectrum. In the example input and output reports presented here only a few points at the beginning and end of the spectrum are listed; from the output report we can see that the actual spectrum includes 4187 tabulated energy points.

Once all input parameters have been read and interpreted the program will either initialize all of the scoring array or, if the restart option is used, read the scoring array from the restart file. It will then read and arrange all required photon interaction data. It then reports how long it took to perform all of this initialization; in this case about 1 second.

The program then begins to process one batch after another. At the end of each batch it outputs results in the PLOTTAB format, so that they can immediately be viewed, writes a restart binary file, and reports cumulative results, both to the output report file and to your screen.

The output listing includes a description of cumulative results that follow. Here I will discuss the interpretation of the output results in more detail (see table II). For each batch the program output report includes five lines. The first line merely defines the batch number and how long this current batch took, e.g., in this case each batch of 1 million photons takes about 49 seconds. Hopefully this line does not require any additional explanation.

The following four lines present analog and expectation results for both events and energy. These results are designed as a brief summary to allow the user to understand what's happening and what's important. The first of these four lines defines how many events occurred within the detector and how photons were lost from the detector; these are analog results.

In this example, per incident photon there were about 0.735 photoelectric events, 0.027 Rayleigh (coherent) scatters, 0.004 Compton (incoherent) scatters and no pair production (since the spectrum maximum energy is below the threshold). The sum of these four types of events is about 0.768 (the sum defined of the beginning of the line).

In addition about 0.33 fluorescence events occurred. These events do not deposit energy directly, they merely produce additional photons that must be transported, which can lead to energy deposition due to any events that occur during their transport. The number of fluorescence events is included in the output report merely to allow the user to judge whether or not it is important in their calculations.

Next about 0.093 photons were reflected, 0.501 transmitted and none laterally leaked from the cylindrical sides of the detector; in this case the 13.1072 radius is so much larger than the 0.0111 cm thicknesses that no photons laterally leak.

During transport the number of photons is not conserved. In this case per incident photon about 0.33 secondary photons were created by fluorescence. From the output report we can see that the sum of photoelectric events and leakage is about 1.33, due to the fluorescence.

Finally the report indicates no photons were terminated because they fell below the lowest energy of interest; in this case 10 eV. As long as the scoring minimum energy is defined by input to be a very low value this result will always be true. At low energies the energy loss due to incoherent scattering approaches zero and fluorescence probabilities approach zero, so there is no available mechanism that can change the energy of photons thereby transferring them below the scoring minimum energy. At low energies the photons will either be absorbed by photoelectric, scatter without losing an appreciable amount of energy or leak from the detector.

The next line presents expectation results for reflection, transmission and lateral leakage, which are comparable to the analog results directly above them. When we run enough histories the analog and expectation results will converge together; by comparing these results we can check both for convergence and for programming errors. From the output results we can see that even after only one batch of histories they are already in very good agreement, and differ very little from the results after 11 batches.

The two lines discussed above present results based on events, e.g., how many photoelectric events or reflections occurred. The next two lines present results based on energy. As in the case of the two preceding lines, the first line presents analog results and the second line expected results. For each MeV of energy incident on the detector exactly one MeV of energy must either be deposited within the detector or leak from the detector. Therefore in this case the sum must be exactly 1, unless there is a program error. In this case we can see that the only significant deposition is due too photoelectric; about 43.3 % compared to 0.03 % for Compton. Of the remaining energy about 8.1 % was reflected and 48.4 % transmitted. Again, the analog and expectation results are in very good agreement.

As on the preceding two lines fluorescence is included here merely as an indication of its importance. In this case for each 1 MeV of energy incident about 242 keV of energy was re-radiated as fluorescence x-rays following photoelectric events. This should not be interpreted to mean all of this energy was deposited; it was merely re-radiated and may subsequently have been deposited by another photoelectric event or it may have leaked.

This brief summary of these cumulative results should allow the user to have a good idea of what is occurring, in terms of both number of photons and energy, and to decide what is or is not important in any given application.

Example Energy Dependent Results

Next, we can look at the energy dependent results by using program PLOTTAB to plot the output. In this case since there is no lateral leakage, we can look at the reflection, transmission and deposition to see what happened. To be able to easily interpret these results figures 6 through 8 present: 1) results with fluorescence turned on, 2) results with fluorescence turned off, 3) both results on the same figure. This not only makes it easier to interpret results, it also illustrates use of the code option to turn fluorescence on or off. When the program option to turn off fluorescence is used at each photoelectric event all of the energy of the incident photon is deposited locally, at the site of the event. When fluorescence is turned on a portion of the incident energy of the photon can be re-emitted as x-rays, usually just below the photoelectric edge energies.

Without fluorescence essentially the only process that is contributing anything is photoelectric and what we see is simple exponential attenuation of the incident source spectrum according to the strength of the source and the magnitude of the cross section at each energy.

Fig. 6

Fig. 7

Fig. 8

With fluorescence the results are quite different. In this case by comparing the two results (see figures 6 through 8) we can see that with fluorescence the deposition at higher energies (~ 35 - 50 keV) is significantly less than without fluorescence. In addition, with fluorescence we see a peak in the deposition in the ~ 5 - 20 keV range that simply doesn't exist in the results without fluorescence. We can also see the narrow peaks in the reflection and transmission due to fluorescence. What the results indicate is that with fluorescence turned on, statistically in some events fluorescence does not occur and the deposition at higher energy (~ 35 - 50 keV) is similar in shape to the results without fluorescence, since both correspond to events in which no fluorescence occurred. The magnitude is suppressed in proportion to the probability of fluorescence not occurring. The second peak in the deposition in the ~ 5 - 20 keV range corresponds to those events in which statistically fluorescence did occur, the fluorescence x-rays leaked from the detector and the remaining energy was deposited; this is similar in shape to the ~ 35 - 50 keV portion of the deposition curve, merely shifted to lower energies by the amount of fluorescence energy that has leaked from the detector. Since without fluorescence this peak cannot occur it is not seen in the results when fluorescence is turned off, nor is any of the other narrow sharp peaks in transmission, reflection or deposition present.

Not only are the energy dependent results different; the integral results are also quite different. Earlier, we saw from the example output listing that about 43.3 % of the energy is deposited, 8.1 % reflected, and 48.5 % transmitted. When fluorescence is turned off the results change to 57.5 % deposited, 0.2 % reflected and 42.3 % transmitted. Without fluorescence at each photoelectric event all of the photon's energy is deposited (57.5 %). With fluorescence a portion of the energy is re-radiated and more energy leaks from the detector, decreasing the deposition to 43.3 %, and increasing both reflection and transmission. Note, in particular the dramatic difference in reflection: 8.1 versus 0.2 %. In this energy range the cross sections above the photoelectric edges are so large that fluorescence is almost a surface effect. A large number of photoelectric events are occurring very close to the incident surface of the detector. Fluorescence x-rays are being created at energies below the photoelectric edge where the cross section is much smaller, allowing these x-rays to leak from the detector; particularly at the nearest, reflection, surface. From figure 8 comparing results with and without fluorescence we can see that virtually all of the reflection is due to the two very narrow fluorescence lines near 28 and 31 keV.

Spatially dependent results

In addition to the energy dependent results presented above this code also calculates and outputs spatially dependent results, namely collisions and energy deposition versus depth into the detector. Even though the detector is treated as a single zone for tracking, for scoring the detector thickness is divided into the number of bins specified by user input and analog collisions and energy deposit are scored to obtain spatially dependent results. Since these results are only analog they will usually show a great deal of statistical variation unless a very large number of histories are run.

Figure 9 illustrates the results for this case. The combination of calculated transmitted photons and energy, reported in the output listing, and this plot of collisions and deposition, can be used when designing an experiment or detector to select the optimum detector thickness to meet your needs.

Checking for convergence

This code does not check for convergence based upon some criteria and stop if this criterion is met; it will merely run as many batches as you allow it to run. This has been done because generally the code has no idea what specific quantities are of interest to the

Fig. 9

user and to what accuracy they are required. By using the output from this code the user should be able to decide when the quantities of interest have been calculated to sufficient accuracy.

The progress of the code can be monitored in real time by simply reading the output report on your screen at the end of each batch, in particular by comparing the analog and expectation results. It can also be monitored in real time by using program PARROT to display the deposition, transmission, reflection and lateral leakage at the end of each batch. Program PLOTTAB can be used to obtain printed results, as I have done to produce all of the figures in this report (see the program comment lines for details).

The combination of energy and spatially dependent results and the output listing are designed to be used to check for convergence in the calculated results. In figure 9 the obvious statistical variation in the results indicates that not enough histories have been run to reach convergence. In this case only one batch of histories was run before producing figure 9; this was done on purpose in order to illustrate the statistical variations that you can check for in results, i.e., in this case we expect smoothly varying exponential variation, and as yet we do not see this in figure 9.

By using this program's restart option (see the description later in this report), the user can continue running any number of histories until it is felt that sufficient accuracy has been attained. You do not have to ask for a restart file to be created. At the end of each batch a restart file is always written. Therefore you always have the possibility to restart any problem and accumulate more statistics in order to improve accuracy (see the program comment lines for details).

Additional Examples

The combination of the above example and the comments from the program should be sufficient for the user to understand how to use this code. Below I present a few additional example results merely to assist the user to understanding the importance of different processes in different energy ranges and to illustrate the use of some of the diagnostic results than can be obtained using this code.

The importance of different processes vs. Energy

Table III presents results using the same detector described above, with different monoenergetic spectra incident for 500, 50, 5 MeV and 500, 50 and 5 keV, with fluorescence turned on and off. Table III can be used to see the relative importance of different types of events, as well as fluorescence, over a wide energy range. In each case the detector thickness was selected to allow roughly half the photons to be transmitted; very roughly half.

The numbers in table III have the same meaning as described above, only in this case for convenience I have only included the analog results. For each case we only have two lines of results; one line for events and one for energy.

In order to better understand these results, see fig. 2, the plot of the composite detector cross sections; by comparing the cross sections for the various processes at the incident energies it is fairly easy to understand and predict the following results. Basically from fig. 2 we can see that photoelectric is the largest cross section below roughly 200 keV, Compton is the largest from 200 keV to 6 MeV, and pair production is the largest at higher energies. In terms of energy loss this view is somewhat modified; I'll let the reader think about that. Below I discuss the results presented in table III.

Table III: Example Results for Different Input Spectra

Sum	Events.(Inside the Detector).....					Losses.(Leakage and Low Energy)				
	Photo.	Rayleigh	Compton	Pair	Fluor.	Reflect	Trans.	Lateral	Low E	
=====										
500 MeV - 2.5 cm Thick										
=====										
Fluorescence										
2.52721	0.95994	0.11548	0.83762	0.61417	0.47386	0.52206	0.60509	0.00094	0.00000	
1.00000	0.00035	0.00000	0.00337	0.61245	0.00003	0.00045	0.38339	0.00000	0.00000	
No Fluorescence										
2.15123	0.55697	0.09947	0.88054	0.61425	0.00000	0.37303	0.68296	0.00129	0.00000	
1.00000	0.00038	0.00000	0.00328	0.61250	0.00000	0.00035	0.38349	0.00000	0.00000	
=====										
50 MeV - 4 cm Thick										
=====										
Fluorescence										
3.29068	1.34785	0.15967	1.14318	0.63998	0.66568	0.45490	0.50088	0.00202	0.00000	
1.00000	0.00476	0.00000	0.03428	0.62337	0.00036	0.00384	0.33372	0.00002	0.00000	
No Fluorescence										
2.72596	0.76226	0.13426	1.18898	0.64046	0.00000	0.31288	0.56299	0.00232	0.00000	
1.00000	0.00515	0.00000	0.03417	0.62387	0.00000	0.00291	0.33388	0.00002	0.00000	
=====										
5 MeV - 10 cm Thick										
=====										
Fluorescence										
4.00309	1.61469	0.18801	1.83119	0.36920	0.79700	0.19571	0.34524	0.01056	0.00000	
1.00000	0.06043	0.00000	0.37447	0.28446	0.00428	0.01568	0.26350	0.00145	0.00000	
No Fluorescence										
3.20789	0.85797	0.14722	1.83417	0.36853	0.00000	0.11865	0.38504	0.00687	0.00000	
1.00000	0.06220	0.00000	0.37421	0.28437	0.00000	0.01048	0.26799	0.00074	0.00000	
=====										
500 keV - 2 cm Thick										
=====										
Fluorescence										
1.47789	0.76180	0.09137	0.62472	0.00000	0.37632	0.05268	0.56184	0.00000	0.00000	
1.00000	0.25585	0.00000	0.18373	0.00000	0.02023	0.02074	0.53967	0.00000	0.00000	
No Fluorescence										
1.07425	0.38856	0.07028	0.61541	0.00000	0.00000	0.03223	0.57921	0.00000	0.00000	
1.00000	0.25523	0.00000	0.18236	0.00000	0.00000	0.01262	0.54978	0.00000	0.00000	
=====										
50 keV - 0.02 cm Thick										
=====										
Fluorescence										
1.08389	1.03326	0.04128	0.00935	0.00000	0.60071	0.14397	0.42348	0.00000	0.00000	
1.00000	0.52780	0.00000	0.00065	0.00000	0.31695	0.08736	0.38419	0.00000	0.00000	
No Fluorescence										
0.70101	0.67383	0.02133	0.00584	0.00000	0.00000	0.00196	0.32420	0.00000	0.00000	
1.00000	0.67350	0.00000	0.00052	0.00000	0.00000	0.00180	0.32418	0.00000	0.00000	
=====										
5 keV - 0.0003 cm Thick										
=====										
Fluorescence										
0.38441	0.38275	0.00162	0.00004	0.00000	0.02100	0.00718	0.63107	0.00000	0.00000	
1.00000	0.36429	0.00000	0.00000	0.00000	0.01614	0.00582	0.62989	0.00000	0.00000	
No Fluorescence										
0.50762	0.50565	0.00194	0.00003	0.00000	0.00000	0.00041	0.49395	0.00000	0.00000	
1.00000	0.50565	0.00000	0.00000	0.00000	0.00000	0.00041	0.49395	0.00000	0.00000	
=====										
Bremsstrahlung Filtered through Cadmium										
=====										
Fluorescence										
0.76772	0.73522	0.02783	0.00467	0.00000	0.33084	0.09371	0.50192	0.00000	0.00000	
1.00000	0.43315	0.00000	0.00030	0.00000	0.24289	0.08134	0.48521	0.00000	0.00000	
No Fluorescence										
0.59072	0.56715	0.02015	0.00342	0.00000	0.00000	0.00280	0.43006	0.00000	0.00000	
1.00000	0.57483	0.00000	0.00024	0.00000	0.00000	0.00245	0.42248	0.00000	0.00000	

At 500 MeV the only thing of importance is pair production; virtually all of the energy deposition is due to pair production. Note, there are actually more photoelectric than pair production events, but the energy deposition indicates they are relatively unimportant compared to pair production. It is important to realize that pair production from 500 MeV photons will create very energetic electrons and positrons - essentially up to 500 MeV. The range of a 500 MeV electron in this detector is about 7 cm, larger than the thickness of the detector. Therefore, in this case, we expect a considerable amount of energy to actually leak from the detector.

At 50 MeV the situation is almost the same, except in this case Compton (incoherent) is contributing about 3.4 % to the deposition. The range of a 50 MeV electron in this detector is roughly 3 cm, comparable to the 4 cm thickness of the detector.

At 5 MeV Compton has become the most important process, contributing 37 %, compared to 28 % for pair production. The range of a 5 MeV electron in this detector is about 0.75 cm, compared to the 10 cm thickness of the detector.

At 500 keV we obviously no longer have any pair production, and photoelectric has become the most important process, contributing 25 %, compared to 18 % for Compton. At this energy Compton is the larger cross section, but in terms of energy loss a photoelectric event contributes a larger photon fractional energy loss than does Compton. The range of a 500 MeV electron is about 0.1 cm, compared to the 2 cm thickness of the detector.

In all of these cases the integral energy deposition is virtually the same with and without fluorescence.

At 50 keV virtually the only thing happening is photoelectric. In this case the deposition with fluorescence is 52 % and without it 67 %; compared to the results with fluorescence, the results without fluorescence are about 29 % higher. The range of a 50 keV electron is about 0.002 cm, compared to the 0.02 cm thickness of the detector.

At 5 keV the results are similar to the 50 keV results; again without including fluorescence badly overestimating the deposition. The range of a 5 keV electron is only 0.0001 cm, but in this case the detector is only 0.0003 cm thick.

The final results are for a bremsstrahlung spectrum filtered through a cadmium filter; once again we see the importance of fluorescence.

Higher Energy Example

As another example I will use a detector of the same composition as described above, in this case 1.5" (3.81 cm) in radius and 3" (7.62 cm) thick, with a monoenergetic 7.48 MeV photon source incident.

Table IV

Batches	Events. (Inside the Detector)					Losses. (Leakage and Low Energy)				
or Sum	Photo.	Rayleigh	Compton	Pair	Flour.	Reflect	Trans.	Lateral	Low E	
3.09952	1.20308	0.14028	1.30650	0.44966	0.59377	0.20362	0.40628	0.23044	0.00000	
1.00000	0.03049	0.00000	0.23870	0.37923	0.00213	0.01126	0.32120	0.01912	0.00000	

For every 7.48 MeV photon incident based on conservation of energy exactly 7.48 MeV must be deposited or leak from the detector. Therefore when we look at the results we expect to see complementary results, in the sense that for every photon that deposits most of its energy we have to see a low energy photon leak, and for every photon that only deposits a small amount of energy we have to see a high energy photon leak.

The above table IV and figure 10 summarize the results. To understand the results let's consider typical histories. At the source energy the photons will undergo either pair production or Compton scatter in roughly equal amounts (see fig. 2 of the composite cross sections to understand this statement - this illustrates the advantage of having this plot available when you want to analyze the results of calculations). On the basis of the model used here, each pair production will create two 0.511 MeV photons and deposit the source energy minus the energy of these two photons (6.458 MeV). Compton scattering will scatter photons to a lower energy.

Below the source energy, pair production can still occur for scattered photons with energies still above the threshold. However, in this energy range the pair production cross section is rapidly decreasing toward zero at 1.022 MeV. Compton scattering will continue to scatter photons to lower energies, including the two 0.511 MeV photons created due to pair production; this is why the number of Compton events is so much larger than the number of pair production events, even though their cross sections are comparable at the source energy. Eventually Compton scattering will reduce the energy of the photons to the point where photoelectric absorption becomes important.

The events described above can deposit energy within the detector. Photons can obviously also leak from the detector.

With that as background, let's take a look at the results (see figure 10). First consider the deposition. If all photons are either transmitted through the detector or interact and lose all of their energy within the detector, the detector response would be non-zero only at the source energy, 7.48 MeV. Instead we see a peak at the source energy (some photons have indeed lost all of their energy), two more peaks 0.511 and 1.022 MeV below the source energy (corresponding to the two 0.511 MeV photons created from pair production), and then a continuous spectrum down to low energy.

The continuous spectrum down to low energy is the result of Compton scatters, at the source and lower energies, in which a photon can lose (deposit) any amount of energy between zero and some maximum amount and then either scatter again or leak. The complement to this low energy tail in the deposition is the high energy tail in the transmission; photons that lose a small amount of energy have scattered through a small angle, continue transporting forward and are transmitted with a high remaining energy. Similar continuous spectra can be seen in the lateral leakage at lower energy (since the photons must scatter through larger angles to laterally leak) and at even lower energies in the reflection (the photons must scatter through at least 90 degrees).

Due to pair production, and the model used here, we will have a large number of 0.511 MeV photons, two per pair production event. If both of these deposit all of their energy in the detector, all of the 7.48 MeV will be deposited and we will have a peak in the deposition at the source energy. If one of these leaks we will have a peak 0.511 MeV below the source energy. If both leak we will have a peak 1.022 MeV below the source energy. From the deposition plot we can see all three peaks. Just above the peaks 0.511 and 1.022 MeV below the source energy we can see the effect of Compton scattering that has caused photons to lose some of their energy before leaking, thereby increasing their deposition.

Fig. 10

We can see complementary effects in the leakage, in that we can see a peak at 0.511 MeV in the transmission, reflection and lateral leakage, and the effect of Compton scatter to decrease the energy of some of these photons before they leak. Note, the complementary effects: the Compton scattering increases the deposition, as seen ABOVE the deposition peaks 0.511 and 1.022 MeV below the source energy, and decreases the energy of the leaking photons as seen BELOW the 0.511 MeV peak in the leakage.

The last point to consider when looking at the results: if we see peaks 0.511 and 1.022 MeV below the source energy in the deposition, why don't we see two similar peaks in the leakage? What's being scored as deposit is one single count corresponding to the total amount of energy lost starting from a source photon and tracking it and any additional photons created until all have leaked or disappeared. What's being scored as leaked is one count per leaked photon corresponding to the energy of that photon. Therefore if one or two 0.511 MeV photons leak from the detector these are scored as one or two events - but both at 0.511 MeV as independent events. In contrast in the case of deposition the case of one or two 0.511 MeV photons leaking corresponds to two distinct depositions, 0.511 or 1.022 MeV below the source energy.

This is an important point to consider when modeling pair production. One might think that following each pair production event we could speed up a calculation by assuming that instead of having two 0.511 MeV photons that we have to track, we only have one 0.511 MeV photon of weight two. This actually works quite well in calculating the leakage. However with this model you can never produce two independent peaks in the deposition 0.511 and 1.022 below the source energy. With this model either both photons leak or they don't, so that you cannot model the case where one photon leaks, leading to the peak in the deposition 0.511 MeV below the source. If you are designing a code to perform photon transport calculations you should consider this fact. Another point to consider is that in the model where we assume the positron has come to rest, the direction of the two 0.511 MeV photons is completely correlated; if one is traveling in a given direction the other must be traveling in the opposite direction. Not only is it better to treat the two photons as completely correlated, it is also usually faster than randomly sampling two independent photons.

That's about everything we can see from figure 10. What we don't see is the effect of electron and positron transport because it hasn't been included here. The range of a 7.48 MeV electron in this detector is roughly 2.5 cm, comparable to the dimensions of this detector. Therefore we expect some of the electrons and positron to escape from the detector with some remaining energy. We also expect some of the positrons to undergo in-flight annihilation, creating photons with energy higher than 0.511 MeV. Both of these effects will tend to broaden the three nice, clean peaks that we see in the deposition. On the basis of actual measurements, the most obvious change is that the deep minimum in the deposition just below the source energy is filled in by cases in which electrons and positrons leak from the detector with a small amount of energy, resulting in a deposition just below the source energy. A similar effect is seen just below the peak in the deposition curve 0.511 and 1.022 MeV below the source energy.

If we define leakage as leakage of photons then the escape of electrons or positrons will have no effect on our calculated leakage spectra. However, in-flight positron annihilation and feedback from the transport of electrons and positrons (bremsstrahlung, electroionization leading to fluorescence, etc.) could effect the leakage spectra. Instead of the nice, clean peaks due to monoenergetic 0.511 MeV photons, in-flight positron annihilation would add a spectrum of higher energy photons. The probability of fluorescence in this case is quite low (see, "Tables and Graphs of Electron Interaction

Cross Sections from 10 eV to 100 GeV Derived from the LLNL Evaluated Electron Data Library (EEDL), Z = 1-100," UCRL-50400 Vol. 31, Lawrence Livermore National Laboratory, (Nov. 1991), by S.T. Perkins, et al.). On the basis of the single collision bremsstrahlung 1/E spectrum of photons produced, most of the photons produced would be at very low energy, where the photon cross sections are very large. Therefore in order to escape from the detector these photons would have to be produced extremely close to the surface of the detector.

In summary, electron and positron transport should be included in order to accurately model this case; this will be done in the near future using EPICP and EPICE in combination to model coupled electron-photon transport problems.

Scattering function example

For Compton (incoherent) scattering, compared to only using the Klein-Nishina formula, the scattering function causes photons to scatter through larger angles and lose more energy.

In the following example the same detector as described above has been used and the program option to turn the scattering function on and off has also been used. When the program option to turn off the scattering function is used the incoherent cross section calculated including the effect of the scattering function is still used, but the scattering function is not used to define the angular and energy distribution of scattered photons; only the Klein-Nishina formula is used. From the plot of the cross sections (see fig. 2) we can see that Compton scattering is the largest cross section near 1 MeV. The following results are for monoenergetic 1 MeV photons incident on a detector 3 cm thick.

From the results in table V we can see very little difference in the deposition; it is increased only slightly due to the larger angle scattering when the scattering function is used. The biggest effect that we see is that the transmission has been decreased by about 3 % and the reflection has been increased by a corresponding amount. In the case of the reflection this is a rather important difference, since using the scattering function, the reflection has roughly doubled.

Table V

1 MeV - 3 cm Thick									
Batches	Events. (Inside the Detector)					Losses. (Leakage and Low Energy)			
or Sum	Photo.	Rayleigh	Compton	Pair	Fluor.	Reflect	Trans.	Lateral	Low E
Scattering Function									
1.45408	0.57398	0.06909	0.81101	0.00000	0.28343	0.06875	0.64054	0.00014	0.00000
1.00000	0.11554	0.00000	0.27220	0.00000	0.00761	0.01754	0.59465	0.00006	0.00000
No Scattering Function									
1.44733	0.57701	0.06892	0.80140	0.00000	0.28480	0.03652	0.67119	0.00007	0.00000
1.00000	0.11446	0.00000	0.26955	0.00000	0.00764	0.00887	0.60709	0.00003	0.00000

In low Z elements the Compton cross section is dominant over a fairly large energy range. In the following example I consider Z=1, hydrogen, at a density of 1 gram/cc, for three different monoenergetic source energies: 1 MeV, 100 and 10 keV. I have used a large radius, so this is essentially a plane of hydrogen. Results are presented in table VI.

At one 1 MeV we see little difference in the energy deposition, but rather dramatic differences in the reflection and transmission. With the scattering function the reflection is

almost doubled. Note, there are also far fewer Compton collisions within the hydrogen; rather than transporting all the way through the hydrogen and being transmitted, many more photons are being reflected. The energy deposit from Compton is about same in both cases, but since there are fewer collisions with the scattering function the energy loss per collision is higher.

At 100 keV, again we see large differences for reflection and transmission. In this case the energy deposition without the scattering function is slightly higher; this is only because the number of collisions is higher; the energy loss per collision is lower.

At 10 keV, we see the same effect on reflection and transmission. The energy deposition due to Compton has now been drastically reduced, because at progressively lower energies Compton becomes a progressively less effective process for losing energy. However, at progressively lower energies the scattering function will tend to make the photons scatter through larger angles, which explains the reflection and transmission results. In this case the photons merely rattle around without losing very much energy and then leak.

Table VI

Batches	Events. (Inside the Detector)				Losses. (Leakage and Low Energy)				
or Sum	Photo.	Rayleigh	Compton	Pair	Fluor.	Reflect	Trans.	Lateral	Low E
1 MeV - 12 cm Thick									
Scattering Function									
3.02910	0.00001	0.00180	3.02729	0.00000	0.00000	0.59169	0.40830	0.00000	0.00000
1.00000	0.00000	0.00000	0.54192	0.00000	0.00000	0.10100	0.35708	0.00000	0.00000
No Scattering Function									
5.31242	0.00142	0.02328	5.28772	0.00000	0.00000	0.32524	0.67335	0.00000	0.00000
1.00000	0.00006	0.00000	0.55255	0.00000	0.00000	0.04530	0.40209	0.00000	0.00000
100 keV - 3 cm Thick									
Scattering Function									
1.21383	0.00001	0.00158	1.21225	0.00000	0.00000	0.41817	0.58183	0.00000	0.00000
1.00000	0.00000	0.00000	0.13841	0.00000	0.00000	0.29297	0.56861	0.00000	0.00000
No Scattering Function									
1.40818	0.00006	0.00218	1.40594	0.00000	0.00000	0.27891	0.72103	0.00000	0.00000
1.00000	0.00005	0.00000	0.14774	0.00000	0.00000	0.19177	0.66044	0.00000	0.00000
10 keV - 3 cm Thick									
Scattering Function									
1.53998	0.01194	0.10275	1.42530	0.00000	0.00000	0.52991	0.45815	0.00000	0.00000
1.00000	0.01166	0.00000	0.02734	0.00000	0.00000	0.50476	0.45624	0.00000	0.00000
No Scattering Function									
1.82850	0.01489	0.12502	1.68859	0.00000	0.00000	0.34585	0.63926	0.00000	0.00000
1.00000	0.01435	0.00000	0.02993	0.00000	0.00000	0.32851	0.62721	0.00000	0.00000

These results indicate that the effect of the scattering function is appreciable when Compton scattering is important. For example, if you have an object that contains a lot of hydrogen, like your body, and you want to predict what will appear on a x-ray plate after transmission through the hydrogen, the above difference in the transmission indicates that it is important to include the scattering function in your calculations.

Form factor example

For Rayleigh (coherent) scattering, compared to only using the Thomson formula, the form factor causes photons to scatter through smaller angles (more forward peaked scattering), which causes photons to transport further in their initial direction of travel. Coherent scattering is never the largest cross section, but it can have a significant effect in high Z elements just below the K edge, where it is about 10 % of the total cross section.

The following example uses 0.254 cm of lead at 11.72 grams/cc, with 80 keV photons incident (just below the lead K edge). The program option to turn the form factor on or off has been used. When the form factor is turned off the cross sections calculated using the form factor are still used, but the form factor is not used to calculate the angular distribution of scattered photons; only the Thomson formula is used. In this case compared to the results without the form factor, using the form factor increases transmission by about 25 %, and decreases the reflection by more than a factor of two. These results are consistent with our expectations, since the form factor causes photons to scatter through smaller angles, continue to transport forward, and increase transmission.

In discussing the effect of the scattering function and form factor we have only considered integral results, i.e., deposition, reflection, transmission. Even in the cases where the overall deposition has not changed, the differences that we can see in reflection and transmission indicate that the spatial distribution of the deposition has changed. In the example lead case described above even though the overall deposition is about the same, if you are interested in the deposition half way through the lead, with the form factor the deposition is about 15 % higher.

Anomalous scattering factor example

Anomalous scattering factors and form factors are used in combination to define our coherent scattering cross section. The effect of anomalous scattering is to reduce the coherent scattering cross section and cause it to approach zero at low energy; without anomalous scattering it approaches a constant. It also causes minima in the coherent scattering cross section just below photoelectric edges (see, fig. 2 of the cross sections for the example detector used here).

We have included the effect of anomalous scattering in our coherent cross section, so it is not possible to perform calculations with and without anomalous scattering to illustrate the effect. However, we can say that for the example lead problem used above anomalous scattering reduces the coherent cross section at 80 keV from about 98.8 barns to 73.8 barns, a reduction of about 25 %. This is roughly 2.5 % of the total cross section, which will allow photons to transport slightly further. Since anomalous scattering will cause the coherent cross section to approach zero at low energy, the effect is much larger at lower energies. For lead at 100 eV the coherent cross section with and without anomalous scattering is about 160 barns versus 4470 barns. At 100 eV in lead photoelectric is by far the dominant cross section and we do not expect to see any appreciable effect on deposition due to scattering. However, if you are performing back scattering measurements the scattering cross sections may be relatively small, but they define the entire answer that you are looking for.

Additional Examples

For additional examples of using options from this code as well as complete documentation of the methods and data used by this code see "A Simple Model of Photon Transport," UCRL-JC-118254, Lawrence Livermore National Laboratory, (July 1994), by D. E. Cullen

Acknowledgments

I thank S.T. Perkins (Lawrence Livermore National Laboratory) and J. Stepanek (Scherrer Institute) for their assistance and many helpful suggestions during the development of Epicp and Epicshow. I thank Clint Logan (Lawrence Livermore National Laboratory) for supplying the example spectrum used in this report. I thank Jim Rathkopf (Lawrence Livermore National Laboratory) for reviewing a preliminary version of this report and making many useful suggestions.

Documentation comments from Epicp follow. In addition, documentation comments are included for the utility codes Epicbin (which translates character files to binary, random access files), Epictab (which translates binary, random access files to character files), and Parrot (which can be used to monitor the execution of Epicp).

C*****
C
C PROGRAM EPICP
C
C =====

C VERSION 92-1 (MARCH 1992)

C VERSION 92-2 (OCTOBER 1992)

*CORRECTED ENERGY BALANCE (THERE
WAS AN ERROR IN FLUORESCENCE)
*CORRECTED NAME OF INPUT PARAMETER
DEFINING LOWER ENERGY LIMIT
*DOUBLE PRECISION GEOMETRY
*DOUBLE PRECISION TALLIES (TO AVOID
ROUND-OFF IN ENERGY BALANCE)
*CHANGED NAME OF PHOTON DATA BINARY
FILE FROM EPDL.BIN TO PHOTON.BIN
(TO AVOID CONFUSION WITH THE
ORIGINAL EPDL LIBRARY THAT THIS
DATA WAS DERIVED FROM).

C VERSION 94-1 (JAN. 1994)

*SWITCHED POSITIONS OF COMPTON AND
RAYLEIGH, TO CONFORM TO EPIC
BINARY LIBRARY STORAGE CONVENTION.
*ENERGY SCORING BINS ARE NOW ALWAYS
EQUALLY SPACED IN ENERGY (EARLIER
LINEAR OR LOG SPACING WAS ALLOWED).
*ADDED ARBITRARY TABULATED SOURCE
SPECTRUM.
*ADDED OPTIMUM SOURCE SPECTRUM
SAMPLING (IN EQUALLY PROBABLE
ENERGY INTERVALS).
*ADDED RESTART OPTION
*LOW ENERGY FLUORESCENCE NOW SCORED
AS LOW ENERGY (PREVIOUSLY DEPOSITED
WITH PHOTOELECTRIC).

C VERSION 94-2 (AUGUST 1994)

C WRITTEN BY
C
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C PURPOSE
C
C =====

C EPICP IS A SIMPLE PROGRAM FOR TRACKING PHOTONS TO TEST CONCEPTS
C FOR LATER USE IN THE MAIN EPIC CODE. THE EMPHASIS OF THIS CODE
C IS ON TESTING CONCEPTS RELATED TO HANDLING OF THE PHOTON DATA
C (BINARY, RANDOM ACCESS FILE) AND THE KINEMATICS FOR EACH PROCESS.

C IN ORDER TO BE ABLE TO EASILY ANALYZE RESULTS THE GEOMETRY HAS
C BEEN KEPT AS SIMPLE AS POSSIBLE = A SINGLE CYLINDRICAL ZONE,
C

TO SIMULATE A CYLINDRICAL DETECTOR.

THE MAIN PORTION OF THE CODE IS DESIGNED AS AN UNOPTIMIZED DRIVER TO USE MONTE CARLO TO TRACK PHOTONS AND SCORE RESULTS. THE EMPHASIS HERE IS NOT TO WORRY ABOUT RUNNING TIME, BUT RATHER TO SPEND AS MUCH AS IS NECESSARY TO SCORE AS MANY DIFFERENT QUANTITIES AS POSSIBLE - IN ORDER TO VERIFY THE ACCURACY OF DATA HANDLING AND KINEMATICS. BOTH ANALOGUE AND EXPECTATION RESULTS ARE CALCULATED.

DOCUMENTATION OF METHODS AND DATA

=====

FOR DOCUMENTATION OF METHODS AND DATA USED BY THIS CODE SEE,

"A SIMPLE MODEL OF PHOTON TRANSPORT", UCRL-JC-118254, LAWRENCE LIVERMORE NATIONAL LABORATORY (JULY 1994), BY D.E. CULLEN

FOR A DESCRIPTION OF THE SOURCES OF THE DATA SEE,

"THE 1989 LIVERMORE EVALUATED PHOTON DATA LIBRARY (EPDL)", UCRL-ID-103424, LAWRENCE LIVERMORE NATIONAL LABORATORY, BY D.E. CULLEN, ET.AL.

SEE ALSO THE ENDF/B-VI PHOTON INTERACTION LIBRARY - THIS LIBRARY IS BASED ON THE EPDL LIBRARY AND IS THE SAME AS THE DATA USED HERE

RELATED CODES

=====

SIMILAR CODES ARE AVAILABLE TO TEST CONCEPTS FOR ELECTRONS AND POSITRONS, LIGHT CHARGED PARTICLES (PROTON, DEUTERON, TRITON, HELIUM-3 AND ALPHA) AND NEUTRONS. ALL OF THESE ARE DESIGNED TO ALLOW ALGORITHMS TO BE OPTIMIZED FOR LATER USE IN EPIC.

THERE ARE ALSO FIVE UTILITY CODES THAT CAN BE USED WITH EPICP

- 1) EPICBIN - READ TABLES AND CREATE BINARY, RANDOM ACCESS FILES
- 2) EPICTAB - READ BINARY, RANDOM ACCESS FILES AND CREATE TABLES
- 3) EPICSHOW - GRAPHICALLY VIEW EPIC DATA FILES
- 4) PARROT - GRAPHICALLY MONITOR OUTPUT FROM EPICP
- 5) PLOTTAB - ON SCREEN OR HARDCOPY OUTPUT OF EPICP RESULTS

FOR COPIES OF THESE UTILITIES CONTACT THE AUTHOR OF THIS CODE.

ELEMENT AND PHOTON ENERGY RANGE

=====

THE EPIC PHOTON DATA BASE CONTAINS PHOTON INTERACTION DATA FOR ALL ELEMENTS BETWEEN HYDROGEN (Z=1) AND FERMIUM (Z=100) OVER THE ENERGY RANGE 10 EV TO 1 GEV. ALL INPUT PARAMETERS MUST RESTRICT ELEMENT AND PHOTON ENERGIES TO WITHIN THESE RANGES.

PROGRAM SOLVED

=====

THIS CODE CAN BE USED TO SOLVE NORMAL PHOTON TRANSPORT PROBLEMS, OR AS A DIAGNOSTIC TOOL TO TEST AND VERIFY INDIVIDUAL ROUTINES AS THEY ARE IMPLEMENTED. IN EITHER CASE THE PROGRAM PERFORMS

C MONTE CARLO CALCULATIONS TO STATISTICALLY PREDICT RESULTS.

C
C
C NORMAL TRANSPORT RESULTS

C =====
C THIS PROGRAM CAN BE USED TO RUN NORMAL PHOTON TRANSPORT PROBLEMS.
C THE NORMAL RESULTS INCLUDE,

C DEPOSITION - ONLY ANALOGUE
C - VS. ENERGY AND DEPTH INTO THE DETECTOR
C REFLECTION - ANALOGUE AND EXPECTATION
C TRANSMISSION - ANALOGUE AND EXPECTATION
C LATERAL LEAKAGE - ANALOGUE AND EXPECTATION

C EPICP CALCULATES THE RESPONSE OF A CYLINDRICAL DETECTOR. IT ALSO
C CALCULATES TRANSMISSION, REFLECTION AND LATERAL LEAKAGE FROM THE
C DETECTOR.

C PHOTONS ARE TRACKED IN 3-D (X, Y, Z) GEOMETRY UNTIL THEY LEAK
C FROM THE DETECTOR, ARE ABSORBED, OR FALL BELOW THE LOWEST
C ENERGY OF INTEREST.

C FOR EACH PHOTON THE DETECTOR RESPONSE IS SCORED AS A SINGLE
C EVENT FOR THE TOTAL ENERGY LOST BY THE PHOTON WITHIN THE
C DETECTOR = THE SUM OF ENERGY LOSSES DUE TO ALL EVENTS.

C TRANSMISSION, REFLECTION, LATERAL LEAKAGE AND LOW ENERGY
C ARE SCORED AS A SINGLE EVENT CORRESPONDING TO THE ENERGY OF
C THE PHOTON WHEN IT IS TRANSMITTED, REFLECTED, ETC.

C DIAGNOSTIC RESULTS

C =====
C THIS PROGRAM CAN ALSO BE USED AS A DIAGNOSTIC TOOL TO TEST AND
C VERIFY EACH ROUTINE AS IT IS IMPLEMENTED - AND ALSO AS A TEACHING
C AID TO HELP THE USER UNDERSTAND THE IMPORTANCE OF EACH PROCESS.

C THE CURRENTLY AVAILABLE DIAGNOSTIC RESULTS ARE CONTROLLED BY AN
C INPUT PARAMETER, AS DESCRIBED BELOW.

C ADDITIONAL DIAGNOSTIC RESULTS

C =====
C IN ADDITION TO THE DIAGNOSTIC RESULTS THAT CAN BE OBTAINED USING
C INPUT PARAMETERS, THIS PROGRAM INCLUDES A SUBROUTINE TURNOFF
C THAT CAN BE USED TO TURN OFF ANY OF THE PHYSICS, E.G., THIS CAN
C BE USED TO OBTAIN RESULTS WITH OR WITHOUT FLUORESCENCE, WITH OR
C WITHOUT THE FORM FACTOR FOR COHERENT SCATTERING, WITH OR WITHOUT
C THE SCATTERING FUNCTION FOR INCOHERENT SCATTERING, ETC.

C THIS ROUTINE MAKES IT VERY EASY TO QUICKLY ASSESS THE IMPORTANCE
C OF ANY EFFECT IN ANY MATERIAL IN ANY ENERGY RANGE - WHICH ALLOWS
C OPTIMIZATION OF THE ALGORITHMS USED.

C PLANAR GEOMETRY

C =====
C ALTHOUGH THIS PROGRAM IS DESIGNED TO PERFORM CALCULATIONS IN
C CYLINDRICAL GEOMETRY, IT CAN ALSO BE USED TO PERFORM CALCULATIONS

IN PLANAR GEOMETRY BY: 1) MAKE THE RADIUS MUCH LARGER THAN THE THICKNESS, 2) DEFINE THE SOURCE POSITION TO BE A POINT AT THE CENTER OF THE FACE OF THE CYLINDER (NOT UNIFORM ACROSS THE FACE). THIS WILL SIMULATE RESULTS IN PLANAR GEOMETRY AND YOU CAN USE THE RESULTS TO DEFINE REFLECTION, TRANSMISSION AND SPATIALLY DEPENDENT DEPOSITION AS A FUNCTION OF DEPTH INTO THE PLANE.

HOW LARGE SHOULD THE RADIUS BE? IT SHOULD BE SO BIG THAT THE RESULTS INDICATE EXACTLY ZERO LATERAL LEAKAGE = NONE OF THE PHOTONS EVER FOUND THE CYLINDRICAL SURFACE, AND THEREFORE THE RESULTS MUST BE EXACTLY THE SAME AS RUNNING IN PLANAR GEOMETRY. TRY MAKING THE RADIUS 1000 TIMES THE THICKNESS, RUN A SMALL BATCH OF HISTORIES. IF YOU GET ZERO LATERAL LEAKAGE IT'S BIG ENOUGH. IF NOT MAKE IT 10 TIMES BIGGER.

SINCE THIS CODE IS EXTREMELY SIMPLE AND DOES NOT USE ANY BIASING TECHNIQUES DURING THE TRANSPORT, IT IS RECOMMENDED THAT YOU NOT USE THIS PROGRAM FOR DEEP PENETRATION PROBLEMS. WITHOUT BIASING YOU WOULD HAVE TO RUN AN ENORMOUS NUMBER OF HISTORIES IN ORDER TO ACHIEVE CONVERGENCE.

PARTS OF PROGRAM

=====

THIS PROGRAM IS DIVIDED INTO A NUMBER OF PARTS

- 1) EPICP.F = A SIMPLE, UNOPTIMIZED PROGRAM TO PERFORM THE ACTUAL TRANSPORT CALCULATIONS OR ALTERNATIVELY TO PERFORM DIAGNOSTIC CALCULATIONS. THIS PART OF THE PROGRAM IS ONLY OF INTEREST IN THE CONTEXT THAT IT IS USED HERE.
- 2) EPICIO.F = HANDLES ALL EPIC BINARY I/O. THIS PORTION OF THE PROGRAM IS OF GENERAL INTEREST, IN THAT IT ILLUSTRATES HOW TO ACCESS AND USE THE EPIC DATA.
- 3) PHOTON.F = HANDLES ALL OF THE PHOTON CROSS SECTIONS AND KINEMATICS. THIS IS THE MAIN FOCUS OF THIS PROGRAM, IN THE SENSE THAT THE OBJECTIVE OF THIS PROGRAM IS TO USE TIMING AND DIAGNOSTIC STUDIES TO OPTIMIZE THESE ROUTINES FOR LATER USE IN THE MAIN EPIC CODE.
- 4) UTILITY.F = COMPUTER DEPENDENT ROUTINES - TO HANDLE RANDOM NUMBER GENERATION AND TIMING INFORMATION.

FORCED FIRST COLLISION

=====

FOR THIN DETECTORS MOST OF THE PHOTONS WOULD STREAM RIGHT THROUGH THE DETECTOR WITHOUT HAVING ANY INTERACTIONS AND A PROGRAM COULD SPENT A GREAT DEAL OF TIME WITHOUT SCORING ANY DEPOSITION.

IN ORDER TO AVOID THIS PROBLEM THIS CODE FORCES ALL PHOTONS TO HAVE AT LEAST ONE COLLISION. ONCE A PHOTON IS SAMPLED FROM THE INCIDENT SPECTRUM, THE PROBABILITY OF TRANSMISSION $\exp(-\text{SIG} \cdot T)$ IS CALCULATED AND SCORED FOR BOTH ANALOGUE AND EXPECTED TRANSMISSION. THE PHOTON IS THEN ASSIGNED WEIGHT $1 - \exp(-\text{SIG} \cdot T)$ AND FORCED TO HAVE A FIRST COLLISION WITHIN THE DETECTOR BY SAMPLING FROM THE RE-NORMALIZED DISTRIBUTION,

$$P(X) * D(X) = \text{EXP}(-X) / [1 - \text{EXP}(-T)]$$

INTEGRATING,

$$\begin{aligned} P(X) &= [1 - \text{EXP}(-X)] / [1 - \text{EXP}(-T)] \\ [1 - \text{EXP}(-T)] * P(X) &= [1 - \text{EXP}(-X)] \end{aligned}$$

WHERE $P(X)$ IS A RANDOM NUMBER BETWEEN 0 AND 1. SINCE $P(X)$ IS A RANDOM NUMBER SO IS $1 - P(X)$ - SO WE CAN WRITE,

$$\begin{aligned} [1 - \text{EXP}(-T)] * [1 - P(X)] &= [1 - \text{EXP}(-X)] \\ [1 - \text{EXP}(-T)] - P(X) [1 - \text{EXP}(-T)] &= [1 - \text{EXP}(-X)] \\ - \text{EXP}(-T) - P(X) [1 - \text{EXP}(-T)] &= - \text{EXP}(-X) \\ + \text{EXP}(-T) + P(X) [1 - \text{EXP}(-T)] &= + \text{EXP}(-X) \end{aligned}$$

$$X = -\text{LOG}[\text{EXP}(-T) + P(X) * (1 - \text{EXP}(-T))]$$

$\text{EXP}(-T)$ IS THE UNCOLLIDED TRANSMISSION PROBABILITY

$1 - \text{EXP}(-T)$ IS THE PROBABILITY OF COLLIDING = THE WEIGHT

SO THIS CAN BE WRITTEN AS,

$$X = -\text{LOG}[\text{TRANSMISSION} + P(X) * \text{WEIGHT}]$$

FOR $P(X) = 0$, $X = T$

FOR $P(X) = 1$, $X = 0$

NOTE, FOR OPTICALLY THICK DETECTORS WHERE $\text{EXP}(-T) \rightarrow 0$ THIS DEFINITION SMOOTHLY APPROACHES THE NORMAL DEFINITION OF SAMPLING A DISTANCE TO COLLISION,

$$X = -\text{LOG}[P(X)]$$

THIS APPROACH TENDS TO SPEED CONVERGENCE BOTH BY FORCING EACH PHOTON TO DEPOSIT ENERGY AND ALSO BY ANALYTICALLY DEFINING THE UNCOLLIDED TRANSMISSION.

METHODICAL SOURCE SAMPLING

=====

WE SHOULD REMEMBER THAT WE KNOW THE SOURCE SPECTRUM - IT IS NOT A RANDOM VARIABLE. AS SUCH THIS PROGRAM DOES NOT TREAT THE SPECTRUM AS A COMPLETELY RANDOM VARIABLE. THE INPUT SPECTRUM IS BINNED INTO A CUMULATIVE INTEGRAL TABLE, WHERE THE TABULATED POINTS INCLUDE ALL OF THE INPUT POINTS PLUS 1000 EQUALLY PROBABLE ENERGY INTERVALS. THIS TABLE IS THEN METHODICALLY RANDOMLY SAMPLED FROM LOW ENERGY TO HIGH FOR EACH BATCH OF HISTORIES, INSURING THAT EACH ENERGY INTERVAL INCLUDES AS CLOSE AS POSSIBLE TO THE ACTUAL NUMBER OF PHOTONS IN THE SPECTRUM.

THIS APPROACH CAN GREATLY SPEED CONVERGENCE BY AT LEAST STARTING AS CLOSE TO THE ACTUAL SOURCE SPECTRUM AS POSSIBLE, AND ONLY SUBSEQUENT COLLISIONS ARE STATISTICAL. FOR EXAMPLE, FOR A CONSTANT SPECTRUM BETWEEN 10 EV AND 1 MEV, RANDOMLY SAMPLING THIS ENTIRE ENERGY INTERVAL TREATED AS ONE INTERVAL RESULTS IN

VERY SLOW CONVERGENCE TO A UNIFORM DISTRIBUTION OVER THE ENTIRE ENERGY RANGE. IN CONTRAST BY DIVIDING THIS ENERGY INTERVAL INTO 1000 EQUALLY PROBABLE BINS AND FORCING 1/1000 OF THE HISTORIES IN EACH BATCH TO BE SAMPLED FROM EACH OF THESE 1000 BINS, WE FORCE QUICK CONVERGENCE TO THE ACTUAL INPUT SPECTRUM.

DEFINITION OF I/O FILES

NUMBER	FILENAME	DESCRIPTION
5	EPICP.INP	INPUT PARAMETERS
6	EPICP.LST	OUTPUT REPORT
16	PLOTTAB.CUR	PLOTTAB FORMATTED OUTPUT
19	PHOTON.BIN	BINARY PHOTON DATA FILE
20	EPICP.BIN	BINARY RESTART FILE

DEFINITION OF INPUT PARAMETERS

LINE	COLUMNS	FORMAT	DEFINITION
1	1-10	E10.3	DETECTOR RADIUS - CM (MUST BE POSITIVE)
	11-20	E10.3	DETECTOR THICKNESS - CM (MUST BE POSITIVE)
	21-30	E10.3	MAXIMUM ENERGY OF SPECTRUM - MEV (MUST BE 10 EV TO 1 GEV)
	31-40	E10.3	MINIMUM ENERGY OF SPECTRUM - MEV (MUST BE 10 EV TO 1 GEV AND LESS THAN MAXIMUM ENERGY OF SPECTRUM)
	41-50	E10.3	MINIMUM ENERGY OF INTEREST - MEV (MUST BE 10 EV TO 1 GEV AND LESS THAN MAXIMUM ENERGY OF SPECTRUM)
2	1-10	I10	NUMBER OF BATCHES < 0 = RESTART (SEE DESCRIPTION BELOW)
	11-20	I10	NUMBER OF HISTORIES PER BATCH (MUST BE POSITIVE)
	21-30	I10	NUMBER OF SCORING BINS (MUST BE 10 TO 1000)
	31-35	I5	SOURCE SPECTRUM = 0 - MONOENERGETIC AT MAXIMUM ENERGY = 1 - CONSTANT FROM MINIMUM ENERGY OF SPECTRUM UP TO MAXIMUM ENERGY OF SPECTRUM. = 2 - 1/E FROM MINIMUM ENERGY OF SPECTRUM UP TO MAXIMUM ENERGY OF SPECTRUM. = 3 - READ TABULATED SPECTRUM (UP TO 5000 E,S PAIRS) (LINEAR INTERPOLATION IN TABLE)

THE SOURCE SPECTRUM CAN BE SAMPLED EITHER DIRECTLY AS INPUT, OR BINNED INTO EQUALLY PROBABLE BINS AND SAMPLED. THIS OPTION ALLOWS YOU TO EVALUATE THE

IMPORTANCE OF NOT TREATING THE SOURCE
AS A TRULY RANDOM VARIABLE - SEE THE
DISCUSSION ABOVE.

IF THIS OPTION IS POSITIVE THE SPECTRUM
WILL BE BINNED AND SAMPLED (RECOMMENDED
OPTION). IF IT IS NEGATIVE, IT WILL BE
SAMPLED AS INPUT (ONLY RECOMMENDED FOR
TESTING PURPOSES).

THIS ONLY APPLIES TO CONSTANT AND 1/E
SPECTRA. MONOENERGETIC SPECTRA ARE
NATURALLY DEFINED WITHOUT ANY SAMPLING.
TABULATED SPECTRA ARE ALWAYS BINNED AND
SAMPLED.

36-40	I5	SOURCE SPATIAL DISTRIBUTION
		= 0 - POINT ON Z AXIS OF CYLINDER
		= 1 - UNIFORM ON THE FACE OF CYLINDER
41-45	I5	OPERATING MODE
		= 0 - NORMAL CALCULATION
		DIAGNOSTICS - SAMPLE THE FOLLOWING
		= 1 - TOTAL CROSS SECTIONS
		= 2 - RAYLEIGH NO FORM FACTOR
		= 3 - RAYLEIGH WITH FORM FACTOR
		= 4 - COMPTON NO SCATTERING FUNCTION
		= 5 - COMPTON WITH SCATTERING FUNCTION
		= 6 - PHOTOELECTRIC CROSS SECTION TIMES (INCIDENT-FLUORESCENCE) ENERGY
		= LOCAL DEPOSITION
		= 7 - PHOTOELECTRIC CROSS SECTION TIMES FLUORESCENCE ENERGY
		= 8 - PHOTOELECTRIC CROSS SECTIONS
		= 9 - FLUORESCENCE ENERGY
		=10 - SOURCE SPECTRUM SAMPLING
		OUTPUT THE FOLLOWING - NO SAMPLING
		=11 - CROSS SECTIONS
		= TOTAL FOR EACH CONSTITUENT
		+ COMPOSITE CROSS SECTIONS BY TYPE
46-50	I5	CROSS SECTION REPRESENTATION
		=-1 - FIXED ENERGIES, TART 176 POINTS 100 EV TO 30 MEV
		(WARNING, IF YOU USE THIS OPTION ALL ENERGIES MUST BE IN THIS RANGE)
		= 0 - ORIGINAL ENERGIES, READ FROM FILE (RECOMMENDED OPTION)
		= 1 - FIXED ENERGIES, 50 PER ENERGY DECADE - 402 ENERGIES - 10 EV TO 1 GEV.

3	11-20	e10.3	COMPOSITE DENSITY - GRAMS/CC (MUST BE POSITIVE)
4-N	1-10	I10	DETECTOR MATERIAL ATOMIC NUMBER = Z (MUST BE 1 TO 100)

11-20	E10.3	DENSITY - GRAMS/CC
21-30	E10.3	DENSITY - ATOMS/(CM-BARN)

THE COMPOSITE DENSITY IS USED TO NORMALIZE THE INPUT DENSITY FOR EACH CONSTITUENT. FOR EXAMPLE, FOR WATER WITH A COMPOSITE DENSITY OF 1 GRAM/CC YOU CAN INPUT 1 GRAM/CC AS THE COMPOSITE DENSITY AND THEN INPUT 2 ATOMS/(CM-BARN) OF HYDROGEN AND 1 ATOMS/(CM-BARN) OF OXYGEN, AND THE PROGRAM WILL NORMALIZE THE ACTUAL ATOMS/(CM-BARN) OF EACH SO THAT THE COMPOSITE DENSITY IS 1 GRAM/CC.

INPUT DENSITY OR ATOMS/(CM-BARN). IF DENSITY IS GREATER THAN ZERO IT WILL BE USED TO DEFINE ATOMS/(CM-BARN) - OTHERWISE THE ATOMS/(CM-BARN) WILL BE USED TO DEFINE DENSITY - BOTH ARE LISTED IN THE OUTPUT REPORT.
(AT LEAST 1 OF THE 2 MUST BE POSITIVE)

THE DETECTOR CAN BE COMPOSED OF FROM 1 TO 10 ELEMENTS, EACH WITH ITS OWN DENSITY.

AFTER THE FIRST 3 INPUT LINES THERE MAY BE 1 TO 10 LINES, EACH SPECIFYING 1 MATERIAL OF THE DETECTOR COMPOSITION.

THE LIST IS TERMINATED BY A BLANK INPUT LINE OR AN END OF FILE.

THIS SECTION IS NEEDED ONLY IF THE SOURCE SPECTRUM ON LINE 2 IS DEFINED = 3 - READ TABULATED SPECTRUM.

(N+1)-K	1-10	E10.3	SPECTRUM ENERGY (MEV)
	11-20	E10.3	SPECTRUM VALUE (PHOTONS/MEV) (UP TO 5000 ENERGY-VALUE PAIRS) (LINEAR INTERPOLATION IN TABLE)

THE LIST IS TERMINATED BY A BLANK INPUT LINE OR AN END OF FILE.

THE ENERGY RANGE OF THE SPECTRUM MUST BE WITHIN THE ENERGY RANGE OF THE AVAILABLE EPIC CROSS SECTIONS = 10 EV TO 1 GEV.

THE SPECTRUM NEED NOT TO NORMALIZED. THIS PROGRAM WILL INTEGRATE THE SPECTRUM OVER ITS ENERGY RANGE, NORMALIZE IT TO UNITY AND SAMPLE IT.

WARNING - YOU MUST INCLUDE ENOUGH ENERGY
POINTS IN YOUR SPECTRUM TO ALLOW LINEAR
INTERPOLATION BETWEEN ADJACENT ENERGIES.

USE OF INPUT ENERGIES

THE MINIMUM AND MAXIMUM ENERGIES OF THE SPECTRUM DEFINE THE
ENERGY LIMITS OF THE SPECTRUM FOR CONSTANT OR 1/E ENERGY
SPECTRA.

THE MINIMUM ENERGY OF INTEREST AND MAXIMUM ENERGY OF THE SPECTRUM
DEFINE THE ENERGY RANGE OF THE SCORING BINS. THESE TWO INPUT
PARAMETERS AND THE NUMBER OF SCORING BINS DEFINE THE ENERGY
WIDTH OF EACH SCORING BIN. THE SCORING BINS ARE EQUALLY SPACED
IN ENERGY BETWEEN THE MINIMUM ENERGY OF INTEREST AND THE
MAXIMUM ENERGY OF THE SPECTRUM. THEIR WIDE IS THIS ENERGY
RANGE DIVIDED BY THE NUMBER OF SCORING BINS.

ANY PHOTONS WITH AN ENERGY BELOW THE MINIMUM ENERGY OF INTEREST
ARE NOT TRACKED. AN EVENT AND THE ENERGY OF THE PHOTON ARE
SCORED AND OUTPUT UNDER LOW ENERGY.

IT IS RECOMMENDED FOR TRANSPORT CALCULATION TO SET THE LOWEST
ENERGY OF INTEREST TO A LOW VALUE = 10 EV - THE LOWEST ALLOWED
ENERGY. WITH THIS LOWER LIMIT THIS PROGRAM WILL TRACK AS MANY
PHOTONS AS POSSIBLE.

EXAMPLE INPUT PARAMETERS

EXAMPLE # 1

FOR A SODIUM-IODIDE DETECTOR 3.81 CM IN RADIUS AND 7.62 CM THICK,
A MONOENERGETIC 4.43 MEV SOURCE, TRACK PHOTONS DOWN TO 10 EV. RUN
1000 BATCHES OF 100,000 PARTICLES EACH. USE 1000 ENERGY SCORING
BINS, MONOENERGETIC SOURCE, POINT ON Z AXIS OF CYLINDER, NORMAL
OPERATION (NOT DIAGNOSTICS). FOR THE CROSS SECTIONS USE ORIGINAL
ENERGIES AS READ FROM FILE. SODIUM AT 0.971 GRAMS/CC AND IODINE
AT 4.93 GRAMS/CC ARE THE COMPOSITE MATERIAL = A COMPOSITE
DENSITY OF 5.901 GRAMS/CC.

THE FOLLOWING 5 INPUT LINES ARE REQUIRED,

```
3.8100+00 7.6200+00 4.4300+00 1.0000-05 1.0000-05
      1000      100000      1000      0      0      0      0
          5.9010+00
      11 9.7100-01
      53 4.9300+00
```

(BLANK LINE=END OF COMPOSITION)

EXAMPLE # 2

THE SAME AS THE ABOVE EXAMPLE, ONLY IN THIS CASE A TABULATED
ENERGY DEPENDENT SPECTRUM IS READ AS INPUT. THE INPUT SPECTRUM
EXTENDS FROM 1 TO 5 MEV. IT NEED NOT BE NORMALIZED (THE PROGRAM
WILL DO THIS FOR YOU).

C
C THE FOLLOWING 11 INPUT LINES ARE REQUIRED,
C

C 3.8100+00 7.6200+00 5.0000+00 1.0000+00 1.0000-05
C 1000 100000 1000 0 0 0 0
C 5.9010+00
C 11 9.7100-01
C 53 4.9300+00

C (BLANK LINE=END OF COMPOSITION)

C 1.0000+00 1.0000+00
C 2.0000+00 5.0000-01
C 3.0000+00 3.3333-01
C 4.0000+00 2.5000-01
C 5.0000+00 2.0000-01

C (BLANK LINE=END OF SPECTRUM)
C

C EXAMPLE # 3
C

C =====

C IF YOU COMPLETE THIS RUN, OR TERMINATE PREMATURELY (AS DESCRIBED
C BELOW) YOU CAN RESTART AND CONTINUE RUNNING MORE HISTORIES FROM
C THE POINT THE PROGRAM TERMINATED BY USING THE ABOVE INPUT, BUT
C WITH A NEGATIVE BATCH COUNT TO INDICATE RESTART, AS SHOWN BELOW,
C

C THE FOLLOWING 11 INPUT LINES ARE REQUIRED,
C

C 3.8100+00 7.6200+00 5.0000+00 1.0000+00 1.0000-05
C -1000 100000 1000 0 0 0 0
C 5.9010+00
C 11 9.7100-01
C 53 4.9300+00

C (BLANK LINE=END OF COMPOSITION)

C 1.0000+00 1.0000+00
C 2.0000+00 5.0000-01
C 3.0000+00 3.3333-01
C 4.0000+00 2.5000-01
C 5.0000+00 2.0000-01

C (BLANK LINE=END OF SPECTRUM)
C

C EXAMPLE # 4
C

C =====

C SAME AS THE ABOVE EXAMPLE, EXCEPT IN THIS CASE THE COMPOSITION
C IS WATER = H2O, AT A COMPOSITE DENSITY OF 1 GRAM/CC. INPUT WILL
C ONLY DEFINE ATOMS/(CM-BARN) AND THE PROGRAM WILL RE-NORMALIZE
C TO THE COMPOSITE DENSITY.
C

C THE FOLLOWING 11 INPUT LINES ARE REQUIRED,
C

C 3.8100+00 7.6200+00 5.0000+00 1.0000+00 1.0000-05
C -1000 100000 1000 0 0 0 0
C 1.0000+00
C 1 2.0000+00
C 8 1.0000+00

C (BLANK LINE=END OF COMPOSITION)

C 1.0000+00 1.0000+00
C 2.0000+00 5.0000-01

3.0000+00 3.3333-01
4.0000+00 2.5000-01
5.0000+00 2.0000-01

(BLANK LINE=END OF SPECTRUM)

WARNING - IF YOU USE THE RESTART OPTION THE ONLY INPUT PARAMETER THAT YOU CAN CHANGE IS THE NUMBER OF BATCHES - THIS PROGRAM DOES NOT CHECK TO INSURE THAT YOU HAVE DONE THIS - IT IS UP TO YOU.

RUNNING TIME

DEPENDING ON THE NUMBER OF MATERIALS AND ENERGY RANGE INVOLVED IN THE CALCULATION, ON A SPARC-10 THIS CODE CAN PROCESS ABOUT 1/2 TO 1 MILLION EVENTS PER MINUTE. AGAIN, DEPENDING ON THE MATERIALS AND ENERGY RANGE, EACH PHOTON HISTORY CAN REQUIRE ABOUT 1 TO 5 EVENTS - SO THAT THIS CODE CAN PROCESS ABOUT 100,000 TO 1,000,000 HISTORIES PER MINUTE.

OUTPUT SCORING BINS

THESE BINS ARE LINEARLY SPACED IN ENERGY BETWEEN THE MAXIMUM INCIDENT PHOTON ENERGY AND THE MINIMUM ENERGY OF INTEREST. FOR EXAMPLE, IF THE MAXIMUM INCIDENT PHOTON ENERGY IS 1 MEV AND THE MINIMUM ENERGY OF INTEREST IS 10 EV, AND YOU REQUEST 100 SCORING BINS, EACH BIN WIDTH WILL BE $(1,000,000 - 10)/100$ EV WIDE, SPACED UNIFORMLY BETWEEN 10 EV AND 1 MEV.

THE SPEED OF CONVERGENCE WILL DEPEND ON HOW MANY OUTPUT BINS YOU REQUEST, I.E., THE MORE BINS YOU USE, THE FEWER HISTORIES WILL BE SCORED IN EACH BINS, SLOWING DOWN CONVERGENCE. IF WE ASSUME THE CONVERGENCE IS ROUGHLY PROPORTIONAL TO ONE OVER THE SQUARE ROOT OF THE NUMBER OF EVENTS SCORED IN EACH BIN, THEN USING 1000 BINS INSTEAD OF 100 BINS, WILL REQUIRE THIS (OR ANY OTHER) CODE TO RUN 100 TIMES AS LONG IN ORDER TO ACHIEVE THE SAME LEVEL OF STATISTICAL CONVERGENCE IN ALL BINS. SO DO NOT GET CARRIED AWAY AND ASSUME YOU SHOULD ALWAYS PERFORM CALCULATIONS USING 1000 BINS.

USE A REASONABLE NUMBER OF BINS THAT CORRESPOND TO WHAT YOU NEED. FOR EXAMPLE, TO SIMULATE THE RESPONSE OF A DETECTOR WITH A 1 % RESOLUTION, YOU PROBABLY DO NOT NEED MORE THAN 100 BINS.

DETECTOR RESPONSE

THIS CODE DOES NOT FOLD THE CALCULATED RESULTS WITH ANY DETECTOR RESPONSE - THE RESULTS ARE EXACTLY AS SCORED BASED SOLELY ON THE PHOTON MONTE CARLO TRANSPORT CALCULATION.

HOWEVER, IF YOU WISH TO FOLD THE CALCULATED RESULTS WITH A DETECTOR RESPONSE YOU SHOULD BE ABLE TO EASILY COMBINE THE OUTPUT RESULTS IN THE PLOTTAB FORMAT WITH YOUR DETECTOR RESPONSE.

TERMINATING EXECUTION

C THE PROGRAM WILL WRITE A RESTART FILE AT THE END OF EACH BATCH.

C THIS PROGRAM WILL TERMINATE EXECUTION,

- C 1) AFTER ALL BATCHES HAVE BEEN RUN, OR,
C 2) AT THE END OF A BATCH, IF ANY KEYBOARD KEY IS PRESSED
C DURING EXECUTION (ONLY ON IBM-PC)
C 3) IF YOU SOMEHOW KILL IT
C

C REGARDLESS OF HOW THE CODE TERMINATES YOU WILL BE ABLE TO
C RESTART, UNLESS YOU ARE UNLUCKY ENOUGH TO TERMINATE EXACTLY
C AT THE END OF A BATCH WHEN THE CODE IS WRITING THE RESTART FILE.
C

C IN ORDER TO AVOID THIS PROBLEM, THE SAFEST TIME TO TERMINATE
C THE CODE IS IMMEDIATELY AFTER IT HAS PRINTED STATISTICS FOR
C A BATCH - THIS IMMEDIATELY FOLLOWS WRITING AND CLOSING THE
C RESTART FILE.
C

C RESTART FILE

C =====
C YOU CAN CONTINUE FROM THE POINT THE PROGRAM STOPPED BY USING
C THE RESTART OPTION. RESTART IS INDICATED ON INPUT BY A NEGATIVE
C BATCH COUNT.
C

C WITH THIS OPTION YOU CAN RUN FOR A PERIOD OF TIME AND THEN LOOK
C AT THE RESULTS USING PLOTTAB. IF THE RESULTS INDICATE THAT YOU
C NEED TO RUN MORE HISTORIES, THIS OPTION WILL ALLOW YOU TO
C CONTINUE FROM THE POINT THAT THE PROGRAM STOPPED. YOU CAN ALSO
C LET THE PROGRAM RUN TO COMPLETION, EXAMINE RESULTS AND DECIDE
C WHETHER OR NOT YOU NEED TO RUN MORE HISTORIES.
C

C WHEN RUNNING USING THE RESTART OPTION, THE NUMBER OF BATCHES
C THAT YOU INPUT WILL BE INTERPRETED TO MEAN RUN THIS MANY MORE
C BATCHES, E.G., IF INPUT INDICATES 1000 BATCHES AND THE RESTART
C FILE INDICATES 100 BATCHES HAVE ALREADY BEEN RUN, THIS PROGRAM
C WILL RUN ANOTHER 1000 BATCHES (BATCHES 101 TO 1100).
C

C WARNING - THE PROGRAM DOES NOT CHECK TO BE SURE THAT YOU ARE
C CONTINUING EXACTLY THE SAME PROBLEM - IT MERELY
C COMBINES THE STATISTICS PREVIOUSLY CALCULATED WITH
C THOSE CALCULATED DURING THE CURRENT RUN.
C

C IT IS THE USERS RESPONSIBILITY TO INSURE THAT THE
C RUNNING CONDITIONS FOR THE CURRENT RUN ARE EXACTLY
C THE SAME AS THE PREVIOUS RUN, IN ORDER TO INSURE
C THAT THE STATISTICS FROM THE PREVIOUS RUN, AS READ
C DURING RESTART, EXACTLY CORRESPOND TO THE CURRENT
C RUNNING CONDITIONS.
C

C TO RESTART THE ONLY INPUT PARAMETER THAT YOU CAN
C CHANGE IS THE NUMBER OF BATCHES - WHICH MUST BE A
C NEGATIVE INTEGER ON INPUT FOR RESTART.
C

C PLOTTAB OUTPUT

C =====
C OUTPUT FROM THIS CODE IS IN THE PLOTTAB FORMAT. THE FORMAT IS
C

C VERY SIMPLE - EACH CURVE STARTS WITH A 1 LINE TITLE TO IDENTIFY
C THE DATA, E.G., ANALOGUE TRANSMISSION - AND IS FOLLOWED BY
C (X,Y) PAIRS, ONE PAIR PER LINE IN 2E11.4 FORMAT - THE CURVE IS
C TERMINATED BY A BLANK (NOT ZERO, BLANK) LINE.
C

C EACH CURVE MAY BE IMMEDIATELY FOLLOWED BY EITHER ANOTHER CURVE
C OR AN END OF FILE.
C

C THE OUTPUT IS FORMATTED IN EXACTLY THE WAY IT IS SAMPLED - AS
C A HISTOGRAM IN EACH ENERGY AND SPATIAL BIN.
C

C EXAMPLE OUTPUT,
C

C ANALOGUE TRANSMISSION
C 1.00000-03 1.00000-02
C 1.20000-03 1.00000-02
C 1.20000-03 1.23000-02
C 1.40000-03 1.23000-02
C .
C .
C .
C .
C .

C (BLANK LINE TERMINATES CURVE)
C

C EXPECTED TRANSMISSION
C 1.00000-03 1.00000-02
C 1.20000-03 1.00000-02
C 1.20000-03 1.23000-02
C 1.40000-03 1.23000-02
C .
C .
C .
C .
C .

C NOTE, THE HISTOGRAM REPRESENTATION - THE RESULT IS CONSTANT
C BETWEEN 1 AND 1.2 KEV - 1.2 AND 1.4 KEV, ETC.
C

C CONTACT THE AUTHOR FOR A COPY OF THE PLOTTAB CODE IF YOU WISH TO
C USE IT TO VIEW AND INTERACT WITH THE OUTPUT FROM THIS CODE OR TO
C OBTAIN HARDCOPY RESULTS.
C

C USING PARROT
C

C =====
C PROGRAM PARROT IS DESIGNED TO ALLOW YOU TO MONITOR THE EXECUTION
C OF EPICP. WARNING - THIS CODE IS DESIGNED ONLY TO MONITOR
C NORMAL TRANSPORT CALCULATIONS - DO NOT TRY TO USE IT TO MONITOR
C DIAGNOSTIC CALCULATIONS - PLOTTAB CAN BE USED TO VIEW RESULTS
C OF DIAGNOSTIC CALCULATIONS.
C

C ON WORKSTATIONS PARROT CAN BE USED TO MONITOR THE EXECUTION OF
C EPICP. ONCE YOU HAVE STARTED EPICP LET IT COMPLETE AT LEAST ONE
C BATCH (SO THERE IS SOME PLOTTAB FORMATTED OUTPUT). THEN USE
C ANOTHER WINDOW TO START PARROT RUNNING IN THE SAME DIRECTORY
C AS EPICP. PARROT WILL READ THE EPICP OUTPUT LISTING TO DEFINE
C RUNNING CONDITIONS (TITLES AT TOP OF PLOT) AND THEN START
C READING THE PLOTTAB FORMATTED OUTPUT. EVERY TIME THE TOTAL

C NUMBER OF HISTORIES CHANGES IN THIS OUTPUT FILE, PARROT WILL
C DISPLAY THE RESULTS = TRANSMISSION, REFLECTION, LATERAL LEAKAGE
C AND DEPOSITION WITHIN THE DETECTOR. THIS WILL ALLOW YOU TO
C MONITOR RESULTS IN REAL TIME AS EPICP IS RUNNING. BASED ON WHAT
C YOU SEE YOU CAN DECIDE TO ALLOW EPICP TO KEEP RUNNING (THE PLOTS
C INDICATE YOU HAVE NOT REACHED CONVERGENCE YET) OR TO TERMINATE
C EPICP (CONVERGENCE HAS BEEN REACHED). SO THAT IT DOES NOT
C COMPETE WITH EPICP FOR PROCESSOR TIME, AFTER COMPLETING EACH
C PLOT PARROT WILL SLEEP FOR 10 SECONDS BEFORE TRYING TO PRODUCE
C THE NEXT PLOT, I.E., PER 10 SECONDS IT WILL USE ALMOST NO
C PROCESSOR TIME AND ALLOW EPICP TO RUN AS FAST AS POSSIBLE.
C PARROT WILL CONTINUING RUNNING UNTIL YOU SOMEHOW TERMINATE IT.

C
C PARROT CAN ALSO BE USED ON IBM-PC (OR COMPATIBLE), BUT NOT IN
C REAL TIME AS EPICP IS RUNNING. IN THIS CASE YOU CAN LET EPICP
C RUN A NUMBER OF BATCHES AND THEN TERMINATE IT BY PRESSING ANY
C KEYBOARD KEY. YOU CAN THEN RUN PARROT TO SEE THE CURRENT
C RESULTS. BASED ON WHAT YOU SEE YOU CAN EITHER DECIDE TO USE
C THE EPICP RESTART OPTION (SEE, DESCRIPTION ABOVE) TO INCLUDE
C MORE BATCHES IN THE RESULTS, OR DECIDE THAT THE RESULTS ARE
C ALREADY ACCURATE ENOUGH. ON IBM-PC PARROT WILL ONLY PRODUCE
C ONE PLOT AND THEN DELAY UNTIL YOU PRESS ANY KEYBOARD KEY AND
C THEN TERMINATE.

C COMPUTER DEPENDENT CODING

C =====
C *THIS PROGRAM HAS NOW BEEN SUCCESSFULLY RUN ON,

C * CRAY
C * SUN
C * SGI
C * IBM-PC
C * MACINTOSH

C FOR USE ON CRAY AND MAC SEE THE BELOW COMMENTS ON IMPLEMENTATION
C AND USE.

C *ALL COMPUTER DEPENDENT ROUTINES ARE IN UTILITY.F. THESE ARE
C RELATED TO RANDOM NUMBER GENERATION AND TIMING. WITHIN THE
C PROGRAM FUNCTION RAND1(I) IS USED TO DEFINE SINGLE PRECISION
C RANDOM NUMBERS. FOR USE ON ANY COMPUTER YOU NEED MERELY
C SUPPLY A FUNCTION WITH THE SAME NAME THAT CALLS YOUR RANDOM
C NUMBER GENERATOR.

C
C WARNING - ON SUN TERMINALS RAND IS A SINGLE PRECISION FUNCTION
C ON SGI TERMINALS RAND IS A DOUBLE PRECISION FUNCTION

C
C BE SURE THAT UTILITY.F PROPERLY DEFINES RAND1 FOR
C USE ON YOUR COMPUTER.

C *THIS PROGRAM CAN BE RUN ON 32 OR 64 BIT PER WORD COMPUTERS.
C AS DISTRIBUTED THE CODE IS SET UP TO BE USED ON 32 BIT PER
C WORD COMPUTERS, SINCE THE BINARY, RANDOM ACCESS FILE HAS
C BEEN CREATED FOR USE ON 32 BIT PER WORD COMPUTERS.

C
C SEE EPICIO.F FOR DETAILS ON HOW TO CREATE THE BINARY, RANDOM
C ACCESS FILE FOR EITHER TYPE OF COMPUTER.

C
C *CRAY USERS - SINCE THIS IS A 64 BIT PER WORD COMPUTER, SEE
C SUBROUTINE BINOLD (INITIALLY DEFINED RANDOM ACCESS FILE) FOR
C HOW TO IMPLEMENT AND USE THIS CODE ON A CRAY.
C
C *MACINTOSH USERS - WE ONLY HAVE A VERY OLD FORTRAN COMPILER FOR
C OUR MAC. THIS COMPILER SUPPORTS THE BINARY, RANDOM ACCESS USED
C BY THIS PROGRAM TO ACCESS THE PHOTON DATA. HOWEVER, THIS
C COMPILER LIMITS RECORD SIZE TO A MAXIMUM OF 1024 BYTES. THIS
C LIMITATION CAN BE ACCOMMODATED TO THIS PROGRAM - SEE SUBROUTINES
C BINOLD (INITIALLY DEFINED RANDOM ACCESS FILE) AND BININ (READ
C BINARY DATA) FOR HOW TO IMPLEMENT AND USE THIS CODE ON A MAC.
C
C*****

C PROGRAM EPICBIN

C =====
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C CREATE BINARY FILES FOR ELECTRONS, PHOTONS AND CHARGED PARTICLES
C =====

C THIS PROGRAM READS THE FOLLOWING CHARACTER FILES,
C

C ELECTRONS
C -----

C ELECTRON.TAB = ELECTRON MAJOR CROSS SECTIONS + ENERGY DEPOSITION
C ESHELLS.TAB = ELECTRON IONIZATION SHELL CROSS SECTIONS
C

C PHOTONS
C -----

C PHOTON.TAB = PHOTON MAJOR CROSS SECTIONS + ENERGY DEPOSITION
C PSHELLS.TAB = PHOTON PHOTOELECTRIC SHELL CROSS SECTIONS
C FLUOR.TAB = FLUORESCENCE YIELD DATA
C FORMFACT.TAB = FORM FACTOR AND SCATTERING FUNCTION DATA
C

C CHARGED PARTICLES
C -----

C CHARGED.TAB = CHARGED PARTICLE DATA
C

C AND WRITES THE FOLLOWING BINARY, RANDOM ACCESS FILES,
C

C ELECTRON.BIN = ALL ELECTRON DATA
C PHOTON.BIN = ALL PHOTON DATA
C CHARGED.BIN = ALL CHARGED PARTICLE DATA
C

C IF ANY OF THE CHARACTER FILES REQUIRED TO MAKE A BINARY FILE
C ARE NOT PRESENT, CREATION OF THE BINARY FILE IS SKIPPED, E.G.,
C IF YOU ONLY WANT TO MAKE AN ELECTRON BINARY FILE REMOVED THE
C PHOTON AND CHARGED PARTICLE CHARACTER FILES.
C

C CONTENTS OF THE BINARY, RANDOM ACCESS FILES
C =====

- C 1) THESE FILES CONTAIN DATA FOR ALL ELEMENTS Z = 1 TO 100.
C 2) THESE FILES CONTAIN FIXED LENGTH RECORDS, WHERE EACH RECORD
C IS 2560 WORDS LONG.
C 3) THE FIRST RECORD CONTAINS THE NUMBER OF POINTS FOR EACH Z,
C THE ATOMIC WEIGHT AND STP DENSITY - IN THE FIRST 300 WORDS
C IN (100,3) FORMAT
C 4) RECORDS 2 THROUGH 101 CONTAIN THE MAJOR CROSS SECTIONS FOR
C Z = 1 THROUGH 100
C 5) RECORDS 102 THROUGH 201 CONTAIN THE SHELL CROSS SECTIONS FOR
C Z = 1 THROUGH 100
C 6) IN THE PHOTON LIBRARY RECORD 202 CONTAINS THE FLUORESCENCE
C YIELD DATA
C

- C 7) IN THE PHOTON LIBRARY RECORD 203 CONTAINS THE FORM FACTOR
C AND SCATTERING FUNCTION DATA.
C 8) IN THE CHARGED PARTICLE FILE RECORDS 2 THROUGH 101 CONTAIN
C DE/DX DATA.
C

C LIMITATIONS
C

- C =====
C 1) A MAXIMUM OF 256 ENERGY POINTS PER ELEMENT.
C 2) ALL DATA IS STORED IN FLOATING POINT FORM (E.G., EVEN
C COUNTS, SUCH AS THE NUMBER OF ENERGIES, ARE IN FLOATING
C POINT). THIS CONVENTION AVOIDS ALL POSSIBLE STORAGE PROBLEMS
C RELATED TO SINGLE VS. DOUBLE PRECISION USE OF THIS DATA - NOT
C PRESENTLY IMPLEMENTED IN THIS ROUTINE, BUT EASILY ADDED IF IT
C IS REQUIRED.
C

C READING AND WRITING THE BINARY, RANDOM ACCESS FILES
C

C =====
C TO OPEN A FILE,
C

C NBYTE = 2560*KBYTE (KBYTE = BYTES PER WORD ON YOUR COMPUTER
C E.G., 4 FOR 32 BIT WORDS, 8 FOR 64,
C SEE SPECIAL HANDLING FOR MAC, BELOW)
C

C WRITING A FILE
C

C =====
C FIRST OPEN IT (ONLY ONCE),
C

C OPEN(20,FILE='PHOTON.BIN',STATUS='UNKNOWN',
C 1 ACCESS='DIRECT',FORM='UNFORMATTED',RECL=NBYTE)
C

C YOU CAN THEN WRITE IT AS FOLLOWS,
C

C DIMENSION PAGE(2560)
C WRITE(20,REC=IREC) PAGE
C

C READING A FILE
C

C =====
C FIRST OPEN IT (ONLY ONCE),
C

C OPEN(20,FILE='PHOTON.BIN',STATUS='OLD',
C 1 ACCESS='DIRECT',FORM='UNFORMATTED',RECL=NBYTE)
C

C YOU CAN THEN READ IT AS FOLLOWS,
C

C DIMENSION PAGE(2560)
C READ(20,REC=IREC) PAGE
C

C YOU NEED NOT READ AN ENTIRE RECORD - YOU CAN READ ANY NUMBER OF
C WORDS FROM THE BEGINNING OF A RECORD, AS LONG AS THE NUMBER DOES
C NOT EXCEED 2560 (THE RECORD LENGTH DEFINED IN THE OPEN STATEMENT).
C

C COMPUTER DEPENDENCE
C

C =====
C VIRTUALLY ANY COMPUTER CAN USE THE ABOVE DESCRIBED FORTRAN
C COMPATIBLE BINARY, RANDOM ACCESS METHOD.
C

C
C FOR USE ON ANY GIVEN COMPUTER SEE SUBROUTINE BINNEW (OPEN NEW
C BINARY RANDOM ACCESS FILE) AND MERELY ACTIVATE THE CORRECT
C BYTE LENGTH OF EACH RECORD. SEE SPECIAL HANDLING FOR
C MACINTOSH, DESCRIBED BELOW.
C

C AS DISTRIBUTED THIS PROGRAM IS SETUP TO BE USED ON 32 BIT PER
C WORD COMPUTERS (E.G., SUN, SGI, IBM, ETC.) AND YOU NEED NOT
C DO ANYTHING TO USE IT. SEE SPECIAL HANDLING FOR MACINTOSH,
C DESCRIBED BELOW.
C

C ON 64 BIT PER WORD COMPUTERS (E.G., CRAY) YOU NEED MERELY
C COMMENTS OUT THE CURRENT DEFINITION OF NBYTE (IN SUBROUTINE
C BINNEW) AND ACTIVATE THE INDICATED 64 BIT DEFINITION.
C

C ON MACINTOSH COMPUTERS THE FORTRAN COMPILER THAT WE ARE
C CURRENTLY USING IS QUITE OLD AND ONLY ALLOWS BINARY, RANDOM
C ACCESS RECORDS UP TO 1024 BYTES LONG. IF YOU HAVE THE SAME
C LIMITATION YOU HAVE TO DO 2 THINGS TO USE THIS CODE,
C

- C 1) IN SUBROUTINE BINNEW ACTIVATE THE INDICATED RECORD LENGTH
C FOR MAC AND DE-ACTIVATE THE CURRENT DEFINITION.
- C 2) IN SUBROUTINE BINOUT ACTIVATE THE INDICATED CODING FOR
C MAC AND DE-ACTIVATE THE CURRENT CODING. FOR USE ON A
C MAC THIS ROUTINE WILL WRITE 10 CONSECUTIVE 1024 BYTE
C RECORDS = A TOTAL OF 10,240 BYTES, INSTEAD OF ONLY
C ONE RECORD OF 10,240 BYTES. USED THIS WAY IT WILL
C EXACTLY SIMULATE THE REQUIRED BINARY, RANDOM ACCESS
C I/O REQUIRED.
C

C WARNING
C

- C =====
- C BEFORE USING THIS PROGRAM ON ANY COMPUTER BE SURE THAT YOU,
- C 1) CONVERT BINNEW AND BINOUT, AS DESCRIBED ABOVE.
 - C 2) DEFINE THE ENERGY CONVERSION FROM MEV TO THE UNITS YOU WANT
C (DEFINE THE PARAMETER UNITS1 BELOW).
 - C 3) DEFINE THE ENERGY UNITS THAT YOU WANT (PRESENTLY SET UP FOR
C MEV - BUT CAN BE CHANGED TO ANYTHING BY DEFINING THE VARIABLE
C UNITS BELOW).
- C

C FOR ANY GIVEN COMPUTER YOU NEED MAKE THESE CHANGES ONLY ONCE.
C
C =====

C PROGRAM EPICTAB

C =====
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C CREATE TABULATED FOR ELECTRONS, PHOTONS AND CHARGED PARTICLES
C =====

C THIS PROGRAM READS THE FOLLOWING BINARY, RANDOM ACCESS FILES,
C

C ELECTRON.BIN = ALL ELECTRON DATA
C PHOTON.BIN = ALL PHOTON DATA
C CHARGED.BIN = ALL CHARGED PARTICLE DATA
C

C AND WRITES THE FOLLOWING CHARACTER FILES,
C

C ELECTRONS
C -----

C ELECTRON.TAB = ELECTRON MAJOR CROSS SECTIONS + ENERGY DEPOSITION
C ESHELLS.TAB = ELECTRON IONIZATION SHELL CROSS SECTIONS
C

C PHOTONS
C -----

C PHOTON.TAB = PHOTON MAJOR CROSS SECTIONS + ENERGY DEPOSITION
C PSHELLS.TAB = PHOTON PHOTOELECTRIC SHELL CROSS SECTIONS
C FLUOR.TAB = FLUORESCENCE YIELD DATA
C FORMFACT.TAB = FORM FACTOR AND SCATTERING FUNCTION DATA
C

C CHARGED PARTICLES
C -----

C CHARGED.TAB = CHARGED PARTICLE DE/DX
C

C IF ANY OF THE BINARY FILES REQUIRED TO MAKE THE TABULATED FILES
C IS NOT PRESENT CREATION OF THE TABULATED FILES WILL BE SKIPPED,
C E.G., TO MAKE ONLY ELECTRON TABULATED FILES REMOVE PHOTON.BIN
C AND CHARGED.BIN.
C

C CONTENTS OF THE BINARY, RANDOM ACCESS FILES
C =====

- C 1) THESE FILES CONTAIN DATA FOR ALL ELEMENTS Z = 1 TO 100.
C 2) THESE FILES CONTAIN FIXED LENGTH RECORDS, WHERE EACH RECORD
C IS 2560 WORDS LONG.
C 3) THE FIRST RECORD CONTAINS THE NUMBER OF POINTS FOR EACH Z,
C THE ATOMIC WEIGHT AND STP DENSITY - IN THE FIRST 300 WORDS
C IN (100,3) FORMAT
C 4) RECORDS 2 THROUGH 101 CONTAIN THE MAJOR CROSS SECTIONS FOR
C Z = 1 THROUGH 100
C 5) RECORDS 102 THROUGH 201 CONTAIN THE SHELL CROSS SECTIONS FOR
C Z = 1 THROUGH 100
C 6) IN THE PHOTON LIBRARY RECORD 202 CONTAINS THE FLUORESCENCE
C YIELD DATA

- 7) IN THE PHOTON LIBRARY RECORD 203 CONTAINS THE FORM FACTOR
AND SCATTERING FUNCTION DATA.
- 8) IN THE CHARGED PARTICLE FILE RECORDS 2 THROUGH 101 CONTAIN
DE/DX DATA.

LIMITATIONS

- 1) A MAXIMUM OF 256 ENERGY POINTS PER ELEMENT.
- 2) ALL DATA IS STORED IN FLOATING POINT FORM (E.G., EVEN
COUNTS, SUCH AS THE NUMBER OF ENERGIES, ARE IN FLOATING
POINT). THIS CONVENTION AVOIDS ALL POSSIBLE STORAGE PROBLEMS
RELATED TO SINGLE VS. DOUBLE PRECISION USE OF THIS DATA - NOT
PRESENTLY IMPLEMENTED IN THIS ROUTINE, BUT EASILY ADDED IF IT
IS REQUIRED.

READING AND WRITING THE BINARY, RANDOM ACCESS FILES

TO OPEN A FILE,

NBYTE = 2560*KBYTE (KBYTE = BYTES PER WORD ON YOUR COMPUTER
E.G., 4 FOR 32 BIT WORDS, 8 FOR 64,
SEE SPECIAL HANDLING FOR MAC, BELOW)

WRITING A FILE

FIRST OPEN IT (ONLY ONCE),

OPEN(20,FILE='PHOTON.BIN',STATUS='UNKNOWN',
1 ACCESS='DIRECT',FORM='UNFORMATTED',RECL=NBYTE)

YOU CAN THEN WRITE IT AS FOLLOWS,

DIMENSION PAGE(2560)
WRITE(20,REC=IREC) PAGE

READING A FILE

FIRST OPEN IT (ONLY ONCE),

OPEN(20,FILE='PHOTON.BIN',STATUS='OLD',
1 ACCESS='DIRECT',FORM='UNFORMATTED',RECL=NBYTE)

YOU CAN THEN READ IT AS FOLLOWS,

DIMENSION PAGE(2560)
READ(20,REC=IREC) PAGE

YOU NEED NOT READ AN ENTIRE RECORD - YOU CAN READ ANY NUMBER OF
WORDS FROM THE BEGINNING OF A RECORD, AS LONG AS THE NUMBER DOES
NOT EXCEED 2560 (THE RECORD LENGTH DEFINED IN THE OPEN STATEMENT).

COMPUTER DEPENDENCE

VIRTUALLY ANY COMPUTER CAN USE THE ABOVE DESCRIBED FORTRAN
COMPATIBLE BINARY, RANDOM ACCESS METHOD.

C
C FOR USE ON ANY GIVEN COMPUTER SEE SUBROUTINE BINOLD (OPEN OLD
C BINARY RANDOM ACCESS FILE) AND MERELY ACTIVATE THE CORRECT
C BYTE LENGTH OF EACH RECORD. SEE SPECIAL HANDLING FOR
C MACINTOSH, DESCRIBED BELOW.
C

C AS DISTRIBUTED THIS PROGRAM IS SETUP TO BE USED ON 32 BIT PER
C WORD COMPUTERS (E.G., SUN, SGI, IBM, ETC.) AND YOU NEED NOT
C DO ANYTHING TO USE IT. SEE SPECIAL HANDLING FOR MACINTOSH,
C DESCRIBED BELOW.
C

C ON 64 BIT PER WORD COMPUTERS (E.G., CRAY) YOU NEED MERELY
C COMMENTS OUT THE CURRENT DEFINITION OF NBYTE (IN SUBROUTINE
C BINOLD) AND ACTIVATE THE INDICATED 64 BIT DEFINITION.
C

C ON MACINTOSH COMPUTERS THE FORTRAN COMPILER THAT WE ARE
C CURRENTLY USING IS QUITE OLD AND ONLY ALLOWS BINARY, RANDOM
C ACCESS RECORDS UP TO 1024 BYTES LONG. IF YOU HAVE THE SAME
C LIMITATION YOU HAVE TO DO 2 THINGS TO USE THIS CODE,
C 1) IN SUBROUTINE BINOLD ACTIVATE THE INDICATED RECORD LENGTH
C FOR MAC AND DE-ACTIVATE THE CURRENT DEFINITION.
C 2) IN SUBROUTINE BININ ACTIVATE THE INDICATED CODING FOR
C MAC AND DE-ACTIVATE THE CURRENT CODING. FOR USE ON A
C MAC THIS ROUTINE WILL READ 10 CONSECUTIVE 1024 BYTE
C RECORDS = A TOTAL OF 10,240 BYTES, INSTEAD OF ONLY
C ONE RECORD OF 10,240 BYTES. USED THIS WAY IT WILL
C EXACTLY SIMULATE THE REQUIRED BINARY, RANDOM ACCESS
C I/O REQUIRED.
C

C WARNING

C =====
C BEFORE USING THIS PROGRAM ON ANY COMPUTER BE SURE THAT YOU,
C 1) CONVERT BINOLD AND BININ, AS DESCRIBED ABOVE.
C 2) DEFINE THE ENERGY CONVERSION FROM MEV TO THE UNITS YOU WANT
C (DEFINE THE PARAMETER UNITS1 BELOW).
C 3) DEFINE THE ENERGY UNITS THAT YOU WANT (PRESENTLY SET UP FOR
C MEV - BUT CAN BE CHANGED TO ANYTHING BY DEFINING THE VARIABLE
C UNITS BELOW).
C

C FOR ANY GIVEN COMPUTER YOU NEED MAKE THESE CHANGES ONLY ONCE.
C
C =====

PROGRAM PARROT - GRAPHICALLY REPEAT WHATEVER EPICP PRODUCES

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PURPOSE

THIS PROGRAM WILL ALLOW YOU TO QUICKLY VIEW EPICP RESULTS TO COMPARE TRANSMISSION, REFLECTION AND LATERAL LEAKAGE (BOTH ANALOGUE AND EXPECTATION), AS WELL AS ENERGY DEPOSITION VS. ENERGY AND Z (DEPTH INTO THE DETECTOR), AND COLLISIONS VS. Z.

PLOT EPICP RESULTS

EPICP PRODUCES 2 FILES THAT ARE READ BY THIS PROGRAM
EPICP.LST - EPICP OUTPUT LISTING REPORT
PLOTTAB.CUR - RESULTS IN THE PLOTTAB FORMAT

AT THE END OF EACH BATCH OF HISTORIES EPICP WILL WRITE THE RESULTS IN PLOTTAB.CUR AND CLOSE THE FILE SO THAT IT CAN BE READ. PARROT CAN READ THIS FILE AND DISPLAY RESULTS - EITHER AT THE SAME TIME THAT EPICP IS RUNNING OR AFTER IT HAS FINISHED.

PLOTTAB FORMATTED RESULTS

EPICP OUTPUTS RESULTS IN THE PLOTTAB FORMAT - FOR GENERAL VIEWING AND HARDCOPY YOU CAN USE THE PLOTTAB CODE - THIS PROGRAM READS THE PLOTTAB FORMATTED OUTPUT FROM EPICP TO ALLOW ON SCREEN VIEWING.

WHAT COMPUTER CAN YOU USE

THIS PROGRAM SHOULD RUN ON VIRTUALLY ANY COMPUTER. IT COMES WITH GRAPHIC INTERFACES FOR IBM-PC AND X-WINDOW TERMINALS. FOR USE ON ANY OTHER COMPUTER, SEE THE ENCLOSED SIMPLE CALCOMP-LIKE GRAPHIC INTERFACE (YOU NEED MERELY SUPPLY EQUIVALENT ROUTINES FOR YOUR COMPUTER).

IBM-PC

ON IBM-PC UNDER DOS OR WINDOWS YOU WILL ONLY BE ABLE TO VIEW THE RESULTS AFTER EPICP HAS FINISHED EXECUTION.

X-WINDOW TERMINALS

C ON X-WINDOW TERMINALS, OR ANY OTHER COMPUTER THAT ALLOWS
C EPICP TO BE RUN IN SIMULTANEOUSLY, YOU CAN USE THIS CODE
C TO PERIODICALLY CHECK ON THE PROGRESS OF EPICP. AT THE
C END OF EACH BATCH OF PARTICLES EPICP WILL WRITE RESULTS
C TO PLOTTAB.CUR AND THEN CLOSE THE FILE. TO CHECK ON THE
C PROGRESS OF EPICP AT ANY TIME YOU NEED MERELY RUN THIS
C CODE TO SEE THE CURRENT RESULTS.

C EXECUTION

C =====

C WHEN IT STARTS PARROT WILL READ THE EPICP OUTPUT REPORT -
C EPICP.LST - TO DEFINE INFORMATION TO APPEAR AT THE TOP
C OF EACH PLOT, E.G., DETECTOR DIMENSIONS, SOURCE ENERGY, ETC.

C PERIODICALLY PARROT WILL CALL SYSTEM('COPYCAT.BAT') -
C COPYCAT.BAT IS A COMPUTER DEPENDENT FILE, THAT MUST BE
C EXECUTABLE, AND COPIES PLOTTAB.CUR TO PLOTTAB.PAR - COPY
C THE EPICP OUTPUT FILE (PLOTTAB.CUR) TO A FILE THAT CAN
C BE READ BY PARROT (PLOTTAB.PAR) - THIS IS DONE TO
C MINIMIZE INTERFERENCE BETWEEN PARROT AND EPICP.

C ON MOST COMPUTERS COPYCAT.BAT IS ONLY 1 LINE LONG.

C UNIX: cp PLOTTAB.CUR PLOTTAB.PAR

C IBM: copy PLOTTAB.CUR PLOTTAB.PAR

C THE FIRST LINE OF PLOTTAB.CUR DEFINES THE NUMBER OF
C HISTORIES RUN SO FAR. EVERY TIME THIS NUMBER CHANGES
C (AT THE END OF EACH EPICP BATCH) PARROT WILL PRODUCE
C A PLOT.

C IF PARROT READS THE FILE AND IT STILL HAS THE SAME
C NUMBER OF HISTORIES IT WILL SLEEP FOR 10 SECONDS
C BEFORE TRYING TO READ THE FILE AGAIN - TO MINIMIZE
C INTERFERENCE BETWEEN PARROT AND EPICP, I.E., PER
C EVERY 10 SECONDS PARROT WILL USE VERY LITTLE PROCESSOR
C TIME.

C TERMINATING

C =====

C ON AN IBM-PC THE PROGRAM WILL PAUSE AT THE END OF THE
C PLOT AND TERMINATE WHEN YOU PRESS ANY KEYBOARD KEY -
C AS DESCRIBED ABOVE, YOU CANNOT RUN PARROT AND EPICP
C AT THE SAME TIME - SO WHEN PARROT IS RUNNING EPICP
C CANNOT BE UPDATING THE OUTPUT FILE - THEREFORE IT
C MAKES NO SENSE TO DO ANYTHING BUT STOP AFTER THE
C FIRST PLOT.

C ON X-WINDOW TERMINALS THE PROGRAM WILL CONTINUE RUNNING
C UNTIL YOU SOMEHOW KILL IT - USE YOUR MOUSE AND
C WINDOW OPTIONS TO KILL THE WINDOW. IF YOU LET IT
C RUN YOU CAN MONITOR EPICP IN REAL TIME.

C=====