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A Monte Carlo Program System for Beam-Materials Interaction Studies

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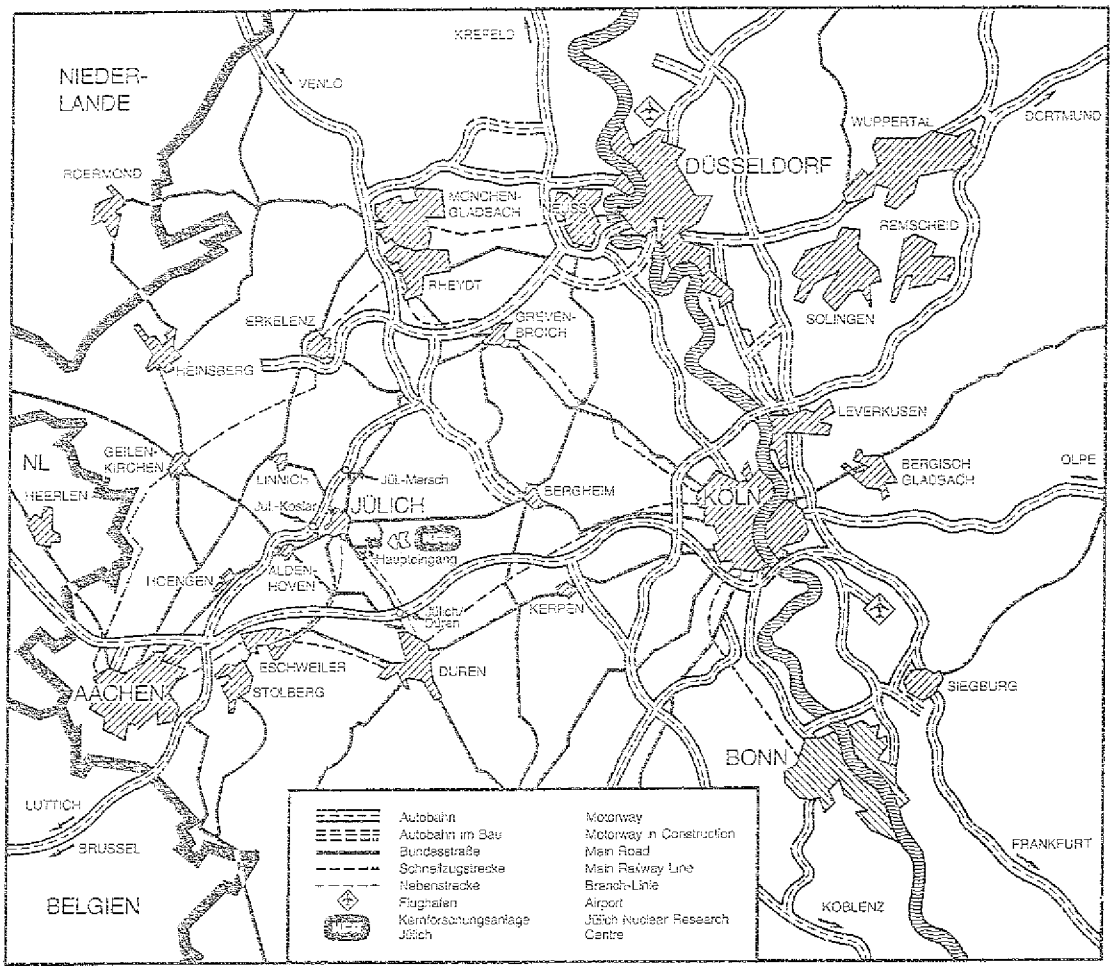

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Hanno Brückmann †

With deep sorrow we remember the sad demise of one of our co-authors, Professor Dr. Hanno Brückmann, on 11th November 1987 during the work on this report.

Hanno Brückmann was the dynamic inspiration behind the creation of the HERMES system. We will miss him personally and his valuable professional guidance.

The Authors

CONTENTS

1. INTRODUCTION

1.1 Overview of the HERMES System

HERMES (High Energy Radiation Monte Carlo Elaborate System) is a system of Monte-Carlo computer codes that are necessary to treat the different physics to be considered in computer simulation of radiation transport and interaction problems. In addition HERMES offers powerful capabilities of Monte-Carlo analysis and of merging the outcomes of partial programs into final results. An interfacing system - the "HERMES submission file" - provides easy interchange of input/output data between programs by standardized data structures and allows unproblematic extension of the HERMES system by introducing new programs.

The HERMES collection of physics programs permits the simulation of secondary particle histories induced by primary particles of any energy up to the regime of high-energy physics and down to thermal energies, e.g. for neutrons. The particles, that are considered by the programs of the HERMES system are p, n, π^+, π^-, π^0, $\mu^\pm$, e^+, e^-, γ, and light ions to A=10. The development of particle cascades can be simulated within very complex geometries and material configurations with only minor restrictions.

The geometry description is identical for all Monte-Carlo programs incorporated in HERMES and made in input terms of the approved "Combinatorial Geometry (CG)" in a KFA extended version.

The well established programs of the HERMES system in general have been taken as original codes as far as possible. However, to satisfy the needs of some applications, e.g., the high energy calorimeter simulation, some extensions and changes became necessary. Also the interfacing technique by HERMES submission files needs some additional programming. Therefore, the name of the original codes were extended by a KFA suffix. All changes made to the original codes are documented within this report. For simplicity reasons, however, we refer to the original names throughout this document, e.g. HETC rather than HETC-KFA 2. Several of the system codes, especially for analysis purposes, are provided by the authors.

To achieve portability of the HERMES system, the original coding of the programs was converted to the FORTRAN77 standard. This, however, was verified only on two computer systems, the IBM 3081 and the CRAY-XMP22.

1.2 Physics with HERMES

The physical phenomenon to be simulated with HERMES is the history of the secondary particles induced in matter by an incident high energy particle. This typical propagation process of high energy radiation in matter in general is referred to as a particle cascade.

To demonstrate the range of physics covered by HERMES we give a brief overview of the basic phenomenology associated with the interaction of high energy particles with matter and with the transport of such high energy radiation, as it may be produced in particle accelerators or exists as cosmic radiation in space.

The energy losses of high energy particles (> 1 GeV) travelling through matter are mainly determined by production of secondary particles. Thus, the main feature of the cascade is an initial increase of the particle intensity with depth and time. If the energy of the produced secondary particles is high enough, they in turn produce additional particles. There exists however a physical limit for the development of the cascade, because the initial energy of the primary particle is dissipated all over the produced particles. Therefore, the multiplicities tend to decrease again during the cascade process and fade away because the average energy of the cascade particles decreases and a greater fraction of the individual particle energy is now dissipated by ionization losses. At the end of the cascade process subsequent production of many low energy particles, mainly neutrons, takes place, known as the evaporation process.

The physics of a high energy cascade in matter is to some extend determined by the type of the incident primary particle. If we are bombarding matter with high-energy hadrons (protons, neutrons, pions etc.) a so called hadronic cascade is produced, which is often accompanied by an electromagnetic cascade depending on the energy of the primary particle. If the primary particle is an electron, a positron or a photon, a purely electromagnetic cascade is produced.

The interaction process of particles with the nuclei of matter may be considered as a particle cascade inside the nucleus, thus the term "intranuclear cascade" is used to describe the process creating a particle cascade inside the nucleus. The nuclear collision products can proceed to produce further collisions with other nuclei to form the "internuclear" cascade.

To analyze the particle shower and its distribution in energy and space, we have to determine the multiplicities, energy and angular distributions of the particles generated by suitable simulation programs. The development of electromagnetic showers with their principal production processes - bremsstrahlung for electrons and positrons, pair production for photons, becoming energy dependent above 1 GeV - are very well described by quantum electro dynamics (QED-theory) over a wide energy range. In HERMES this is taken into account by the EGS4 code.

In contrast to the electromagnetic shower, physics is considerably more complex for hadronic showers, therefore, some restrictions exist on determination of the shower parameters in detail as a function of energy in consistent theory, e.g. quantum chromo dynamics (QCD theory). To study the relevant physics associated with the interaction of high-energy hadrons with matter, a very potent theoretical model, the "Intra-Nuclear-Cascade-Evaporation" model (INCE), treating nonelastic and elastic interaction of high-energy hadrons with nuclei, is available in the HETC (High Energy Transport Code) Monte Carlo program.

Full use of the above described cascade physics, which can be investigated by HERMES simulation, is made in high energy physics, especially considering high-energy calorimeter techniques. All parts of the cascade contribute significantly to the responses of these detectors frequently used in high energy physics. To get an impression of the HERMES capabilities, one may consider the sample problem (a) in Appendix E.

The structure of the HERMES system is also highly in favour of simpler or partial problems as compared to the calorimeter physics, e.g., problems which can be solved with only one of the physics programs. In addition the system allows further treatment of all those problems for which the single physics programs have been originally designed. However, with partly considerable extended and enhenced analysis features. Two examples for this type of application - namely cross-section computation with HETC and thick-target particle flux calculations using HETC and MORSE-CG are also given in Appendix E.

2. GENERAL DESIGN CHARACTERISTICS OF THE HERMES MONTE-CARLO SYSTEM

To simulate the histories, i.e. production, interaction with matter and transport, of high energetic particles the latest state-of-the-art radiation transport codes and event generators are used in HERMES. All the codes employ Monte Carlo techniques with 3 dimensional geometry description, therefore, it is possible to treat in detail the reaction mechanism and the transport of the high energy particles as well as of the low-energy particles created. An overview of the main physics models is given in the following section with some detailed description of the codes HETC, MORSE, and EGS. All codes make use of a common data interface named "HERMES Submission File" (see Section 2.5).

2.1 Scheme of HERMES Performance

The problems which can be solved with the aid of the HERMES system cover a wide range of incident particle energies and a set of particle types. Therefore, the computational work had to be shared between several Monte-Carlo codes, each solving a specific part of the general problem. Currently three Monte-Carlo codes are implemented, namely HETC, MORSE-CG and EGS4.

We decided to use offline coupling of the codes, due to practical and scientific reasons:

- With off-line coupling it is much easier to implement additional Monte Carlo codes or to replace codes. Thus, HERMES can be extended in an easy way to represent the state of the art, without need for changing of programs.
- Some problems, that require a large amount of computer power (storage and CPU time), can be partitioned in steps.
- The results of each step can be examined to find out errors as well as the statistical and physical quality of intermediate results. Subsequent steps can be tailored according to the statistical properties of prior steps.
- Intermediate results may also improve the understanding of the problem of the physical models used and the dependency between these models.

The coupling procedures affect the flow of particles through the system and the collection of results. We designed a general data structure used by the programs in HERMES,

- to accept particle sources generated in other programs,
- to submit particles for further treatment in other programs,
- to submit detector results at the end of each independent batch and at the end of a run.

A detailed description of the communication file structure is given in Section 2.5. Particle and detector data flow is illustrated in Fig. 2.1.

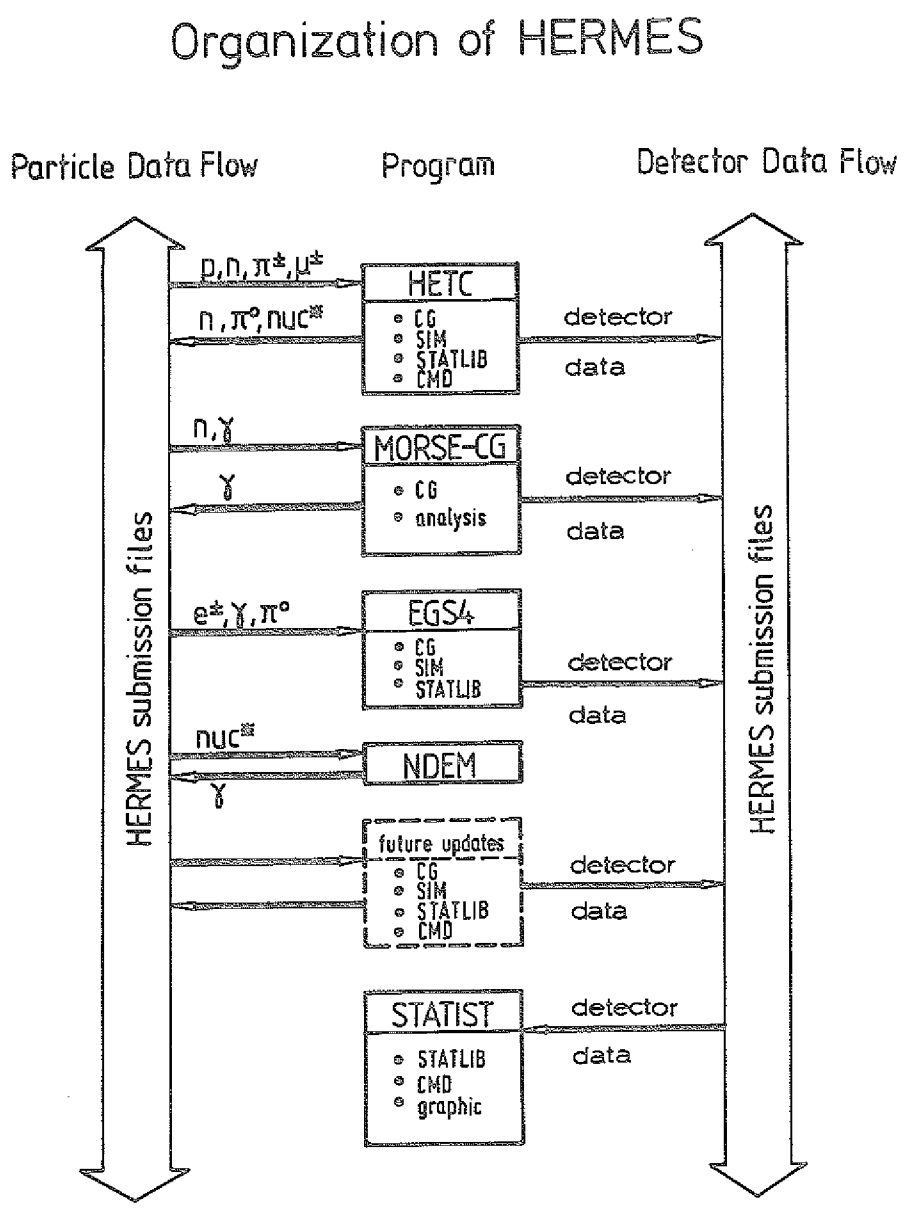

Fig. 2.1: Organization of the HERMES (High Energy Radiation Monte Carlo Elaborate System) program system for theoretical studies on beam materials interaction

Whenever a particle cannot be handled by a program, it may be submitted to a HERMES submission file. Also the residual nuclei from HETC are submitted to that file. Particles can be picked up directly by another Monte-Carlo program. The residual nuclei, however, are processed by the auxiliary code NDEM (see Section 2.2.4) which computes the de-excitation γ's from these nuclei and submits the γ's to another submission file.

In some cases (if no strict correlation is needed) it may be sufficient to pick up only a representativ subgroup of all the particles found on a submission file. (In a later release of HERMES) we will provide a code to select particles from submission files, merge submission files and examine their contents. The detector data submitted by the Monte-Carlo codes working on the same problem can be handled by the auxiliary code STATIST (see Section 2.3.3).

We provide some subroutine packages with HERMES to aid the Monte Carlo codes in solving problems, which are the same for each of the Monte Carlo codes.

The most important subroutine package is the Combinatorial Geometry CG-L2 (see Section 2.3.1), which we have implemented in HETC, MORSE-CG and EGS4. Therefore, the geometry description of a problem can be made once for all codes. The Combinatorial Geometry has been increased in its capabilities. A test program has been developed so that extensive testing of the geometry setup can be made prior to the Monte Carlo runs. Additionally we provide a set of routines named STATLIB which are used in the analysis part of all programs and an input interpreter CMD (see Section 2.3.4), which provides a standard tool to express input for the Monte-Carlo codes. In the current release we use CMD to setup the geometry input, test the geometry, setup the input for the HETC-analysis code SIM and for the final statistics code STATIST, which is used to combine the results of different Monte-Carlo codes working on the same problem.

In the analysis of coupled Monte-Carlo runs we use trigger events to identify the results coming from the same incident sample. This sample may consist of one or more source events. In applications, where mean values are of interest it is suitable to use batches of more than one source event, whereas in

applications, where the fluctuations of physical properties are also or of main interest, it is necessary to use one source event per batch. The statistical analysis is done on the basis of samples (i.e. batches).

It should be noticed, that the measurement of fluctuations prohibits the use of most of the biasing methods, which are commonly used in Monte-Carlo programs to reduce the computation time and increase the stability of mean value estimates. Therefore, the Monte Carlo codes used in HERMES have been modified to allow a maximum of analog (i.e. also unbiased) performance.

2.2 The Physics Modules

2.2.1 The Hadron Cascade Module HETC-KFA-2

HETC (High Energy Transport Code) is implemented in a version based on the original coding given in Ref. /1/. An overview about changes, updates and physics involved is given below (for details see Appendix A). The user, who is not familiar with the original HETC should also read Refs. /1,2,3/.

Name: HETC-KFA-2	(High-Energy-Radiation-Transport-Code, KFA Version 2) For simplicity reasons we refer to this version also as HETC in this document.
Implementation:	based on Ref. /1/ (Report ORNL-4744)
Extension:	FORTRAN77 compatible on IBM3081 and CRAY-XMP22
Particleas transported:	n, p, $\pi^{\pm}$, $\mu^{\pm}$
Extension:	d, t, He^3, α, heavy ions A < 20
Mechanism:	- collision model - Intra-Nuclear-Cascade-Evaporation (INCE) (for p,n,$\pi^{\pm}$;π^- capture at rest; non-elastic nuclear collisions; π^0,d,t,He^3,α-production; residual nuclei and residual excitation energy) - charged particle ionization energy loss (dE/dx) - primary particle small angle multiple

Coulomb scattering
- decay (weighted fashion) for $\pi^{\pm}$ and $\mu^{\pm}$ in flight and at rest
- scaling model - automatic parameter update for nonelastic collisions above 3.5 GeV
(limited energy range for scaling
p/n - $E_{max} \leq 25$ GeV
$\pi^{\pm}$ - $E_{max} \leq 15$ GeV)

Extensions:
- elastic collision module for p/n elastic nucleus collisions up to 20 GeV
- high energy fission included in evaporation model
- automatic parameter update for B_0 in level density formula
- nonisotropic angular distribution of evaporated particle
- analog decay for $\pi^{\pm}$

Geometry: standard CG geometry interface
Extension: CG-KFA geometry module (see Section 2.3.1)

Additional Extensions: submission of particles and nuclei for further processing (see Section 2.5) structure of HERMES submission files)

2.2.2 Neutron-γ Transport Code MORSE-CG-KFA

MORSE-CG (Multigroup Oak Ridge Stochastic Experiment with Combinatorial Geometry) was implemented in a KFA version based on the original code (see Appendix A).

The user, who is not familiar with MORSE should read Refs. /4,5,6/. MORSE does a stochastic simulation on neutral particle transport.

Name: MORSE-CG-KFA (Multigroup Oak Ridge Stochastic Experiment)
In this document we refer to this version also as MORSE-CG.

Implementation: based on Ref. /4/ (Report ORNL-4972)
Extension: FORTRAN77 compatible on IBM3081 and CRAY-XMP 22

Source:	fixed neutron- or γ-source or fission feedback
Extension:	submitted neutron- or γ-source distribution in phase space (see Section 2.5 about the structure of HERMES submission files)
Mechanism:	- Elastic neutron nucleus collisions including hydrogen collisions; non-elastic neutron nucleus collisions; inelastic neutron nucleus collisions; capture and fission; γ production and transport (capture, fission, inelastic, and nonelastic) - analysis of fluxes and reaction rates in phase space - variance reduction methods: russian roulette, particle splitting, path length stretching, simulated absorption, and productive nuclear collision (n,2n, etc.), importance sampling, leakage rejection and albedo scattering
Extensions:	- modifications in some parts from weighted to analog Monte Carlo (particle absorption using russian roulette procedure, fission, γ-generation, inelastic scattering using splitting feature) to allow analog treatment of particle yields for calorimeter design - simultaneous implementation of volume-, surface-, and point-detectors - escape, leakage current and fluxes at surfaces - features in calculating light response functions for scintillators
Geometry:	standard CG geometry interface
Extension:	CG-KFA geometry module (see Section 2.3.1)
Additional extensions:	- submission of fluxes and reaction rates for further processing (see Section 2.5) (e.g. light response or visible energy in scintillators) - binary storage of results on RSYST /7/ data base - revision of input to allow fast vector assignment using REA formats - γ rays are stored via HERMES submission files for EGS transport

Cross section standard:	- Multigroup cross section libraries for neutron and γ's or coupled neutron-γ libraries in ANISN or DTF4 format
Extension	- multigroup cross-section libraries in RSYST format

2.2.3 The Electron-Photon Transport Module EGS4-KFA

The EGS4 (Electron Gamma Shower) was implemented in a KFA version based on the original code (see Appendix A). The EGS computer codes provide Monte-Carlo simulation of the coupled transport of electrons and photons with energies from a few keV upto several TeV. The user, who is not familiar with the EGS4 code should read Refs. /8,9/.

Name: EGS4	(Electron Gamma Shower)
Implementation:	based on Ref. /9/ (Report SLAC-265)
Extension:	Standard user code (see Section 3.4) FORTRAN77 compatible on IBM3081 and and CRAY-XMP 22
Source:	e^+, e^-, γ's
Extension:	submitted electro-magnetic particle sources (e^+,e^-, γ's in phase space) (see Section 2.5 about structure of HERMES submission files)
Mechanism:	- small and wide angle scattering - bremsstrahlung, pair production, Compton scattering, Moeller effect, Bhabha effect, photo-electric effect - annihilation - continuous e^+, e^- energy loss - step length correction (Rogers formalism)
Additional Extensions:	- submission of electron-, positron- and gamma fluxes and currents, energy deposition and reaction rates (see Section 2.5 about structure of HERMES submission files)

2.2.4 The Nucleus de-Excitation Module NDEM

The NDEM code is used to generate a γ-ray source from the de-excitation of residual nuclei, the assumption is made that all particle decay modes have been exhausted; thus γ emission does

not compete with particle emission. The NDEM formalism is taken from the Los Alamos PHT code /10/. The input to NDEM is a HERMES submission file of the residual nuclei information recorded by HETC. The γ ray source also on a HERMES submission file can be input into MORSE-CG or EGS4.

It is assumed that there exists a range of known energy levels given by the Gilbert Cameron formulae /11/. The library of level data is based on the CDRL82 library with over 50,000 listed levels. If the excitation energy of a residual nucleus lies between two levels, it is assigned randomly to the one or the other of the levels with a probabilities that depend linearly on the distances from these levels. If the excitation is above the maximum known level, the level is assumed to be in the continuum.

The probability of a transition between levels is assumed to be proportional to the Weisskopf single-particle estimates /12/, unless specified by the library. For levels in the continuum and for known levels with unknown spin and parity, a spin state is randomly assigned using the Gilbert Cameron spin densities to generate a sampling distribution; parities, at the present time, are assigned with equal probabilities. For a transition within the continuum to a state of given spin, the transition probability is also proportional to the level density for the final spin state.

The gamma cascade procedes with the above assumptions. For an excitation energy lying in the continuum, transition to another level in continuum competes with transitions to known levels. If the initial excitation energy lies within the known levels, or a level has been reached by transition from the continuum, the probability of a transition to lower levels is obtained from library data, if available, or from the model otherwise. When specified in the library data, a 0+ to 0+ transition is permitted to occur without γ emission (representing internal conversion).

The user has the option of selecting the level of the physics model to be used in the NDEM calculation. It is possible to ignore the experimental branching ratios and perform a pure model calculation. The user may also choose to treat all transitions as E1 transitions, corresponding to the model previously employed by Troubetzkoy /13/.

At the present time, the emission of de-excitation γ's is assumed to be isotropic in the lab frame, ignoring nuclear recoil.

2.3 Geometry and General Analysis Programs, Statistics and Auxiliary Codes

2.3.1 Three Dimensional Geometry Model based on Combinatorial Geometry

(1) Conception of the Combinatorial Geometry

The Combinatorial Geometry cuts space into pieces called input-zones. Input-zones consist of one or more code-zones. Code-zones are composed of one or more bodies. A problem description as input to the Combinatorial Geometry starts with the definition of the bodies:

Definition of Bodies

Bodies are defined by the body type (sphere, box, etc.), an identification number and parameters which define location and dimensions of the body.

For example a sphere with midpoint coordinates (1,2,2) and radius 6 can be described as follows:

```
SPH    8        1.0        2.0        2.0        6.0
```

Where "SPH" identifies the body as of type sphere; the reference number is 8.

Each body divides space into two pieces: The area inside the body and the area outside the body.

The area inside the body can be referenced by a poisitive body identification number, whereas the area outside the body is referenced by a negative body identification number.

Definition of Code-Zones

Code-zones are coded as a sequence of body inside/outside references, e.g.,

```
+3     +4     -1
```

is a code-zone consisting of all points lying within body 3, within body 4, but outside body 1.

Note, that code-zones are intersections of body inner and outer areas!

In the example above points lying within body 3, but not within body 4 do not belong to the specified code-zone.

Note, that all space must be completely defined by code-zones and that code-zones should not overlap!

Definition of Input-Zones

Input-zones are coded as a sequence of code-zones combined by the OR operator. For each input-zone a medium and region number is specified, e.g.,

```
1  100     +3     +4     -10R   +3     -4
```

defines an input-zone with medium number 1 and region number 100. It consist of all points inside body 3 and inside body 4 but outside body 1 and all points inside body 3 and outside body 4.

Note, that input zones must not overlap!

When all zones are defined, every point in space will belong uniquely to a medium and a region number.

Some medium numbers are reserved for special purposes:

- Medium -1 denotes the external void.
  whenever medium -1 is entered , the transport of the particle is terminated.
  Medium -1 should be used as the outer bound of a geometry. It is the only medium which may consist of infinite areas.

- Medium 1000 denotes internal void.
  Internal voids can be used in MORSE to specify a vacuum area. Both the meaning of the calling parameters and the action of the Combinatorial Geometry program is different compared to normal media, when medium 1000 is encountered. For HETC and EGS4 one should use medium 6666, which is treated as any other medium in the geometry routines.
- Medium 999 is used to terminate zone-input.
  No more information is required on that card.

For detailed information on input formats, body definitions, and extensions of this basic concept, refer to Section 3.9.

(2) KFA-Extensions of the Combinatorial Geometry

Two types of extensions have been incorporated into CG:

- additional bodies have been implemented, which help to avoid redundant surfaces, and numerical problems caused by multiply defined surfaces.
- a method is provided to divide zones into sub-zones.

(a) Additional Body Types

In basic CG only finite bodies like SPH, RPP or RCC are available. The use of these bodies can introduce unwanted or redundant surfaces and (even worse) multiply defined surfaces. Consider the following example:

To define a cylinder which is partitioned along the axis, one could use a series of RCC bodies.

```
RCC    1        0.        0.        0.        0.        0.        1.
               10.
RCC    2        0.        0.        1.        0.        0.        1.
               10.
RCC    3        0.        0.        2.        0.        0.        1.
               10.
END
  1     1      +1
  1     2      +2
  1     3      +3
  999
```

Here we have multiply defined surfaces at z=1, z=2 and r=10. CG may have to calculate the same intersection point up to 3 times, possibly with slightly different results due to numerical uncertainties. This may cause numerical problems in the program, at least computational work is increased.

```
RCC    1        0.        0.        0.        0.        0.        3.
               10.
RCC    2        0.        0.        1.        0.        0.       15.
               15.
RCC    3        0.        0.        2.        0.        0.       15.
               15.
END
  1     1      +1      -2
  1     2      +1      +2      -3
  1     3      +1      +3
999
```

Above the same geometry is decribed without multiply defined surfaces, but this time 4 redundant surfaces are defined.

Such problems can be solved by defining semi-infinite bodies. We have implemented PLANES, where the half space lying in the normal direction of the plane is considered to be the inside of the body. The available planes are listed in Table 2.1. We also made available CYLINDERS of infinite length (Table 2.2).

Table 2.1
Infinite Planes as CG Bodies

body	type	parameter	points inside
PX	K	X	x > X
PY	K	Y	y > Y
PZ	K	Z	z > Z
P	K	UX UY UZ D	all points lying beyond a plane with normal direction (UX,UY,UZ) and distance D from origin.
PS	K	SX SY SZ UX UY UZ D	all points lyling beyond a plane with normal direction (UX,UY,UZ) and distance D from (SX,SY,SZ)

The cylinders are specified by a point (SX,SY,SZ) lying on the axis, a direction vector (UX,UY,UZ) for the axis and the radius R.

Table 2.2
Infinite Cylinders as CG Bodies

body	type	parameter	axis direction	radius
CX	K	SX SY SZ R	(1,0.0)	R
CY	K	SX SY SZ R	(0,1,0)	R
CZ	K	SX SY SZ R	(0,0,1)	R
C	K	SX SY SZ UX UY UZ R	(UX,UY,UZ)	R

Using these bodies we can describe the above geometry example as:

```
CZ      1         0.          0.          0.         10.
PZ      2         0.
PZ      3         1.
PZ      4         2.
PZ      5         3.
END
  1     1      +1       +2       -3
  1     2      +1       +3       -4
  1     3      +1       +4       -5
999
```

(b) Subdivision of Zones

For many applications it is necessary to define mesh-like geometry structures. In basic Combinatorial Geometry such structures require large input (because each mesh element has to be defined separately), and much computer time is consumed because the CG algorithm cannot take advantage of the regular structure of a mesh. Normally this problem is solved by writing special problem dependent geometry codes. But this is also not convenient because of the large amount of manpower absorbed by such a work; furthermore it is not trivial to construct a geometry code, when the mesh structures are embedded in a non-regular environment.

Thus, a method has been developed to enable CG-L2 to handle hierarchically organized geometry structures. Additionally an input preprocessor (CMD) has been designed to minimize the amount of input data needed.

In CG-L2 the user may design the geometry in up to three levels of refinement. First the global zone structure is defined as usual. Each zone which shall be subdivided in a subsequent step is marked by the GO operator and the sequence number of the code zone card sets where the subzones will be defined. Additionally the region number is chosen as a negative integer number between -1 and -999. The absolute value of this number will be used as the first three digits of all subzone-region numbers associated with this zone. Also the medium number can be specified as an integer value less than -1 indicating the medium will be assigned in the definition of the subzones. The global zone structure is terminated by a card with IMED=777 (or SUBGEO; in CMD language). Then the second zone card-set starts, i.e., the card-set which is called with GO 3. Up to 10

card-sets may be specified. The last one must be terminated with 999 (or ENDGEO; in CMD language) as usual. The nesting level of GO operations is limited to three as mentioned above. Thus, the resulting region numbers have 9 digits (3 from each nesting level). The assignment of the medium number may occur in any of the 3 levels: A medium number > -2 in level one will be used for all subzones of level 2 and 3. A medium number > -2 in level two will overwrite the media assigned in level 3. Similarly the region number assignment is overwritten by the first positive region number found in a refinement path.

These conventions allow the use of subzones with the same medium but different region numbers or the same region but different medium numbers.

As an example we may consider a geometrical setup of a radiation shield. Fluxes shall be mapped with respect to the z-coordinate and the radius around the z-axis. First the shield is described as constructed. All media are assigned positive. The region numbers are set negative. A second zone card-set is used to define the z-structure of the flux mesh and a third to define the r-structure. All regions of level one, which are to be mapped have the GO 2 operator in the definition card. All z-zones defined in card-set 2 refer to the r-structure (GO 3).
Then the regions found by the geometry will be of the form
$[ireg_1] * 1000000 + [IZreg] * 1000 + [IRreg]$

2.3.2 The General-Purpose Analysis Module SIM

We have implemented an online-analysis subroutine package into HETC, which is used to provide scoring of the physical results of the HETC run. This package, named SIM, includes routines to read-in user analysis requests (coded as CMD-commands), to compute the contributions of an event to the detector signals, to provide estimates of the statistical errors of detector signals and to interface HETC to the final processing code STATIST. Table 2.3 presents the currently available detector types.

Table 2.3
Available SIM Detectors

Type	Symbol	Description
1	Y_c(E,A,IR1)	Yield of secondary particles from the intranuclear cascade (INC)
2	Y_e(E,A,IR1)	Yield of secondary particles from evaporation and fission model
3	Y (E,A,IR1)	Yield of secondary particles
4	E (ctyp,IR1)	Energy deposited by various deposition schemes
5	L_s(ctyp,IR1)	Scintillation light generated by various schemes
6	J^+(E,A,IR1-IR2)	Forward particle current through given surfaces
7	ϕ^+(E,A,IR1-IR2)	Forward particle flux through given surfaces
8	ϕ (E,A,IR1)	Particle tracklength flux in given regions
9	E^+(ptyp,IR1-IR2)	Particle energy passing given surfaces.

Functional Description of the SIM Analysis

SIM is called by HETC after each collision and after each particle flight. It scans all detectors defined to decide whether the event will contribute to the detector signal.

- First the particle type is checked against the required type in the DEFDET command.
- Then the region or surface index is found.
- Energy binning is performed, if requested.
  - when secondary particle yield, surface flux, current or neutron tracklength flux is measured, the actual energy of the particle is used to find the energy bin index.
  - when charged particle tracklength flux is measured, the flight path of the particle is subdivided into pieces which correspond to the path length travelled in the appropriate groups using the slowing down algorithm of HETC.

- Angular binning is performed, if required.

  - If a detector reference direction is given in the DEFDET command, the angle is taken between the flight direction of the particle and a detector reference direction.

  - If a detector reference direction is not given and yields are measured (detector type 1-3), then the angle is taken between the flight direction of the particle and the flight direction of the incident particle.

  - If a detector reference direction is not given and surface flux or current is measured, then the angle is taken between the flight direction of the particle and the normal direction of the boundary in the intersection point.

At the end of each batch SIM keeps track of the mean detector signals and the second moments of these signals. Optionally the batch results are stored on a HERMES submission file (IOSIM) for further processing in STATIST.

At the end of run SIM automatically computes the mean values of the detector signals and the statistical errors of these mean values.

No normalization is performed automatically except to the number of source particles. Thus, normalization has to be performed per request of CMD commands at the end of run or off-line using the binary files which can be produced to store the SIM results.

A definition of the contributions (signals) derived by the detectors follows:

(1) Particle Yield Detectors (Types 1-3)

measure the average number of secondary particles of type "prt" generated in energy group IE, angle group IA and region IR1(I) per source particle.

(2) Energy Deposition Detectors (Type 4)

measure the energy deposition [MeV] in 19 channels representing the various schemes of energy deposition, integrated over the region volumes of regions IR1(i). The channels are explained in what follows:

ctype	Description
1	ionisation energy loss of protons
2	ionisation energy loss of π^+
3	ionisation energy loss of π^-
Note!	p, π^+,π^- reaching their transport cutoff energy are assumed to deposit the remaining kinetic energy in place. Captured π^- mesons, however, deposit their energy through the collision products and nucleus excitation.
4	ionisation energy loss of μ^+
5	ionisation energy loss of μ^-
Note!	stopped μ's are assumed to decay. We take $(E + m_0c^2)/(m_0c^2)$ * 33.328 MeV to be the energy of the electron (positron) and deposit this amount in place. For μ^- we substract .511 MeV representing the mass of a captured e^-.
6	Energy deposited by evaporation deuterons
7	Energy deposited by evaporation tritons
8	Energy deposited by evaporation He^3 ion
9	Energy deposited by evaporation α's.
Note!	Since this particles are transported in HETC, because of their low range we assume that they deposit their kinetic energy in place.
10	The recoil energy of the struck nucleus is also deposited in place
11	kinetic energy of protons escaping from geometry
12	kinetic energy of neutrons escaping from geometry
13	kinetic energy of π^+ escaping from geometry
14	kinetic energy of π^- escaping from geometry
15	kinetic energy of μ^+ escaping from geometry
16	kinetic energy of μ^- escaping from geometry
Note!	The energy of escaping particles is measured in order to provide an impression of the energy loss from the target and must not be taken into account when the total deposition energy is measured.
17	Kinetic energy of neutrons which are discarded (and optionally submitted for further treatment) below the neutron cutoff energy

18 Total energy of π^0 (optionally submitted for further treatment in EGS4)

19 The excitation energy of struck nuclei (optionally submitted for further treatment in NGEM and EGS4)

Note! Since this energy contributions cannot be handled by HETC itself they are measured as source energy so far. Normally the spread of this energy can be handled by MORSE, EGS4, and NDEM.

(3) Scintillation Light Detector (Type 5)

Detector Type 5 measure the "visible energy" deposited in [MeV] integrated over the volumes of regions IR1(i). This detector is also divided into 19 contribution channels. Channels 10 to 19 measure energy as described above. There are no means available in HETC and SIM to convert these channels to the visible energy fraction. The channels 1 to 9, however, can be converted using Birk's law. We have tabulated the scintillation light as a function of particle energy for protons, charged pions and muons and for the ions resulting from evaporation. The tables are generated and stored along with the setup of energy range tables in HETC.

$$L(E) = S_{med} \int_0^E \frac{1}{1+k_{Bmed}\, dE/dx\ (\varepsilon)}\, d\varepsilon \qquad (2.1)$$

For charged particles in flight

$$L(E) - L(E_c)$$

is deposited, where E is the energy of the particle at the start of the flight path and E_c is the energy at the end. Particles below transport cutoff are assumed to deposit their energy without escaping the region, so L(E) can be used. (For details see APPENDIX A.2.4).

(4) Forward Current Detector (Type 6)

This detector measures the number of particles crossing the specified boundaries from region IR1(I) to region IR2(I) (i.e. forward) per source particle in energy group IE and angle group IA. It may be renormalized to [A] multiplying it with the source current and normalizing it to the area of the specified boundaries.
The dimension is 1/source particle.

(5) Forward Flux Detector (Type 7)

This detector measures the (surface integrated) flux of particles crossing the specified boundaries from region IR1(I) to region IR2(I) (i.e., forward) per source particle in energy group IE and angle group IA. The contribution of the particle is taken as $wt/[\cos(u,N_s)]$

where wt is the statistical weight of the particle
u is the particle flight direction
N_s is the surface normal direction at boundary crossing point.

The dimension is 1/source particle.

(6) Tracklength Detector (Type 8)

This detector measures the (volume integrated) particle flux [cm] by tracklength of particle type "prt" in region IR1(i), energy group IE and angle group IA. As mentioned above the energy binning is splitting down the flight path according to the appropriate energy groups. The dimension is cm/source particle.

(7) Energy Transfer across Boundaries (Type 9)

This quantity is measured in [MeV] on all specified boundaries from regions IR1(i) to regions IR2(i), separately for 7 particle types

1 protons
2 neutrons
3 π^+
4 π^-
5 μ^+
6 μ^-
7 ions (not yet implemented)

The dimension is MeV/source particle.

2.3.3 The Statistics Module STATIST

STATIST has been created to combine the results of correlated Monte-Carlo runs. It reads the detector results stored on HERMES submission files at the end of each Monte-Carlo batch. Arithmetical and logical operations can be applied on the loaded data to derive additional information from the detector output. Detector logic like coincidence or veto can be simulated. Finally a set of physical quantities is available for each batch. Frequency distribution functions of these variables can be requested. A set of statistical moments is computed for each frequency distribution function including the mean value, the fractional standard deviation, scewness, and kurtosis based on empirical estimate statistics. Also the mean value, the f.s.d., the mode and the median of the grouped data are shown in a histogram. The mean and the f.s.d. of a Gaussian fit can be obtained in the range $\mu_e \pm 2\sigma_e$, where μ_e, σ_e are the empirical moments.

The correlation between variables can be shown by means of scatter plots. A linear regression procedure is provided to measure the correlation of variables. The variable set derived from loaded detector results can be stored on a file for further processing in more advanced statistics modules like SAS /14/.

Since STATIST produces plots, it is not totally machine independent. We offer routines which produce line printer plots to overcome this problem (see APPENDIX D). The interfacing requirements for a user provided graphic software can be found also in APPENDIX D.

2.3.4 The Command Input Interpreter CMD

Since HERMES consists of a number of independent programs working on the same problem, it would be helpful to have a problem oriented standard input to avoid inconsistant and redundant input coding. Furthermore this input should not require fixed column formats which always cause troubles like misplaced input items or dummies for data actually not needed. We also would like to increase the legibility of the input; this means input items should be associated with names identifying their meaning.

We made a very first approach to provide such a tool called CMD for input processing. Currently it is used to prepare geometry input for the Monte Carlo programs, analysis input for HETC and

the input for the STATIST code. CMD input tools for the material data input of the Monte-Carlo codes and other parts will follow in subsequent releases of HERMES.

CMD is organized in syntactic levels. The lowest level allows free column input of constants. In the second level we have implemented a syntax of user variable and array definition. The highest level is the most problem oriented one and provides command and statement syntax.

2.4 Planned Future System Extensions

2.4.1 Fast Time-Dependent Neutron History Module DYMO

The code DYMO (Dynamical Model) was specially designed to calculate the dynamics of sampling calorimetry, that means the time dependence of the various nuclear processes of the low-energy neutron component ($E_{kin,n} \leq E_{cut} \leq 20$ MeV), released by the HETC module.

In depleted uranium-scintillator calorimeters these are mainly the number of fast fission processes, the number of fast fission produced secondary neutrons, the number of neutron capture processes (mainly in DU, of minor importance for calorimetry also in hydrogen) and the number of recoil processes in hydrogeneous materials (like scintillators TMP/TMS liquids or wrapping papers). Most important is the release of neutron kinetic energy to the protons in the read-out medium. Though the 3-dimensional MORSE-CG module can be operated in a time dependent mode (which is more CPU time consuming, of course), the separate code DYMO /15/ was developed.

DYMO operates in the homogenized (and infinite) material mixture of the calorimeter considered. The simplified use of a homogeneous (zero dimensional) mixture (called material mix, expressed in atoms/cm^3, corresponding to the thicknesses used) is justified by the fact that the mean free path for several MeV neutrons is in the range of 10 to 50 mm, which is quite large compared to the usual plate thicknesses of several mm's only used in sampling calorimeters.

DYMO uses small steps in time (e.g. 0.1 ns) to evaluate the number of neutrons being affected either in their energy or lost by fission capture. After each step in time, all neutron energy groups are updated in content according to the group to group transfer probability $w_{gg'}(E_g)$:

$$W(E_g \rightarrow E_{g'}, \Delta t) = \rho \cdot w_{gg'}(E_g) \cdot \Delta x(E_g, \Delta t) \qquad (2.2)$$

with ρ = effective density of the mix and

$$\Delta x = \sqrt{(2E_g/m_n)} \cdot \Delta t = \text{fictitious path of neutrons} \qquad (2.3)$$

with masses m_n and kinetic energy E_g. The time step Δt has to be chosen so small that the reaction probability W is below a certain value (e.g. 0.1) even for the highest neutron energy group and the highest group-to-group transfer probabilities $w_{gg'}$. Otherwise the result would depend on the choice of E_g and of the reaction type.

DYMO is therefore not a Monte Carlo but a deterministic code, iterating in time steps up to a certain limit, typically 1 μsec. The group-to-group transfer probabilities are extracted from the same large evaluated nuclear data libraries used by the MORSE-CG module.

The updating in time includes the gain of neutrons by fast fissions (secondary or even tertiary fissions; the primary fission was the high-energy fission, calculated with the HETC module). For the fast fission spectrum a Maxwellian distribution with kT=1.33 MeV is used up to now.

Since DYMO keeps continuously track of the neutron spectrum versus time and takes into account the transition rates to all neutron induced reactions specified, one can also determine the abundances of the various nuclear γ sources (neutron capture, fast fissions, inelastic and nonelastic neutron induced reactions) versus time by using coupled neutron-γ cross-section libraries.

For DYMO a surface loss correction can be taken into consideration, accounting for the fractional loss of those recoil protons, which gain enough recoil energy to escape from the scintillator layer (or other hydrogeneous read-out media) into the absorber (or other nonactive media). Since there are no real layers in DYMO, this correction applies only for the mean.

The saturation effect of the read-out material is included in the evaluation of the visible proton recoil energy. As discussed in Section 2.3.2, Equ. (2.1) the saturation is described by the KB parameter in the Birks formula. The energy of the recoil proton is determined by subtracting the neutron energy (given as the mean of the corresponding energy group) after the time step Δt from the energy before the time step, if the transfer probability for elastic scattering on hydrogen was used.

2.4.2 The Myon Transport Module MEGS-CG

A Monte-Carlo technique is provided to investigate the energy loss of muons in sampling calorimetric devices. Two Monte-Carlo codes have been combined to calculate the muon transport with δ electrons-, bremsstrahlung- and pair production and the transport of these secondaries (EGS4, Section 2.2.3). The passage of a muon travelling through many interleaved layers of absorber (high Z) and detector (low Z) sheets results in δ ray production, bremsstrahlung and e^+,e^- pair production. These effects are energy and material dependent and are in general quite different for absorber and detector layers. δ electrons created in the absorber can deposit part of their energy in the detector material and, vice versa, δ electrons created in the detector can deposit part of their energy in the absorber material. Furthermore bremsstrahlung and pair production give rise to electromagnetic showers, which can extend over several layers.

For the transport of the primary muon we use the Monte-Carlo code MUDEX of Lohmann, Kopp and Voss, CERN. This program randomly produces δ electrons, bremsstrahlung, γ's and e^+,e^- pairs.

Interactions with energy transfers below a given threshold are taken into account by calculating a mean value for this part of the energy loss. The energy is assumed to be deposited locally. In a second step, using EGS4, each of the produced higher energetic δ rays, bremsstrahlung and particle pairs is followed through the calorimeter. We call the new code obtained by linking MUDEX to EGS4 MEGS-CG /16/. Such a Monte-Carlo code offers the possibility to calibrate sampling calorimeters with the help of muons.

2.4.3 The Hadron Cascade Code FLUKA

At the higher energies of present interest, i.e. hundreds of GeV, the most reliable model now available seems to be a multichain fragmentation model of hadron-nucleus collision developed and implemented into the Monte Carlo code FLUKA by J. Ranft et al. /17/ following the work of A. Capella et al. /18/.

We converted the FORTRAN IV version of FLUKA86 into a FORTRAN77 version for being adapted to the HERMES system and the CG-geometry CG-L2.

An analysis package on SIM basis has been written which is analog to SIM-HETC analysis routines. Coupling to the HERMES submission file is being prepared.

2.5 Structure of the HERMES Submission File

The modular structure of the HERMES code system requires the introduction of a convention for all inter-code communication data.

We designed a simple sequential file structure for this purpose. The data needed by the programs to communicate are

- physical properties of particles which are to be transported through the physical domain of more than one Monte-Carlo-code,
- trigger events like events like "start of run", "end of run", "start of batch (event)" and "end of batch (event)", which help to identify correlated data, and
- detector output data.

For each of the above data items one or two records are written on the HERMES submission file. All records begin with a record name (CHARACTER*8) and a the record type (integer number) to identify the meaning of the record. The following Tables 2.4-8 illustrate the structure of the records currently used.

Table 2.4
Format of trigger event records

item	name	type	description
1	VERB	char*8	record name
2	KEY	integer	situation key record type
3	ISEED	integer	current random seed
4	IRUN	integer	problem number
5	IBAT		current batch number
6	IHIS		current history number
7	NNEU	integer	no. of neutrons submitted (HET)
8	NPIO		no. of π^0 submitted (HET)
9	NNUC		no. of excited nuclei submitted (HET)
10	JOB	char*8	Time stamp to identify the job
11	DATE		
12	TIME		
13	dummy		dummy words to get same record
14	dummy		length of IBM and CRAY/XMP
15	dummy		

Table 2.5
Types of trigger event records

VERB	KEY	situation
SOR pgm	-1	Start of run
SOB pgm	-2	Start of batch
EOB pgm	-3	End of batch
EOR pgm	-4	End of run

Table 2.6
Format of particle submission records

item	name	type	description
1	VERB	char*8	record name
2	KEY	integer	=0 for all particle submission records
3	ISEED	integer	current random seed
4	A	real	struck nucleus mass number
5	Z		struck nucleus charge number
6	E*		struck nucleus excitation energy [MeV]
7	TYP	real	particle type
8	X		
9	Y		particle site
10	Z		
11	U		
12	V		particle direction cosines
13	W		
14	E		particle energy [MeV]
15	WT		particle statistical importance

Table 2.7
Types of particle submission records

VERB	KEY	TYP	description
N pgm	0	1.	n (below cut)
GAM pgm	0	7.	γ
PIO pgm	0	3.	π^0
NUC*pgm	0	14.	excited nucleus
E+ pgm	0	8.	e^+
E- pgm	0	9.	e^-
MU+ pgm	0	5.	μ^+
MU- pgm	0	6.	μ^-

Table 2.8
Format of (detector) data array submission records

item	name	type	description
1	VERB	char*8	record name=data array name
2	KEY	integer	record type
3	LEN	integer	total data array length
4	N1		
5	N2		array dimensions
6	N3		
7	V1	real	
8	V2		arbitrary real information
9	V3		
10	JOB	char*8	time stamp of the
11	DATE		generating job
12	TIME		
13	dummy		not used
14	dummy		
15	dummy		

The above data array control record is followed by a data record of length LEN, representing the data array VERB(N1,N2,N3).
For integer arrays KEY must be 1, for real arrays KEY must be 2.

2.6 References Chapter 2

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3. INPUT DESCRIPTION AND OPERATION OF THE HERMES CODE SYSTEM

3.1 Guide to HERMES Operation

The organization scheme of the HERMES system is illustrated in Fig. 2.1 of Chapter 2.

The operation of HERMES proceedes in up to 7 steps:

(1) Generation of the Geometry Description

Programs: CMD, CG-L2, GEOTEST routines

Input: CG-L2 input in CMD language, additional CMD commands to test the geometry setup (see Section 3.9)

Output: CG-L2 input file in card image format, test results (tables and viewgraphs)

Detailed description: Section 3.6

(2) Run of HETC with Online Analysis

Programs: HET/KFA2, SIM, CG-L2, CMD, STATLIB

Input:
- CMD-commands defining the detectors for online analysis, specification of materials, the particle source, and the model options
- CG-L2 geometry input in card image format
- a binary file containing nucleon cross-sections and evaporation data

Output:
- a print file containing the HET run log and the online analysis results (from SIM)
- a HERMES submission file containing low energy neutrons, π^0 and the residual nuclei after INCE
- a HERMES submission file containing the SIM detector results for each batch

Detailed description: Sections 3.2 and 3.7

(3) MORSE Transport of Low Energy Neutrons

Programs: MORSE/KFA, CG-L2

Input:
- specification of model options, particle source, materials used, detectors
- CG-L2 input in card image format
- a submission file containing the source neutrons (from HET)
- a cross-section library (e.g. EPR) containing the neutron (and γ) group cross-sections

Output:
- a print file containing the MORSE run log, and detector results
- a HERMES submission file containing γ's from (n,γ) processes
- a HERMES submission file containing the detector results of each batch

Detailed description: Section 3.3

(4) Generation of γ Sources by NDEM from de-Excitation of Residual Nuclei

Programs: NDEM

Input:
- a HERMES submission file containing the nuclei to be de-excited
- a library containing the decay modes (level densities) of excited nuclei
- specification of model options

Output:
- a HERMES submission file containing the γ's generated
- a print file

Detailed description: Section 3.5

(5) Preparation of Material Data to be Used by EGS

Programs: PEGS4

Input:
- specification of the materials to be used
- a data file containing data for the photoelectric effect, pair production and Rayleigh scattering (Storm and Israel)
- a data file containing the Rayleigh scattering form factor

Output:
- a cross-section file to be used in EGS4
- miscellaneous printed output, the generated data and viewgraphs

Detailed description: Section 3.4.2

(6) Run of the EGS Code

Programs: EGS4/KFA1, STATLIB, CG-L2

Input:
- specification of the model options, material names, and the particle source
- CG-L2 geometry input in card image format
- a HERMES submission file which may contain π^0, e^-, e^+ or γ
- cross-section data generated by PEGS

Output:
- a print file containing the EGS4 run log and detector results
- a HERMES submission file containing the detector results of each batch

Detailed description: Section 3.4

Note! EGS4 may be used several times in the same problem picking up EM sources of different origins, namely π^0 decay, residual nucleus de-excitation, (n,γ) reactions etc.

(7) Final Analysis of the Combined HET, MORSE and EGS Results

Programs: STATIST, CMD

Input:
- a command file (CMD) specifying the analysis to be made
- one or more HERMES submission files containing detector results from Monte Carlo runs

Output:
- viewgraphs of frequency distributions, scatterplots, tables of statistical moments
- a binary file containing processed results of each batch for use in SAS or other statistical procedures

Note! STATIST can be used after each Monte Carlo run to analyse intermediate results

Detailed description: Section 3.8

3.2 HET Input Description

HET input/output is illustrated in Fig. 3.1.

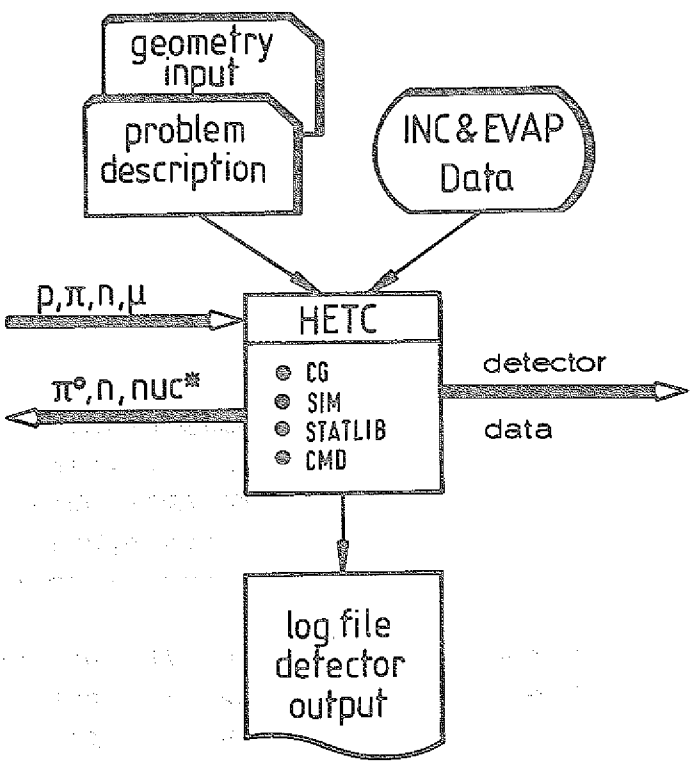


Fig. 3.1: HET input-output

HET requires up to three input files:

- Unit 5 is used for primary input as decribed below.
- Unit INSUB is used for external source particles on a HERMES submission file
- Unit INGEO is used for geometry-description input as described in Section 3.6.
- Unit IBERTP is used for INC cross-sections and EVAP data.

The primary input is read from unit 5. First CMD is called to read in the detector definitions for online analysis. This part of input must be terminated by the RUN command. Next to this HET reads in a single namelist record &RUN containing the physical parameters of the problem to be solved. The variables used, their default values and meanings are given in Table 3.1. (CMD see Section 3.7.1).

Finally CMD is called again to provide final processing of the analysed data. This CMD input section must be terminated with the EXIT command.

Table 3.1

VARIABLE	Default	Description
IRUN	1	Identification number for the run
MAXCAS	2	Number of source events per batch
MAXBCH	2	Number of batches to be run
ISEED	123456789	Starting random seed
INSUB	0	Unit number for external source file in HERMES format.
IOSUB	0	Unit number of particle submission file in HERMES format.
INGEO	5	Unit number of geometry input data read by JOMIN
IOGEO	6	Unit number for JOMIN print file
NHSTP	0	Unit number for history file
IBERTP	-20	Unit number for INC EVAP data file if >0 nucleon pion transport only if <0 nucleon pion muon transport
EMIN(1)	15.0	Transport energy cut for protons [MeV]
EMIN(2)	15.0	Transport energy cut for neutrons [MeV]
EPICUT	1.0	Transport energy cut for pions [MeV]
EMUCUT	1.0	Transport energy cut for muons [MeV]
EMAX		Maximum particle energy [MeV]
N1COL	0	if >0 stop history after second generation useful in debugging

Table 3.1 continued

VARIABLE	Default	Description
NPIDK	1	π^- capture option if =1 π^- decay at cut-off energy if =0 π^- are captured at cut-off energy
KEYDK	0	Pion decay-in-flight option if =0 weighted decay to increase number of muons if =1 analog decay
NBOGUS	1	Option to correct residual nucleus excitation with the recoil energy
NSPRED	0	Option to allow small angle multiple Coulomb scattering of charged source particles
NWSPRD	0	Option to report small angle multiple Coulomb scattering to history file
NSEUDO	1	Option to report pseudo events to history file
ISTRAG	0	Option to perform charged-particle range straggling.
IANG	1	Option to allow non-isotropic evaporation
IFISS	0	Option to allow high energy fission
IBO	1	Option to use automatic B_0 in evaporation
BO	8.0	Level density parameter to be used in evaporation
IELAS	0	Elastic scattering option if =0 no elastic scattering performed (except with ^1H) if =1 neutron elastic scattering switched on if =2 neutron and proton elastic scattering switched on
MXMAT		Number of media used (<17, except voids)
SO(M)	1.0	Detector efficiency of light detectors in medium M
KB(M)	0.0	Saturation parameter of light detectors in medium M

Table 3.1 continued

VARIABLE	Default	Description
DENH(M)		Numerical density of ^{1}H in medium M [atoms/cm^3 *1.E24]
NEL(M)		Number of elements other than ^{1}H in medium M
A(L,M)		Mass number of element L in medium M
ZZ(L,M)		Charge number of element L in medium M
DEN(L,M)		Numerical density of element L in medium M [atoms/cm^3 *1.E24]
LHI	0	Switch for heavy ion sources use 1 for d , 2 for t 3 for He3 , 4 for He4 5 for arbitrary heavy ion
HIA(5)		mass of arbitrary heavy ion (<20)
HIZ(5)		charge of arbitrary heavy ion
HIBE(5)		binding energy of arbitrary heavy ion
TIPSR	0	Source particle type use 0. for protons , 1. for neutrons, 2. for π^+ , 4. for π^- 5. for μ^+ , 6. for μ^- 7. for d(LHI=1) , 8. for t(LHI=2) 9. for ^{3}He(LHI=3), 10. for ^{4}He(LHI=4) 11. for heavy(LHI=5)
XSR YSR ZSR	0	Starting coordinates for source particles
XSIG YSIG ZSIG		Standard deviations for XSR YSR ZSR
USR VSR WSR	0.0 0.0 0.0	Direction cosines for source particles Default refers to isotropic distribution
ESR		Energy of source particles [MeV]
WTSR	1.0	Statistical weight of source particles

Note! source particle parameters may be omitted for external sources; e.g. when INSUB>0

Note! Geometry input is read from unit INGEO. If INGEO=5, then geometry input must follow the HET/KFA2 NAMELIST record on the same file.

3.3 MORSE-CG Input Description

MORSE-CG input/output is illustrated in Fig. 3.2.

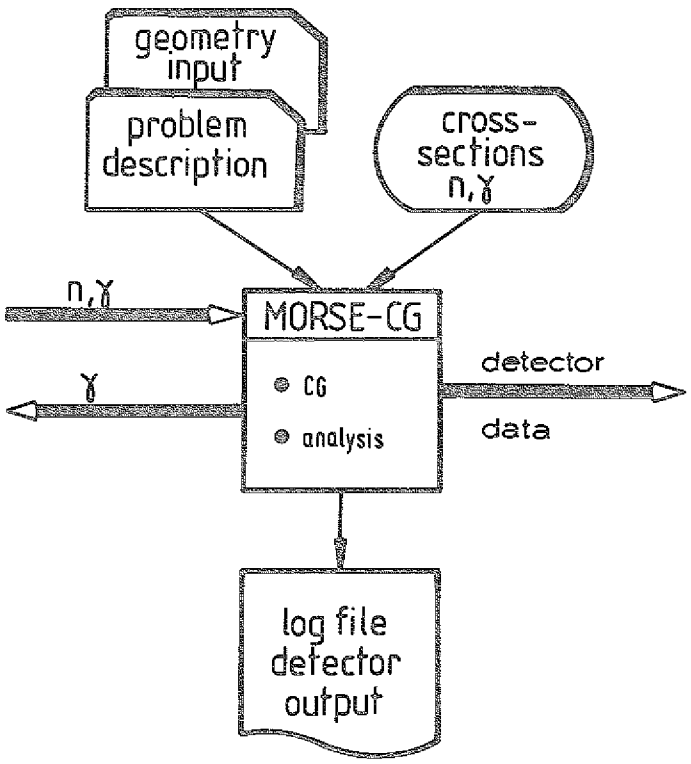


Fig. 3.2: MORSE-CG input-output

MORSE-CG requires up to four logical units for input:

- Unit 5 is used for primary input as decribed below.
- Unit IHETTP is used for external source particles on a HERMES submission file
- Unit INGEO is used for geometry description as described in Section 3.6.
- Unit IXTAPE is used for binary cross-section data (e.g. the EPR library)

MORSE-CG requires up to six logical units for output:

- Unit 6 is used for primary output
- Unit IOGEO is used for geometry description
- Unit IORSY is used for detector response data in RSYST structure /1/
- Unit IOCNT is used for MORSE counters
- Unit ISIMTP is used for the detector response data file on a HERMES submission file
- Unit IGAMTP is used for γ rays of (n,γ) coupled MORSE runs on a HERMES submission file

The primary MORSE-CG input is read from unit 5. Input to MORSE-CG is written in card image or REA format as described below (Section 3.3.1).

Geometry input is read from unit INGEO. If INGEO=5, geometry input must follow the random walk module input in the same file.

(1) Randwalk Module Input Instructions

The input read by subroutine INPUT1 is as follows:

Card A FORMAT (20A4)
Title card.
(Any character other than blank or alphameric in column 1 will terminate the job.)

Card A2 FORMAT (*)

IOCNT	Unit number for counter output
IORSY	Unit number for RSYST /1/ output
INGEO	Unit number for geometry input
IOGEO	Unit number for geometry output

Card B FORMAT (*)

NSTRT	Number of particles per batch; unused in case of particle input from a HERMES submission file
NMOST	Maximum number of particles allowed in the bank(s) may equal NSTRT if no splitting, fission, and secondary generation and no use of HERMES submission file otherwise NMOST > maximum number of particles per batch
NITS	Number of batches
NQUIT	Number of sets of NITS batches to be run without subroutine INPUT; unused, must be 1
NGPQTN	Number of neutron groups being analyzed to simulate energy cut).
NGPQTG	Number of gamma ray groups to be analyzed.
NMGP	Number of primary particle groups for which cross sections are stored; should be same as NGP (or the same as NGG, when NGP = 0) on Card XB read by cross-section module
NMTG	Total number of groups for which cross-sections are stored; should be same as NGP+ NGG as read on Card XB read by cross-section module

NCOLTP	Unit number for collision file; to be set greater than zero if a collision file is desired; the collision file is written by the user routine BANKR; not used in this version of MORSE-CG
IADJM	set greater than zero for an adjoint problem
AXTIM	unused variable
MEDIA	Number of cross section media; should agree with NMED on Card XB read by the cross-section module. For using the volume light detector, MEDIA must be number of media + one extra medium for each light response (containing ^{1}H)
MEDALB	Albedo scattering medium is absolute value of MEDALB; if MEDALB = 0, no albedo information to be read in, MEDALB < 0, albedo only problem - no cross sections are to be read, MEDALB > 0, coupled albedo and transport problem.

Card C	FORMAT (*)
ISOUR	Source energy group if > 0, if ISOUR < 0 or ISOUR = 0 and NGPFS ≠ 0, SORIN is called for input of Card E1 and E2.
NGPFS	Number of groups for which the source spectrum is to be defined. if ISOUR <= 0, NGPFS >=2.
ISBIAS	No source energy biasing if set equal to zero; otherwise the source energy is to be biased, and Cards E2 are required
NOTUSD	An unused variable
WTSTRT	Weight assigned to each source particle.
EBOTN	Lower energy limit of lowest neutron group (eV) (group NMGP)
EBOTG	Lower energy limit of lowest gamma-ray group (eV) (group NMTG)
TCUT	Age in sec at which particles are retired; if TCUT = 0, no time kill is performed.
VELTH	Velocity of group NMGP when NGPQTN>0; i.e., thermal neutron velocity (cm/sec) where VELTH=SQRT((WTS(I)+WTS(I+1))/2) · 1.383E+6.

TABLE 3.2
Sample Group Input Number for Some
Representative Problems*

Case A - Neutron Only Cross Sections (22 groups)
Case B - Gamma Ray Only Cross-Sections (18 groups)
Case C - Neutron-Gamma Ray coupled Cross-Sections (22-18 groups)

Input Variable	Case A Top 14 groups	Case B Top 17 groups	Case C Neutrons only Top 14 groups	Case C gamma-rays only Top 17 groups	Case C Neutron-gamma-rays Top 14 Neutron Top 17 gamma-rays	
MORSE Input						
NGPQTN	14	0	14	0	14	
NGPQTG	0	17	0	17	17	Card B
NMGP	22	18	22	18	22	variables
NMTG	22	18	22	18	40	
NGP	22	18	22	0	22+	
NGG	0	0	0	18	18	Card XB
INGP	22	18	40	40	40	variables

*For cross sections with full downscatter, NDS=NGP, NDSG=NGG, INDS=INGP, and ITBL=number of downscatters + number of upscatters +3.
Usually, ISGG=number of upscatters + 4; i.e. NUS+4.
+Must be = to total number of neutron groups in the data, otherwise it picks up gammas from wrong location.

Card D1 FORMAT (*)

XSTRT
YSTRT } Coordinates for particles
ZSTRT

AGSTRT Starting age for source particles

UINP
VINP } Source particle direction cosines, if all are zero, isotropic distribution is assumed
WINP

Note! Source data on Cards C and D1 will be overridden by using a HERMES submission file

Card D2 FORMAT (*)

IHETTP	Logical unit number of HERMES submission file, if greater zero
ISIMTP	Logical unit number of response data file in HERMES submission file structure, if greater zero
IGAMTP	Logical unit number of gamma ray particle file in HERMES submission file structure, if greater zero

Cards E1 FORMAT (*)
(omit if ISOUR on Card C > 0 or if ISOUR = NGPFS = 0)
NGPFS values of FS, where FS equals the unnormalized fraction of source particles in each group.

Cards E2 FORMAT(*)
(omit if ISOUR > 0 or if ISOUR <= 0 and ISBIAS = 0)
If ISBIAS > 0, NGPFS values of BFS, the relative importance of a source in group I is required.

Cards F FORMAT(REAG)
NMTG values of ENER, the energies (in eV) at the upper edge of the energy group boundaries.

Note! The lower energies of groups NMGP and NMTG were read on Card C

Card G FORMAT(*)
(omit if NCOLTP on Card B <= 0)

NHISTR	Logical unit number for the first collision file
NHISMX	The highest logical unit number that a collision file may be assigned to.
NBIND(J),J=1,36	An index to indicate the collision parameters to be written on file
NCOLLS(J),J=1,13	An index to indicate the types of collisions to be put on file

Note! unused in this MORSE-CG version
Note! See Table 3.3 for information concerning NBIND

Table 3.3
Variables that may be Written on Tape (NBIND)

J	Variable*	J	Variable
1	NCOLL	19	WTBC
2	NAME	20	ETAUSD
3	IG	21	ETA
4	U	22	AGE
5	V	23	OLDAGE
6	W	24	NREG
7	X	25	NMED
8	Y	26	NAMEX
9	Z	27	WATEF
10	WATE	28	BLZNT
11	IGO	29	BLZON
12	UOLD	30	VEL(IG)
13	VOLD	31	VEL(IGO)
14	WOLD	32	TSIG
15	XOLD	33	PNAB
16	YOLD	34	NXTRA
17	ZOLD	35	EXTRA1
18	OLDWT	36	EXTRA2

* These variables are defined in tables 4.4 and 4.5 of Ref. /2/

Card H — FORMAT(Z12)
- RANDOM — Starting random number

Card I — FORMAT(*)
- NSPLT — Index indicating that splitting is allowed if > 0.
- NKILL — Index indicating that Russian roulette is allowed if > 0.
- NPAST — Index indicating that exponential transform is invoked if > 0
- NOLEAK — Index indicating that non-leakage is invoked if > 0.
- IEBIAS — Index indicating that energy biasing is allowed if > 0.
- MXREG — Number of regions described by geometry input (will be set to one if <= 0.
- MAXGP — Group number of last group for which Russian roulette or splitting or exponential transform is to be performed. For adjoint, set = NMTG or overstoring result.
- IOCNT — option for Region output

Card I2 — FORMAT(REAI)
(only if MXREG < 0)
- geometry regions

Card I3 — FORMAT(REAI)
(only if MXREG = -2)
- MORSE regions

Card J FORMAT(*)
(omit if NSPLT + NKILL + NPAST =)

NGP1	From energy group NGP1 to energy group NGP2,
NDG	inclusive, in steps of NDG and from region
NGP2	NRG1 to region NRG2, inclusive, in steps of
NRG1	NDRG, the following weight standards and
NDRG	path-stretching parameters are assigned.
NRG2	If NGP1=0, groups 1 to MAXGP will be used; if NRG1=0, regions 1 to MXREG will be used (both in steps of 1). Usually NDG=1 and NDRG=1.
WTHIH1	Weight above which splitting will occur
WTLOW1	Weight below Russian roulette is played
WTAVE1	Weight given those particles surviving Russian roulette
PATH	Path-length stretching parameters use in exponential transform (usually 0<=PATH<1)

Note! The above information is repeated until data for all groups and regions are input
End Card J with negative value of NGP1 (i.e. -1 /)
Note! In runs with quasi analog calculation of splitting, fission and gamma production WTHIH1, WTLOW1 and WTAVE1 must be 1.

Card K FORMAT(REAG)
(omit if IEBIAS on Card I<= 0)
((EPROB(IG,NREG), IG=1, NMTG), NREG=1,MXREG)
Values of the relative energy importance of particle leaving a collision in region NREG.

Card L FORMAT(*)

NSOUR	Set <=0 for a fixed source problem; otherwise the source if from fissions generated in previous batch. (NSOUR=1 for k_{eff} calculations)
MFISTP	Index for fission problem, if <=0 no fissions are allowed.
NKCALC	The number of the first batch to be included in the estimate of k; if <=0 no estimate of k is made.
NORMF	The weight standards and fission weights are unchanged if <=0; otherwise fission weights will be multiplied, at the end of each batch, by the latest estimate of k and the weight standards are multiplied by the ratio of fission weights produced in previous batch to the average starting weight for the previous batch. For time-dependent decaying systems, NORMF should be > 0.

Card M FORMAT(REAG)
(omit if MFISTP on Card L <= 0)
(FWLO(I), I=1,MXREG) values of the weight to be assigned to fission neutrons.

Card N FORMAT(REAG)
(omit if MFISTP on Card L <= 0)
(FSE(IG,IMED), IG=1,NMTG), IMED=1,MEDIA)
The fraction of fission-induced source particles in group IG and medium IMED

Card O FORMAT(REAG)
(omit if NGPQTN=0 or NGPQTG=0, i.e. include if coupled neutron-gamma ray problem)
((GWLO(IG,NREG), IG=1,NMTG), NREG=1,MXREG)
Values of weight to be assigned to the secondary particles being generated.

(2) Cross-Section Module Input Instructions

The input read by subroutine XSEC is as follows:

Card XA FORMAT(20A4)
Title card for cross sections. This title is also written on file if a processed file is written.

Card XB FORMAT(*)

NGP	The number of primary groups for which there are cross-sections to be stored. Should be same as NMGP read on Card B in randwalk module
NDS	Number of primary downscatters for NGP (usually NGP). Includes $\sigma(g\ g)$ in case of downscatter cross-section matrix.
NGG	Number of secondary groups for which there are cross sections to be stored
NDSG	Number of secondary downscatters for NGG (usually NGG)
INGP	Total number of groups for which cross-sections are to be input.
ITBL	Table length, i.e., the number of cross-sections for each group (usually equal to number of downscatters + number of up-scatter + 3)
ISGG	Locations of within-group scattering cross-sections (usually equal to number of up-scatter + 4).

NMED	Number of media for which cross-sections are to be stored; should be same as MEDIA read on Card B in random walk module. for using the volume light detector NMED must be number of media + extra medium for each light response
NELEM	Number of elements for which cross-sections are to be read.
NMIX	Number of mixing table entries (must be >= 1).
NCOEF	Number of coefficients for each element, including P0.
NSCT	Number of discrets angles (usually [NCOEF/2])
ISTAT	Flag to store Legendre coefficients if greater than zero. (must be = 1 for point detector)
Card XC	FORMAT(*)
IRDSG	Switch to print cross-sections as they are read, if > 0
ISTR	Switch to print cross-sections as they are stored, if > 0.
IFMU	Switch to print intermediate results of mean value calculation, if > 0
IMOM	Switch to print moments of angular distribution, if > 0
IPRIN	Switch to print angles and probabilities, if > 0
IPUN	Switch to print results of bad Legendre coefficients, if > 0 if = 1 message in case the first moment is wrong; in case P2 and P3 are wrong, they are ignored and MORSE calculates just P1.
IDTF	Switch to signal that input format is DTF-IV format, if > 0; otherwise ANISN format is assumed
IXTAPE	Logical unit number if binary cross-section file, set equal to 0 if cross-sections are read from cards. if negative, then the processed cross-sections and other necessary data from a previous run will be read; in this case (IXTAPE<0) no cross-sections from cards and no mixing cards may be input and switches are ignored the absolute value of IXTAPE is the logical unit number

JXTAPE	Unit number of a processed cross-section file to be written. this processed file will contain the title card, the variables from common LOCSIG and the pertinent cross sections from blank common
IO6RT	Unit number of a point cross-section file in O6R format
IGQRT	Last group (MORSE multigroup structures) for which the O6R point cross-sections are to be used (must be <= NMGP)
IRBA	if IRBA=0, EPR-Library or 99-group Library =1, cross sections generated by RSYST are input. these cross-sections do not contain the factor (2L+1), so they are multiplied by (2L+1) in MORSE =2, ANISN-formatted Library, e.g. LASL
ICRO	Switch to print neutron to gamma transfer cross-sections, if > 0
IBAD	Switch to print bad moments, if > 0

Card XD FORMAT(REAI)
(omit if IXTAPE <= 0)
Element identifiers for cross section file. If element identifiers are in same order as elements on file, the efficiency of the code is increased due to fewer file rewinds.

Card XE
(omit if IXTAPE ≠ 0)
If cross sections are in free-form, a card with ** in columns 2 and 3 must precede the actual data.
ANISN format if IDTF <= 0; otherwise, DTF-IV format. Cross sections for INGP groups with a table length ITBL for NELEM elements each with NCOEF coefficients are read in.
Note! should not be used in this MORSE-CG version

Cards XF FORMAT(*) MIXING TABLE
(omit if IXTAPE < 0)
NMIX (see Card XB) cards are required.

KM	Medium number
KE	Element number occuring in medium KM (negative value indicates last mixing operation for this medium). If the medium consists of only one element, this has to be negative, where KE is the cross section numbers read on Card XD in order of the input Failure to have a negative value causes code not to generate angular probabilities for that medium.
RHO	Atom density of element KE in medium KM

Note! for each medium (scintilator material) for which visible energy is to be calculated (by using the volume light detector) an extra medium containing ^{1}H must be defined with the same density as the ^{1}H density in the scintillator material.

Card XG FORMAT(*)
(omit if IO6RT <= 0)
NXPM Number of point cross-section sets per medium found on an O6R-file.
= 1, total cross-section only
= 2, total + scattering cross-section
= 3, total, scattering and ν*fission cross section

(3) SAMBO Analysis Input Instructions

The following data are read from cards by subroutine SCORIN:

Card AA FORMAT(20A4)
Title information - will be immediately output.

Card BB FORMAT(*)
ND Number of detectors (set =1 if <=0).
NNE Number of primary particle (neutron) energy bins to be used (must be <= NE).
NE Total number of energy bins (set =0 if <=1) if NNE < NE the first NNE-1 energy bins and the last one are used. There will be a message in the output
NT Number of time bins for each detector (may be negative, in which case the absoltue values of NT are to be read and used for each detector) (set =0 if <=1)
NA Number of angle bins (set =0 if <=1)
NRESP Number of energy dependent response functions to be used (set =1 if <=0)
NEX Number of extra arrays of size NMTG to be set aside (useful, e.g., as a place to store an array of group-to-group transfer probabilities for estimator routines) must be >=1 for point detector
NEXND Number of extra arrays of size ND to be set aside (useful, e.g., as a place to store detector dependent counters) must be = NNE for volume light detector
IORESP Switch to print responses, if > 0
IOFLUX Switch to print fluence, if > 0

```
Card BC              FORMAT(A)
   CHOICE            Detector type
                     VQ  : volume flux detector
                     VL  : volume light detector
                     P   : point detector
                     SQ  : surface flux detector
                     SC  : surface current detector
                     SE  : surface energy current detector

Cards CC1-CC5        Detector information

Format:  Card CC1    FORMAT(REAG)
         Card CC2    FORMAT(REAG)
         Card CC3    FORMAT(REAG)
         Card CC4    FORMAT(REAI)
         Card CC5    FORMAT(REAI)
```

Note! The meaning of these input variables is totally dependent on the detector type that is chosen!

(a) Volume Detector: VQ and VL

CC1	must be :	F 0. ;	
CC2	must be :	F 0. ;	
CC3	must be :	F 0. ;	
CC4		IREG	region number, where the response is to be estimated
CC5	must be :	F 0 ;	for volume flux detector
		IMEDIA	for volume light detector medium number of 1H IMEDIA(I) with the same 1H density as in the material of detector IREG(I)

(b) Point Detector: P

CC1		X	X-Coordinates of detector points
CC1		Y	Y-Coordinates of detector points
CC1		Z	Z-Coordinates of detector points
CC4	must be :	F 0 ;	
CC5	must be :	F 0 ;	

(c) Surface Detector: SQ, SC, SE

CC1	U	U,V,W specify the zero degree
CC2	V	direction for the desired detec-
CC3	W	tors, they reference to direction cosines for angular dependent calculations
CC4	IR1	regions before surface crossing
CC5	IR2	regions after surface crossing

Note! In case of time dependent calculations with volume or surface detectors the lower limit of the fine time bin is set to zero.

Note! In case of the point detector, the distance between the x,y,z points and XSTRT, YSTRT, ZSTRT values and the initial age, AGSTRT, will be used to define the lower limit of the first time bin

Card DD FORMAT(20A4)
Title or units for total responses for all detectors. Will be used in columns 54 through 133 of the title prior to the print of these arrays

Card EE FORMAT(20A4)
Title or units for each total response for all detectors

Card FF FORMAT(REAG)
Response function values. NMTG values will be read on each set of FF Cards. Input order is from energy group 1 to NMTG (order of decreasing energy)

Note! Cards EE and FF are read in the following order:
NRESP sets of (EE - FF) cards

Card GG FORMAT(20A4)
(omit if NE <= 1)
Units for energy dependent fluence for all detector

Card HH FORMAT(REAI)
(omit if NE <= 1)
Energy group numbers defining lower limit of energy bins (in order of increasing group number). The NNE (if > 0) energy must be equal NGPQTN: the NE entry must be set to NMGP + NGPQTG for a combined problem, or else NGPQTG or NGPQTN.

Card II FORMAT(20A4)
(omit if absolute value of NT <= 1)
Units for time dependent total responses for all detectors

Card JJ FORMAT(20A4)
(omit if absolute value of NT <= 1 or NE <= 1)
Units for time and energy dependent fluences for all detectors.

Cards KK FORMAT(REAG)
ND Cards must be input
NT values of upper limits of time bins for each detector (in order of increasing time and detector number). The values for each detector must start on a new card. Absolute values of NT only are read if NT is negative. They are then used for each detector

```
Card LL                FORMAT(20a4)
(omit if NA <= 1)
   Units for angle and energy dependent fluence for all
   detectors

Card MM                FORMAT(REAG)
(omit if NA <= 1)
   NA values of upper limits of angle bins (actually cosine
   bins; the NAth value must equal one, that means the values
   have to be specified in increasing order of cosine.
```

(4) Additional Input

Following is the input to the SAMBO analysis module, input cards for user-written routines

For point detector only : CHOICE=P

For detailed information about using the point detector see Section A.4.2 of Appendix A.

```
Card P1                FORMAT(*)
   IDR(I,1),           ND values, giving the number of regions,
       I=1,ND          that are specified for each detector i
                       IDR = 0 : no specification of regions, i.e.
                                 all regions are regarded
                       IDR > 0 : only those collisions are regar-
                                 ded, that occur in one of the re-
                                 gions defined on Card P2
                       IDR < 0 : collisions, that occur in one of
                                 the regions defined on Card P2,
                                 are disregarded

Cards P1               FORMAT(*)
(for each I with IDR(I,1) ≠ 0 a new card with:)
   IDR(I,J),           Regions for each detector
   J=1,IDR(I,1)
```

For volume light detector only : CHOICE=VL

```
Card VL1               FORMAT(*)
   NUMBR               Number of light response functions
```

NUMBR sets of following cards must be input

Card VL2	FORMAT(*)
NDETEC	Number of detector using this light response function
S	Scintillation efficiency of this light response (fraction of ionization energy converted to fluorescent light energy)
KB	Saturation parameter of this light response
NEL	Number of elementes (other than ^{1}H) of detector medium
DENH	Atom density of ^{1}H in detector medium
Card VL3	FORMAT(REAI)
ID	NDETEC region numbers of detectors with same medium and using this light response function
Card VL4	FORMAT(REAG)
ZZ	The NEL charge numbers of elements in this medium
Card VL5	FORMAT(REAG)
A	The NEL mass numbers of elements in this medium
Card VL6	FORMAT(REAG)
DEN	The NEL atom densities of elements in this medium

3.3.1 Implementations in MORSE-CG

MORSE-CG was implemented into HERMES to simulate low energy neutron and gamma transport.

(1) Input and Output Files

To use MORSE in the context of HERMES an interface to HERMES submission files has been included. This allows MORSE to receive particle sources generated by other programs (HET,NDEM or by MORSE itself), to report its results for further processing (in STATIST) and to write generated gamma-rays to be read in other programs as a source.

The analysis code of MORSE generates response data records (in HERMES submission format) at the end of each batch, if chosen. The verbs of all these records are in the following form:

Rxxx@EOB with xxx is the response function number in order as read-in from 001 to 999

If chosen, the generated γ rays will be written on a HERMES submission file to be used in other programs, e.g., EGS4, or in MORSE itself as source particles). Therefore, the energy of the γ rays generated in γ-energy group g will be uniformly distributed between the low and high energy boundaries of this group.

(2) The REA Format

To simplify the input of data arrays, MORSE uses two subroutines REAG and REAI, to input arrays from cards. REAI reads INTEGER arrays, REAG REAL arrays. Each input of an array begins on a new card. To read variable 'A', means the whole array or an array element, in REA format use following syntax:
Where 'OP' is an operator given as one character,
' N' is the repetition factor given as INTEGER constant
and ' V' is the value given as REAL constant for REAL variable 'A' or INTEGER constant for INTEGER variables
All elements should be separated by blanks;

Table 3.4

OP	N	Value	Meaning
		V	A(I)=V ; I=I+1
R	N	V	N-times : A(I)=V ; I=I=1
Q	N	M	repeat the last M values N-times
F		V	fill remainder of A with V
A	N	V	N-times : A(I)=A(I-1)+V ; I=I+1
M	N	V	N-times : A(I)=A(I-1)*V ; I=I+1
/			Skip to next line
S			Skip to next line
;			Terminate input (must be the
T			last 'OP')

A message occurs, when too many or too few values are given.

Examples:

```
F 0. ;          Fill the whole REAL vector with the value 0.
R 41 1 F 2 ;    Vector elements A(1) - A(41) have the INTEGER
                value 1, the remaining element the INTEGER
                value 2.
5. A 4 2.       means: A(1)=5., A(2)=7., A(3)=9., A(4)=11.,
                       A(5)=13.
```

(3) Auxiliary Routine NDMMOR for γ-Data Input

This program merges together the HERMES submission files generated by NDEM and MORSE, both containing the produced γ rays. Thus one single run can be made for γ rays produced by high and low energy particles.
The unit numbers used by the program are:

- Unit 10 for the HERMES submission file generated by NDEM
- Unit 11 for the HERMES submission file generated by MORSE
- Unit 12 for the HERMES submission file generated by NDMMOR

3.4 EGS4-HERMES Implementation

To use EGS4 in the context of the HERMES code system, a standard user code has been written, which solves the following tasks:

- Interfacing with HERMES submission files.
  This allows EGS4 to accept particle sources generated by other codes (NDEM, MORSE) and to report its results for further processing (in STATIST).
- Interfacing of EGS4 with the combinatorial geometry code CG-L2. By means of this interface EGS4 can share the geometry description used also in HET, MORSE etc.
- A standard analysis was incorporated to measure energy deposition, flux and leakage current by tracklength of particles dependent on type and region.

Since the user code is rather large, problem dependent data (such as NMED, NREG, ECUT, etc.) are read-in from an input file rather than being assigned in the MORTRAN source text. Thus, EGS4 in the version used here can be used like a conventional FORTRAN program. The FORTRAN source of the standard implementation is delivered along with the MORTRAN source.

EGS newcomers are adviced to use the FORTRAN standard setup. After some practice with EGS4 tutorials given in Ref. /3/, it should be possible to understand the MORTRAN source of the standard user code and to tailor it for special purposes.

The analysis code of EGS4-HERMES generates four response data records at the end of each batch:

(1) EDEP@EOB (NREG,3,5)

energy deposition [MeV] per

- region 1 to NREG

- particle 1 e^-
  2 γ
  3 e^+

- type 1 deposition in flight
  2 deposition at ECUT/PCUT discard
  3 deposition at AE/AP discard
  4 leakage energy loss
  5 deposition of photo electrons generated below cutoff energy

(2) HARG@EOB (NREG,3,5)

frequency of analysis calls per
- region
- particle
- type see above

(3) PHIB@EOB (NREG,3)

flux by tracklength [cm] per
- region
- particle

(4) EESC@EOB (NREG,3)

leakage current [arbitrary units] per
- region
- particle

At end of run, the same information, averaged over all batches is reported using the following data record names:

EDEP@EOR for energy depostion,
HARG@EOR for calling frequencies,
PHIM@EOR for tracklength flux, and
EESC@EOR for leakage current.

3.4.1 EGS Input Description

EGS4 input/output is illustrated in Fig. 3.3.

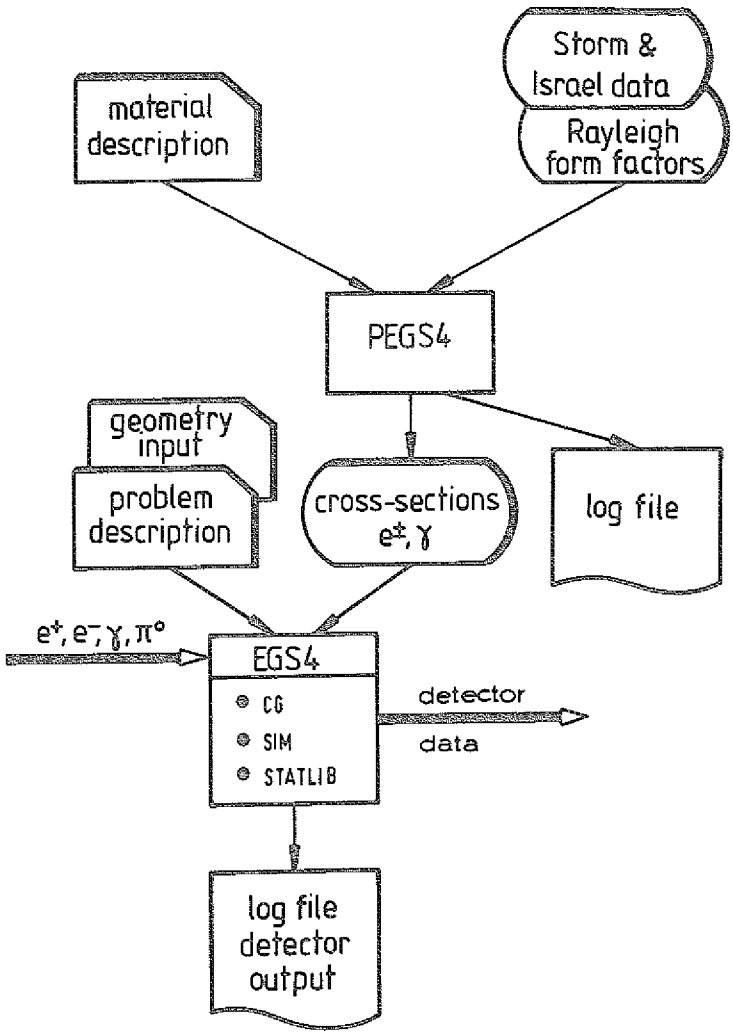


Fig. 3.3: EGS4/PEGS4 input-output

This input description refers to the standard EGS4 user code for the HERMES system. It is delivered along with some additional macros to enable the user to construct his own user code for special purposes.

Note, that a proper implementation of EGS4 into the HERMES system requires

- interfacing to combinatorial geometry (in HERMES version)!
- the correct coupling to HERMES submission files!

EGS4 requires upto four input files:

- Unit 5 contains the primary input (problem description) as described below.
- Unit INGEO is used for the geometry description. For details of HERMES-CG input refer to Section 3.6
- Unit KMPI is read by subroutine HATCH and must include the cross-section data generated by PEGS4.
- Unit INEGS can be used to read in an external particle source. This file must be written in HERMES submission file format as described in Section 2.5 of Chapter 2.

The primary input on unit 5 is organized in a single NAMELIST record &EGS. The items are described in Table 3.5.

Table 3.5

VARIABLE	Default	Description
IRUN	1	identification number of the run
MHIS	1	number of source particles started within one batch. For external particle sources MHIS is not used.If frequency distributions are to be measured, MHIS must be set to 1.
MBAT	10	maximum number of independent batches to be run.
INEGS	0	unit number of an external source particle file in HERMES submission file format. If INEGS=0 an internal particle source is used.
IOEGS	0	unit number of an output file in HERMES submission file format. This file is used to report the measured detector data for further processing in STATIST.
INGEO	5	input unit number for the combinatorial geometry input (refer to Section 3.6). If INGEO=5 CG input must follow the NAMELIST record.
IOGEO	6	output unit number for the combinatorial geometry print file (refer to Section 3.6)

KMPI	12	input unit number for the cross-sections prepared by PEGS4 (refer to Section 3.4.2 for PEGS4 input)
KMPO	8	output unit number for the cross-section print file generated by HATCH.
IXX	123456789	initial random seed. This should be a large odd integer number.
NMED		number of media used. NMED must not exceed 16 which is also the limit in HET. If more media are required the EGS4 user code is to be changed.
MEDNAM(NMED)		array of CHARACTER*24 strings containing the media names as used in PEGS4.
ESTEPE(NMED)		array of real numbers. ESTEPE limits the electron step size to an energy loss of ESTEPE(i) percent in one step for medium i. It is used by subroutine FIXTMX.
NREG		number of regions used in EGS4 (≤1000).
LSTREG(NREG)		array of integer numbers containing the region key for each region as assigned by the geometry package.
MED(NREG)		array of integer numbers containing the medium index of the media to be used for each region.
ECUT(NREG)		electron/positron cutoff energy for each region.
PCUT(NREG)		photon cutoff energy for each region.
IRAYLR(NREG)		integer switches (0=off, 1=on) to toggle coherent rayleigh scattering for each region.
IQI		particle type of source particles -1 - electrons 0 - photons +1 - positrons +2 - π^0

XI,YI,ZI	coordinates of source particles.
UI,VI,WI	direction cosines of source particles.
EI	total energy of source particles
WTI	statistical weight of source particles.

Note! IQI, XI,YI,ZI, UI,VI,WI, EI and WTI are not used for external particle sources (with INEGS>0)

3.4.2 PEGS4 Input Description

PEGS4 input/output is illustrated in Fig. 3.3.

PEGS4 must be used tc generate cross section data for EGS4. The program is used as designed by Nelson et al. /3,4/ without any changes. Refer to /3/ for a detailed description of the code and input. Here we only give a compendium of the input description.

PEGS4 requires 3 input files:

- Input data for photoelectric, pair production and Rayleigh scattering (from Storm and Israel) is read from FORTRAN unit number 8.
- Input data for Rayleigh scattering form factors is read from FORTRAN unit 9.
- User input data, as described below, is read from unit 5.

PEGS4 generates output files:

- Data to be used by EGS4 is written on FORTRAN unit 7 in card image format.
- Primary print output is written on FORTRAN unit 6.
- A copy of the data provided for EGS is written on FORTRAN unit 10 in printer format.

PEGS user input consists of a set of processing options read in a loop. For each option PEGS4 reads

- a card containing the option name in (A4) format,
- the namelist record &INP containing the parameters used for the option,
- additional literal data needed for the option in fixed FORTRAN formats.

Cards A: Set Energy Cutoffs

A1: FORMAT (A4)
ENER

A2: FORMAT (namelist)
&INP
AE = electron/positron cutoff energy [MeV]
AP = γ cutoff energy [MeV]
UE = highest electron/positron energy [MeV]
UP = highest γ energy [MeV]
&END

Cards A are followed by a medium specification:

Cards B: Setup an element medium

B1 FORMAT(A4)
ELEM

B2 FORMAT (namelist)
&INP
RHO = density [g/cm^3] (optional)
WA = atomic weight (optional)
IRAYL = 1 to include Rayleigh scattering
= 0 otherwise
IUNRST = 1 to allow unrestricted collision stopping power
= 0 otherwise
ISSB = 1 to use user defined Sternheimer density effect coefficients
= 0 otherwise
AFACT = a (=0 for ISSB=0) (see Ref. 3)
SK = m_s (=0 for ISSB=0)
X0 = x_0 (=0 for ISSB=0)
X1 = x_1 (=0 for ISSB=0)
CBAR = C (=0 for ISSB=0)
IEV = I(eV) (=0 for ISSB=0)
&END

B3: FORMAT (A24,6X,A24)
MEDIUM identifier assigned to medium data
IDSTRN identifier of Sternheimer coefficients predefined in PEGS (see Ref. 3)

B4: FORMAT (A2)
SYM atomic symbol of the element

Cards C: Setup a medium as a mixture of elements

C1: FORMAT (A4)
MIXT

C2: FORMAT (namelist)
&INP
RHO = density of the mixture [g/cm^3]
NE = number of elements in mixture
RHOZ(I) = relative amount of element I in mixture (must be given for all NE elements)
GASP = 0. for solid or liquid media (default)
= gas pressure [atm.]
WA(I) = atomic weight of element I (optional)
IRAYL = 1 to include Rayleigh scattering
IUNRST = 1 to allow unrestricted collision stopping power
ISSB = 1 to use user defined Sternheimer density effect coefficients
AFACT = a (=0 for ISSB=0) (see Ref. 3)
SK = m_s (=0 for ISSB=0)
X0 = x_0 (=0 for ISSB=0)
X1 = x_1 (=0 for ISSB=0)
CBAR = C (=0 for ISSB=0)
IEV = I(eV) (=0 for ISSB=0)
&END

C3: FORMAT (A24,6X,A24)
MEDIUM identifier assigned to media data
IDSTRN identifier of Sternheimer coefficients predefined in PEGS (see Ref. 3)

C4: FORMAT (24(A2,1X))
SYM(I) atomic symbols of all NE elements

Cards D: Setup a medium as a compound of NE elements

D1: FORMAT (A4)
COMP

D2: FORMAT (namelist)
&INP
RHO = density of the compound [g/cm^3]
NE = number of elements in compound
PZ(I) = relative number of atoms of element I in compound (must be given for all NE elements)
GASP = 0 for solid or liquid media (default)
= gas pressure [atm.]

WA(I) = atomic weight of element I (optional)
IRAYL = 1 to include Rayleigh scattering
= 0 otherwise
IUNRST = 1 to allow unrestricted collision stopping power
= 0 otherwise (default)
ISSB = 1 to use user defined Sternheimer density effect coefficients
= 0 otherwise (default)
AFACT = a (=0 for ISSB=0) (see Ref. 3)
SK = ms (=0 for ISSB=0)
X0 = x_0 (=0 for ISSB=0)
X1 = x_1 (=0 for ISSB=0)
CBAR = C (=0 for ISSB=0)
IEV = I(eV) (=0 for ISSB=0)
&END

D3: FORMAT (A24,6X,A24)
MEDIUM identifier assigned to media data
IDSTRN identifier of Sternheimer coefficients predefined in PEGS (see Ref. 3)

D4: FORMAT (24(A2,1X))
SYM(I) atomic symbols of all NE elements

After each medium definition the "piecewise linear fit" option must be called to compute the cross section set needed by EGS.

Cards E: invoke the "piecewise linear fit"

E1: FORMAT (A4)
PWLF

E2: FORMAT (namelist)
&INP &END
normally no parameters are needed. For details refer to Ref. 3.

When the cross sections have been computed with PWLF use the DECK option to store them on FORTRAN unit 7 for further processing in EGS.

Cards F: save cross section data for EGS

F1: FORMAT (A4)
DECK

F2: FORMAT (namelist)
&INP &END
no parameter needed

For subsequent media the input must be continued with another medium setup (ELEM, MIXT or COMP) followed by PWLF and DECK. The last option must be the STOP option:

Cards G: terminate the PEGS run

G1: FORMAT (A4)
STOP

G2: FORMAT (namelist)
&INP &END
no parameters needed

Note! A slightly modified user code has been developed to run EGS4 on the CRAY-XMP computer.

3.5 NDEM Input Description

NDEM input is illustrated in Fig. 3.4.

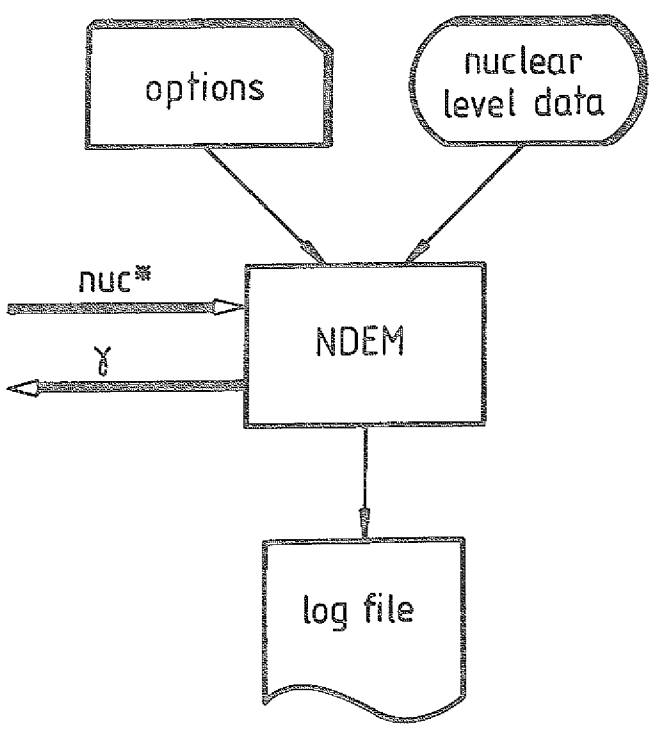


Fig. 3.4: NDEM input-output

The NDEM run consists of two steps:
- TRX: translation of the level library from ASCII to binary code as read in NDEM
- NDEM: calculation of the gamma rays from residual nuclei on HERMES submission file written by HET

(1) Run of TRX

TRX requires two input units:
- Unit 12 is used for primary input as described below
- Unit INBCD is used for BCDLIB, the level library in ASCII code

TRX requires three output units:
- Unit 6 is used for primary output
- Unit IOPHT is used for PHTLIB, the level library in binary code
- Unit LOUT is used for printed output (optional)

TRX input is written in card image format as described below

Card TRX1	FORMAT (*)
INBCD	Logical unit number for level library ASCII file
IOPHT	Logical unit number for level library binary file
LOUT	Logical unit number to print level data, if > 0

Note! The file LOUT has more than 15000 lines.
Print is only usefull for general information about level library.

(2) Run of NDEM

NDEM requires three input units
- Unit 5 is used for primary input as described below
- Unit INUCTP is used for HERMES submission file containing the residual nuclei data
- Unit 30 is used for level library PHTLIB as created by TRX in the first step

NDEM requires two output units
- Unit 6 is used for primary output
- Unit IGAMTP is used for NDEM output file containing generated γ rays in HERMES submission file structure

NDEM input is written in card image or REA format as described below and in Section 3.3.1.

Card PHT1	FORMAT(*)
ICC	The level of physics to be applied. Values of 0-4. (For detailed information see Section 3.5.1)
NERG	The number of energy bin boundaries to represent the de-excitation γ spectra, if >0; if <0, [NERG] energy bin boundaries from 10 keV in steps of 10 keV will be calculated
FNORM	An overall weighting factor to be applied to the printer and plotter output. The default is 1.
KPLOT	flag to turn on plotting. =0 implies no plotting, default. =1 requests plots
Card PHT2	Format(*)
INUCTP	unit number of HERMES submission file containing residual nuclei
IGAMTP	unit number of HERMES submission file to hold generated γ rays
ICPL	switch to copy neutron records from INUCTP to IGAMTP, if > 0 ; usefull if IGAMTP should be input tape for MORSE
Card PHT3 (omit, if NERG <=0)	FORMAT(REAG)
ERGB	NERG upper energy bin boundaries (in MeV) for editing the de-excitation γ spectrum is required. NERG energies may be entered from low to high.

3.5.1 The NDEM Model Option ICC

(1) ICC=0 : The Pure Continuum

When ICC=0 is specified, the continuum is assumed to exist at all nulcear excitations above the pairing gap for the residual nucleus. As a consequence, there is no line spectrum but rather only a continuous γ energy distribution. All transitions, within the continuum or from the continuum to the ground state, are assumed to be E1 transitions.

(2) ICC=1 : The Troubetzkoy (E1) Model

For ICC=1, the nuclear energy levels specified in the data library are used, the continuum is assumed to begin above the highest specified level. However, all transitions, whether continuum-to-continuum, continuum-to-level or level-to-level, are assumed to be E1 transitions.

(3) ICC=2 : The Intermediate Model

When ICC=2, the model employed is really a hybrid between models (2) and (4). The nuclear levels and their spins and parities are obtained from the data library. The continuum begins above the highest specified level. However, all levels above the lowest that has unknown spin and parity are also considered to have unknown spin. All transitions within or from the continuum, or that involve a level with unknown spin, are treated as E1 transitions as in model (2). All transitions involving only states of known spin and parity utilize the Weisskopf single-particle transition model as in option (4).

(4) ICC=3 : The Spin Dependent Model

When ICC=3 option gives the full model as described as option (1), with the exception that any experimental branching ratios are ignored and a pure model calculation is performed for the transition probabilities using the Weisskopf single-particle transition estimates.

(5) ICC=4 : The Full Model with Experimental Branching Ratios

With ICC=4, the full procdure described as option (1) is employed, including the use of library-specified branching ratios when available.

3.6 Description of Combinatorial Geometry Input

Combinatorial geometry input can be written either in card image format, as described in the Section 3.6.2, or in CMD command laguage. In CMD the user need not care about column formats, he can use symbolic variables instead of constants to define geometry data, and he can use general CMD commands like LOOP etc. to simplify the input for regular geometric patterns.

3.6.1 Combinatorial Geometry Input in CMD Language

The user creates a file containing the geometry description in CMD laguage. Then CMD must be called to compile this file to card-image format input, which can be included in HET, EGS or MORSE input files.

This should be done preferently using a suitabel procedure within an interactiv operating system. For IBM-CMS users the REXX procedure GEOGEN is available on the HERMES distribution tape.

A summary of CG related CMD commands is given below.

(1) Use GEOCMP Command to Start the Geometry Description.

```
GEOCMP nbody nzone nczone lenfpd lenma;
       nbody = number of bodies used
       nzone = number of input zones used
       nczone= number of code  zones used
       lenfpd= length of floating point storage needed
       lenma = length of integer storage needed
```

(2) Use the Following Commands to Define Bodies.

```
ARB    k vv1 ... vv8  is1 ... is6 ;   arbitrary polyhedron
SPH    k vv r;                        sphere
RCC    k vv hh r;                     rectangular circular cylinder
REC    k vv hh rr1 rr2;                "    elliptic cylinder
TRC    k vv hh r1 r2;                 truncated rectangular cone
ELL    k vv1 vv2 b;                   ellipsoid
BOX    k vv hh1 hh2 hh3;              box
WED    k vv hh1 hh2 hh3;              wedge
RPP    k xmin xmax ymin               rectangular parallel epiped
         ymax zmin zmax;
P      k uu d ;                       plane (hesse form)
PX     k d;                           plane rectangular on x
                                      (y,z plane)
PY     k d;                           plane rectangular on y
                                      (x,z plane)
PZ     k d;                           plane rectangular on z
                                      (x,y plane)
PS     k vv uu d;                     plane (hesse form,shifted)
C      k vv uu r;                     cylinder
CX     k vv r;                        "     uu = x direction
CY     k vv r;                        "     uu = y direction
CZ     k vv r;                        "     uu = z direction
END    ;                              end of body input
```

```
        k  =  body key number
        vv =  vertex vector
        uu =  direction cosinus of axis
        rr =  radius vector
        hh =  hight vector
        r  =  scalar radius
        d  =  scalar distance used in Hesse-form

(3) Use the Following Commands to Define Zones

ZONE   imed ireg  condition-list;  define geometry zone
SUBGEO  ;                          start subgeometry-zone set

        define the medium returned by the geometry for the zone
        imed = -1 for external (black) voids
             = 1000 for internal voids in MORSE
             = 6666 for internal voids in HET and EGS
             < -1 to leave medium key undefined

        define the region number returned by CG for the zone
        ireg > 0 to define region number
             < 0 to define only 3 digits of a composed 9 digit
               region number

        define the geometrical domain of the zone-
        condition list
        syntax of condition list:
        code-zone ( OR code-zone ( ... ))   (GO set-number )

        syntax of code-zone:
        k1 k2 ....
        ki>0 means all code-zone points lie inside body ki
        ki<0 means all code-zone points lie outside body ki

        OR operator may be used to join code-zones together

        GO may be used to pass control to a subgeometry-zone
        set to subdivde the zone into subzones. The top
        set of zone descriptions refers to set number 1.
        When SUBGEO is encountered the set number is incre-
        mented

        In set number 1  ireg<0 will generate nreg=-ireg*100000

        The set called by GO from set number 1 will generate
        nreg = ireg               if ireg>0 or
        nreg = nreg -ireg*1000    if ireg<0
```

The set called from this level will generate
nreg = ireg if ireg>0 or
nreg - nreg -ireg if ireg<0

Thus, the maximum nesting level of zone descriptions is 3, and the minimum ireg per level is -999.

(4) Terminate Card Image Input by ENDGEO

```
ENDGEO  ;
```
terminates the geometry input, the object output is now available on unit 22.

(5) Use the Following Commands to Test the Geo Description

```
GEOIN  in,io;                          load geo object
```
invokes subroutine JOMIN of the CG-L2 package to read card image input.

```
LOOKZ  ss;                             query point properties
RAY    ss   uu  raylength;             ray tracing
PICM   ss   uu  vv  size;              medium picture
PICR   ss   uu  vv  size;              region picture
PICZ   ss   uu  vv  size;              zone   picture
NEXT   ;                               prepare for next picture
MARK   iarea kline;                    shade "area" with "kline"
HEAD   no text;                        define label 1 TO 7
```

ss shift vector
uu direction cosines of u axis
vv direction cosines of v axis

3.6.2 Combinatorial Geometry Input in Card Image Format

Card A: FORMAT(*) Header card 1

```
NUMB     number of bodies (default 100)
NUMR     number of input zones (default 100)
NCOD     number of code zones (default 100)
LFPD     length of floating point data needed (default 1000)
LMA      length of integer data needed (default 1000)
LOUT     not used
IDBGO    if 0, zone overlap will be checked by LOOKZ
```

Card B: FORMAT(*) Header card 2

IVOPT volume option
- 0 set all volumes equal to 1.0
- 1 invalid in this version
- 2 invalid in this version
- 3 read in NUMR volumes
- 4 bypass volume calculation

MEDREG boundary option
- -1 return from GEOM at region boundaries
- 0 return from GEOM at all boundaries
- 1 return from GEOM at medium boundaries

Card C: FORMAT(*) Header card 3

IPRINT taylor CG printing
- 0 no print
- 1 print geometry description
- 2 print description and storage dump

STRETCH scale factor (default=1.)

Cards D: FORMAT(2X,A3,1X,I4,6E10.3) Body cards

TYPE Body type
INR body number
$PARAM_i$ up to six parameters describing the body

Note! There must be a card D for each of the NUMB bodies.
The last one must be "END".
If a body requires more than six parameters, continuation cards must be used leaving TYPE and INR blank.
See Table 3.6 to find the parameters needed for body input.

Table 3.6
CG-Body Types and Parameters

ARB	k vv1...vv8 is1...is6 ;	arbitrary polyhedron
SPH	k vv r;	sphere
RCC	k vv hh r;	rectangular circular cylinder
REC	k vv hh rr1 rr2;	" eliptic cylinder
TRC	k vv hh r1 r2;	truncated rectangular cone
ELL	k vv1 vv2 b;	ellipsoid
BOX	k vv hh1 hh2 hh3;	box
WED	k vv hh1 hh2 hh3;	wedge
RPP	k xmin xmax ymin ymax zmin zmax;	rectangular parallel epiped
P	k uu d ;	plane (hesse form)
PX	k d;	plane rectangular on x (y,z plane)
PY	k d;	plane rectangular on y (x,z plane)
PZ	k d;	plane rectangular on z (x,y plane)
PS	k vv uu d;	plane (hesse form,shifted)
C	k vv uu r;	cylinder
CX	k vv r;	" uu = x direction
CY	k vv r;	" uu = y direction
CZ	k vv r;	" uu = z direction
END	;	end of body input

k	body key number
vv	vertex vector
uu	direction cosines of axis
rr	radius vector
hh	hight vector
r	scalar radius
d	scalar distance used in Hesse-form

Cards E:FORMAT(2I5,9(A2,I5)) Input zone cards

IMED medium number
use 1000 for internal void
-1 for external void
-2 to leave unspecified
777 to indicate start of subgeometry
999 to terminate zone input
blank on continuation lines

IREG region number (blank on continuation cards)
use IREG>0 for normal regions
blank on continuation lines
IREG<0 to define three-digit part of the region number in connection with the GO operator

OPi,Ni up to 9 geometry conditions

Note! An input-zone consists of one or more code-zones.
Each code zone "CZ" describes a set of points in space:
[(Xcz,Ycz,Zcz)]
Code zones may be combined to one input-zone using the OR operator on card E.
A code zone is defined by one or more bodies, referenced by number "Ni".
If Ni>0, all points of the code-zone must lie inside body Ni; if Ni<0, all points of the code-zone must lie outside body Ni.

If OPi="GO" , then Ni refers to the input-zone card set which is called for subdividing the zone into subzones.
Input-zone card sets are numbered sequentialy. On input they are separated by a card with IMED=777.
Zone input is terminated by a card with IMED=999.

3.7 SIM Input Description

Detector input must be coded prior to the primary HET input, using CMD commands. The analysis input consist of:

- One DEFDET command for each detector wanted
- A SIMIO command to specify the binary output of the detectors
- A RUN command to switch back to the HET input.

At the end of run (i.e., after the HET input) additional commands can be used to normalize detector results etc. This input section must be terminated with the EXIT command.

There are some additional CMD commands which can be used in both analysis input sections to assist the user in defining data for binning, normalization and some other useful techniques, e.g. to enter data into arrays. These commands are described in the CMD command language summary given in Section 3.9.
Here we will describe an easy to use method only:

3.7.1 CMD Commands for SIM Input

DEFDET name, type, prt, ud, ebin, abin, IR1, IR2;

name - a four-character name used to identify all arrays associated with the detector

type - the integer representation of the detector type as described in Section 3.7.2.

prt - a real value indicating the particle type to be taken into account (not used for detector types 4,5, and 9)

use prt = 0 for protons
1 for neutrons
2 for π^+
3 for π^0
4 for π^-
5 for μ^+
6 for μ^-
7 for deuterons
8 for tritons
9 for ^{3}He ions
10 for α's

for flux and current detectors also prt=-1 can be used to score source particles only.

ud - is a cartesian unit vector, indicating a reference direction of the detector used for angle binning. It may be specified by three real constants.

ebin - is a list of energy-bin boundaries in [MeV] ordered from high to low (used in detectors 1-3 and 6-8, if desired).
ebin may be coded as a list of real constants enclosed in < >, all values separated by blanks.

abin - is a list of angles [^{o}] ordered from low to high for the angular binning in detectors of types 1-3 and 6-8. Abin may be coded as a list of real constants enclosed in < >, all values separated by blanks.

IR1 - is a list of region numbers as defined by the geometry defining the regions to be used with the detector.
IR1 may be coded as a list of integer constants enclosed in < > all values separated by blanks.

IR2 - is a second list of region numbers used to define surfaces.
For detector types 6, 7 and 9 a surface is identified by the common surface of two regions IR1(i)

Parameters of the DEFDET command, which are not used, may be omitted coding position holding commas only.

SIMIO [IOSIM iosim] [IORSY iorsy];

iosim - unit number of a binary file on which the detector results are to be stored after each batch and at the end-of-run in HERMES submission file structure.
If iosim is specified, data records are generated for each detector defined. The record names are constructed of the four-character detector name followed by the string "@EOB" at the end of batch and "@EOR" at the end-of-run.

iorsy - unit number of an RSYST file /1/ including the end of run results of the detectors.

RUN;

The RUN command terminates the first analysis-input section and returns control to HET-input reading from the primary input.

EXIT;

EXIT immediately stops the execution of the program

3.7.2 Available Estimator Types

(1) Secondary Particle Yield Detectors

DEFDET name,1,prt,[ud],[ebin],[abin],[ir1];
particles generated in INC
prt may be 0.,...,6. for p,n,π^+,π^0,π^-,μ^+,μ^-

DEFDET name,2,prt,[ud],[ebin],[abin],[ir1];
particles generated in evaporation and fission
prt may be 0.,1.,and 7,...10. for p,n,d,t,He^3,α

```
DEFDET   name,3,prt,[ud],[ebin],[abin],[ir1];
         particles generated in INC, evaporation and fission.
         prt may be 0.,...,10.
```

When we define:

- E - secondary particle energy
- ω - the angle between the secondary particle flight direction and the detector reference direction "ud"
- θ - the angle between the secondary particle flight direction and the direction of the projectile particle (ud must not be given)
- IR - the region where the collision occured.

then we can setup histograms of the following functions using the given DEFDET commands

Y	DEFDET name,type,prt;
Y(E)	DEFDET name,type,prt,,ebin;
Y(ω)	DEFDET name,type,prt,ud,,abin;
Y(θ)	DEFDET name,type,prt,,,abin;
Y(IR)	DEFDET name,type,prt,,,,ir1;
Y(E,ω)	DEFDET name,type,prt,ud,ebin,abin;
Y(E,θ)	DEFDET name,type,prt, ,ebin,abin;
Y(E,IR)	DEFDET name,type,prt,ebin,,ir1;
Y(E,ω,IR)	DEFDET name,type,prt,ud,ebin,abin,ir1;
Y(E,θ,IR)	DEFDET name,type,prt,,ebin,abin,ir1;
Y(ω,IR)	DEFDET name,type,prt,ud,,,abin,ir1;
Y(θ,IR)	DEFDET name,type,prt,,,abin,ir1;

Example 1: Measurement of the number of protons generated by evaporation and fission in regions 1 and 20 as function of energy Y(E,IR)

```
REAL EB(11);
DATA EB=<100. 90. 80. 70. 60. 50. 40. 30. 20. 20. 0.>;
DEFDET PEVA,2,0.,,EB,,<1 20>;
```

This example also illustrates the use of auxiliary CMD commands, which help in defining data referencing them by name. The DATA statement could also be coded as

```
DATA EB=<100. A 10 -10.>;
```

using fast-array input format. Refer to CMD language summary for details. (Section 3.9)

Example 2: Measurement of the angular distribution of all seondary neutrons with respect to the z direction in steps of 10 degrees.

```
DEFDET NANG,3,1.,0. 0 .1.,,<0. A 9 10>;
```

again the binning data is coded in fast-array input format.

(2) Energy Deposition Detector

```
DEFDET name,4,,,,,[ir1];
```
energy and angle binning is not allowed
for detectors of type 4.
"prt" must not be specified.
ir1 may be used to specify the regions
where the detector is to measure the energy
deposition.

(3) Scintillation Light Detector

```
DEFDET name,5,,,,,[ir1];
```
energy and angle binning is not allowed;
"prt" must not be given
"ir1" may be used to specify the regions
where scintillation light is to be measured.

omitting "ir1" in detector types 4 and 5 results in a summary over the whole geometry

```
DEFDET name,4;
DEFDET name,5;
```

(4) Forward Current Detectors

Count of the number of particles of type "prt" passing through the region boundaries denoted by "ir1" and "ir2", optionally binned in energy and angle per source particle.
Particle types allowed are 0.,1.,2.,4.,5.,6. for p,n,$\pi^+\pi^-$, μ^+,μ^- and -1. for source particles

```
DEFDET name,6,prt,[ud],[ebin],[abin],ir1;
```
count particles leaving the regions ir1(i)
```
DEFDET name,6,prt,[ud],[ebin],[abin],,ir2;
```
count particles entering the regions ir2(i)
```
DEFDET name,6,prt,[ud],[ebin],[abin],ir1,ir2;
```
count particles passing from ir1(i) to ir2(i)

Consider

IS as the surface index according to ir1 and ir2.
E as the particle energy on boundary
ω as the angle between the particle flight direction and the detector reference direction "ud"
ψ as the angle between the particle flight direction and the normal vector of the surface at the intersection point,

then we can setup histrograms of the forward current J^+ using the following DEFDET commands.

J^+(IS)	DEFDET name,6,prt,,,,[ir1],[ir2];
J^+(E,IS)	DEFDET name,6,prt,,ebin,,[ir1],[ir2];
$J^+(\omega$,IS)	DEFDET name,6,prt,ud,,abin,[ir1],[ir2];
$J^+(\psi$,IS)	DEFDET name,6,prt,,,abin,[ir1],[ir2];
J^+(E,ω,IS)	DEFDET name,6,prt,ud,ebin,abin,[ir1],[ir2];
J^+(E,ψ,IS)	DEFDET name,6,prt,,ebin,abin,[ir1],[ir2];

Example 1: Count all μ^- escaping from the geometry.
The external void has region number 99.
DEFDET MUES,6,6.,,,,,<99>;

Example 2: Compute a double differential spectrum of n entering regions 1 and 2 with respect to the z direction in 1 MeV energy bins and 30^o angle bins.

```
DEFDET NUES,6,1.,0. 0. 1.,
   <1000. A 999 -1.>
   <0. A 7 30.>,,<1 2>;
```

(5) Forward Surface Flux Detector

Measurement of the flux of particles of type "prt" passing through the common region boundaries denoted by "ir1" and "ir2" per source particle,
optional energy and angle binning is provided. Particle types allowed are 0.,1.,2.,4.,5.,6. for p,n,π^+,π^-,μ^+,μ^- and -1. for source particles.

DEFDET name,7,prt,[ud],[ebin],[abin],[ir1],[ir2];

for details of the command syntax refer to the description of the forward current detector.

(6) Tracklength Flux Detectors

Measure the (volume integrated) flux of particles of type "prt" in the regions specified by "ir1". Optional energy and angle binning is provided.
Particle types allowed are 0.,1.,2.,4.,5.,6. for p,n,π^+,π^-, μ^+,μ^- and -1. for source particles.

```
DEFDET name,8,prt,[ud],[ebin],[abin],[ir1];
```

When ω is the angle between the particle-flight direction and the detector-reference direction "ud"
and E is the particle energy
and IR is the considered region
then histograms of the flux ϕ [cm] can be defined as:

```
φ            DEFDET name,8,prt;
φ(E)         DEFDET name,8,prt,,ebin;
φ(ω)         DEFDET name,8,prt,ud,,abin;
φ(IR)        DEFDET name,8,prt,,,,ir1;
φ(E,ω)       DEFDET name,8,prt,ud,ebin,abin;
φ(E,IR)      DEFDET name,8,prt,,ebin,,ir1;
φ(ω,IR)      DEFDET name,8,prt,ud,,abin,ir1;
φ(E,ω,IR)    DEFDET name,8,prt,ud,ebin,abin,ir1;
```

(7) Detector for Particle Energy Passing Given Surfaces

This detector counts for the energy of all particles passing through a given surface. All particle types are considered simultaniously. "prt" need not be specified. Energy and angle binning is not provided.

```
DEFDET name,9,,,,,ir1;
       counts particle energy of particles having
       region ir1(i)
DEFDET name,9,,,,,,ir2;
       counts particle energy of particles entering
       region ir2(i)
DEFDET name,9,,,,,ir1,ir2
       counts particle energy of particles passing
       from ir1(i) to ir2(i)
```

When IS is the surface index as requested by ir1(i) and ir2(i) a table of energy E^+ is generated

E^+(ptyp,IS)
with ptyp is p n π^+ π^- μ^+ μ^-

3.8 STATIST Input Description

STATIST input/output is illustrated in Fig. 3.5.

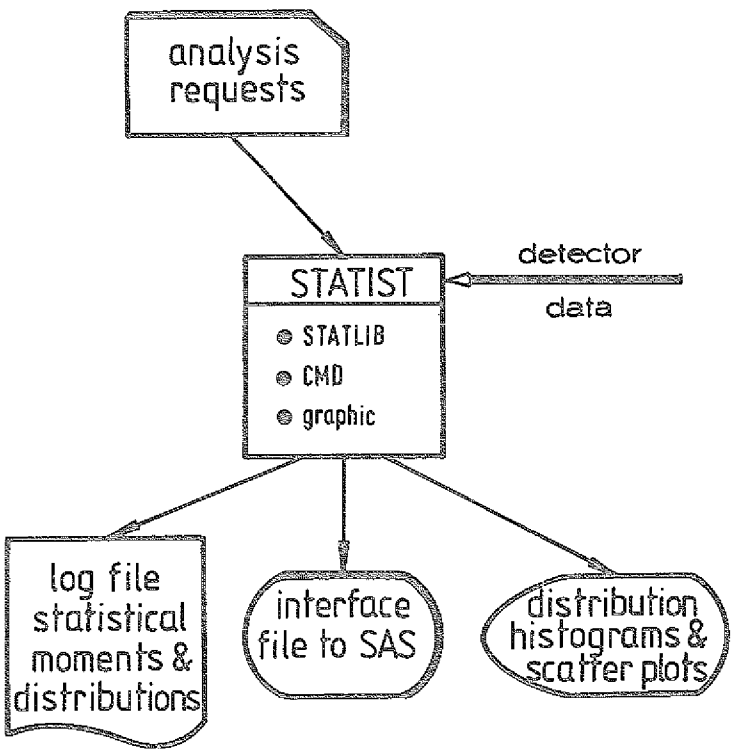


Fig. 3.5: STATIST input-output

STATIST input consists of

- one ore more HERMES submission files containing detector output data from Monte Carlo runs,
- a command file containing the user requests of how to select, combine and present the data stored on the submission files. The command file is read from unit 5 and must be coded in CMD command language (see Section 3.9).

3.8.1 Structure of the STATIST Command File

(1) Initialisation Section

The user must allocate array variables to keep data that are loaded from submission files, data computed in the data entry section or static arrays like weighting tables etc.

(2) Data Entry Section

This section represents a loop over all events (batches). It comprises commands to
- load data from submission files,
- for arithmetical and logical operations on loaded data, resulting in a set of variables V_i of each event on a file.

(3) Presentation (Analysis) Section

In this section the user can request histograms of
- the frequency distribution functions of V_i,
- the statistical moments of V_i,
- analysis of correlations between variables.

3.8.2 Syntax of STATIST Commands

The commands used in STATIST are CMD commands; for a complete description of all CMD commands refer to the CMD command language summary (Section 3.9).

(1) Initialization Section

Allocation of arrays:

REAL name (n_1,n_2,n_3) [,...];
INTEGER name (n_1,n_2,n_3) [,...];

Array specification is done like in FORTRAN, upto 3 dimensions are allowed.

Initialization of arrays:

DATA name = <list of data elements>;

only one array can be initialized in a DATA command. Subsequent DATA commands for the same array name overwrite the preceeding assignment.
The list of data elements may include constants and symbolic sequences of constants (like Rnv for repeat constant v n times or Anv for add n-times constant v).

(2) Data Entry Section - Event Loop

This section begins with the STATIN command:

STATIN nv,neut;

STATIN establishes a buffer for "nv" variables and "nevt" events.

LOAD unit, record name, array;
scans the HERMES submission file associated with unit number "unit" for the next occurence of a data record named "record name" and reads this record into "array".

SET dest = srs_1 [srs_2][+...];d

dest may be a variable name of dimension 1,
a subscripted array name.

srs_i may be a variable of dimension 1,
a subscripted array name,
a constant.

SET can be used to compute linear combinations of loaded data items or to apply weights.

DOT d = s_1*s_2 [(n_1,n_2,n_3)];

d array name of the destination matrix
s_i array names of the source matrices
(n_1,n_2,n_3) if coded, then the dimensions of the arrays d, s_1 and s_2 are temporarily overwritten and
$d(n_1,n_3)=s_1(n_1,n_2)*s_2(n_2,n_3)$ is calculated.
DOT calculates the inner product (DOT product) of matrix s_1 and matrix s_2 and stores it into matrix d.
DOT can be used to fold results with weighting tables.

Logical operations:

IF condition;
AND condition;
OR condition;

condition may be srs_1=srs_2
srs_1<srs_2
srs_2>srs_2

IR, AND, and OR set the condition code examined in the commands LIST and DROP.

DROP;
causes the current event to be discarded from the analysis. DROP is executed only if the condition code set by IF, AND, or OR is true.

LIST;
if the condition code set by IF, AND or OR is true, the current event variables V_i are printed.

VETO condition;

condition may be variable < constant
variable = constant
variable > constant

VETO can be used to discard an event from analysis.
VETO is equivalent to IF condition;DROP;

(3) Presentation (Analysis) Section

BIN iv, from, to, nbin, label;

iv - the variable index of the variable V to be used in construction of a histogram
from - lowest binning limit
to - highest binning limit
nbin - number of binning intervals to be used
label - descriptive text to be used in histogram output enclosed in inverse commas.

The BIN command results in the construction of a frequency distribution plot of V(iv), the computation of the empirical moments of V(iv) and the grouped moments of the associated histogram.

FIT iv, from, to;

iv - index of the variable V(iv) to be fitted
from - lowest value of V(iv) to be used in the fit.
to - highest value of V(iv) to be used in the fit.

FIT computes the parameters of a Gaussian fit of the frequency distribution function of V(iv) in the range <V(iv)<to.

SCAT ivx, ivy;

ivx - index of V(ivx) to be used on x axis
ivy - index of V(ivy) to be used on y axis.

SCAT generates a scatter plot of V(ivy) vs. V(ivx) in the value window as specified in the corresponding BIN commands. Scatter plots can be used to examine the correlation between variables. The correlation factor is computed automatically.

This section ends with the STATIST command.

STATIST ioplot, splot, IOSAS;

ioplot may be "print" to select line printer plotting or "plot" to select plotter software, which has to be user provided.
splot is the size of viewgraphs in cm, if plotter software is chosen. The features of this software are discussed in Appendix D.
IOSAS is a unit number to store V for analysis in SAS.
"STATIST" must be followed by "nv" BIN commands to specify the histogram parameters for the variable V(iv) with iv=1 to nv.

The STATIST input must be terminated by the EXIT command.

EXIT;

3.9 CMD Command Language Summary

3.9.1 CMD Syntactic Rules

In this chapter we describe the syntactic rules for all input parts entered in CMD command language.
CMD commands begin with a keyword (the command verb) identifying the function of the command, followed by a list of parameters and a semicolon (;).

```
verb parameter-list;
```

Parameters can be:

- integer constants	123, -7
- real constants	-4.5, 3.12E-10
- integer array constants	<2 9 15>
- real array constants	<1. 3. 7. 10.>
- character strings	'string'
- vector constants	$K 10. 1. 7.
- variable names	A, RVAL, I
- subscripted variable names	B(1,I,J)

- Integer, real and character constants can be entered as in FORTRAN read statements.
- Vector constants are used to enter the coordinates of points in space or directions in space. They can be entered 5 ways:
  1) x y z — in kartesian coordinates
  2) $K x y z — in kartesian coordinates
  3) $S r ϕ θ — in spherical coordinates
  4) $C r ϕ θ — in cylindrical coordinates
  5) $N — symbolic for $K 0. 0. 0.
     $X — symbolic for $K 1. 0. 0.
     $Y — symbolic for $K 0. 1. 0.
     $Z — symbolic for $K 0. 0. 1.

  x, y, z, r, ϕ, θ may be real constants, names of real variables and subscripted names of real array variables.

- Array constants are a list of constants and series expansions separated by blank and enclosed in < >.
  The following syntax items are allowed in array constant input:

c	- constant
R n c	- repeat n-times c
Q n m	- repeat n-times the last m values
A n c	- add n-times c to the last c
M n c	- multiply n-times with c
L c_1 c_2 c_3	- generate c's starting with c_1 to c_3 in steps of c_2

c_1 I n c_2	- interpolation of n values between c_1 and c_2 in n steps
F c	- fill array with c

3.9.2 Commands Used to Define User Variables

REAL name (n_1,n_2,n_3) [,...];
INTEGER name (n_1,n_2,n_3) [,...];

name - 1 to 8 characters first alphabetic
n_i - integer constant or variable specifying up to 3 dimensions

Data can be entered into user variables by the DATA command or the assignment statement.

DATA name = <array constant>;

array constants are explained above
Assignment statement;

destination=expression;

where destination may be the name of a single variable or a subscripted array name,
and expression may consist of constant-operands, variable or subscripted array variables connected by numerical operators like in FORTRAN. Some numerical functions can be used:

SIN, COS, TAN	sin, cos and tan of x
SIND, COSD, TAND	sin, cos and tan of angle in degrees
ARC, DEG	convert degrees to x and vice versa
EXP, LOG, LOG10	exponential and logarithmic
SQRT	square root
CEIL, FLOOR	next integer >x or <x, respectively

some functions are used in a different way than in FORTRAN conventions:

MIN(array)	minimum of all elements of an array
MAX(array)	maximum of all elements of an array
PMIN(array)	minimum of all positive elements of an array
PMAX(array)	maximum of all positive elements of an array
SUM(array)	sum of all elements of an array.

When the destination of an assignment statement is an array or a subarray written as

name(l_1:h_1, l_2:h_2, l_3:h_3),

then the assignment expression is evaluated for each subscript of the destination in a loop structure

```
DO i3=l3,h3
DO i2=l2,h2
DO i1=l1,h1
name (i1,i2,i3) = expression (i1,i2,i3)
ENDDO
```

In array assignments the expression may include arrays and subarrays. The subscripts of array operands are incremented automatically for each evaluation of the expression. When there are constant arguments, undimensioned variable operands or array operands arguments with fixed subscript in the expression their associated values are repeated for each evaluation of the expression. If the automatic incrementation of the subscript of an array operand runs out of the subscript range, the last valid subscript is used for all subsequent evaluations of the expression. See the following examples for illustration:

Example 1

```
A(3:5,1) = B(7:9) + C*3.;
results in
A(3,1) = B(7) + C*3.;
A(4,1) = B(8) + C*3.;
A(5,1) = B(9) + C*3.;
```

Example 2

```
REAL A(5), B(2);
A = B*5.;
results in
A(1) = B(1)*5.;
A(2) = B(2)*5.;
A(3) = B(2)*5.;
A(4) = B(2)*5.;
A(5) = B(2)*5.;
```

3.9.3 Commands Used to Control User Variables

QN;
: Query Names displays a list of all user variables allocated.

DN name;
: Display Name displays the values associated with a user variable

```
SAVE      name;
          writes a user variable on unit 7
```

3.9.4 Commands Used to Control the Program Flow of the Input Interpreter

```
EXIT;
          terminates the program.

RUN;
          return to the calling application program.

UNIT      iunit;
          continue input interpretation on unit iunit.

LOOP      n;
ENDL;
          the input between LOOP and ENDL is repeated n-times.

FOR ivar=i1,i2,i3;
ENDFOR;
          the input between FOR and ENDFOR is repeated like a
          FORTRAN DO-loop.
          ivar  name of an integer variable
          i1    integer start value for ivar
          i2    integer maximum (or minimum) value for ivar
          i3    integer increment of ivar

GOTO      line;
          continue interpretation of input at the specified line
          number of the input file.
```

The commands described above can be used to prepare input data for any application. The following commands, however, are application dependent.

3.9.5 Commands Used for Geometry Description

```
GEOCMP    nbody nzone nczone lenfpd lenma;
          nbody     integer  number of bodies used
          nzone     integer  number of zones used
          nczone    integer  number of c-zones used
          lenfpd    integer  length of floating point data needed
          lenma     integer  length of integer data needed
```

GEOCMP must be the first command used for geometry description.

Body definitions:

ARB k vv1...vv8 is1...is6;

k	integer	body reference number
vv1...vv8	8 vectors	corners of the body
is1...is6	6 integers	surfaces of the body; each surface is described by a 4 digit integer, (digits representing the index of the corner vvi)

definition of an arbitrary hexahedron, defining the 8 corners and describing all 6 surfaces by 4 the corners each.

SPH k vv r;

k	integer	body reference number
vv	vector	midpoint of the sphere
r	real	radius

definition of a sphere

RCC k vv hh r;

k	integer	body reference number
vv	vector	midpoint of the bottom surface
hh	vector	height vector
r	real	radius

defines a rectangular, circular cylinder starting at point vv; axis direction and height are given by hh; the radius is r.

REC k vv hh rr1 rr2;

k	integer	body reference number
vv	vector	midpoint of the bottom surface
hh	vector	height vector
rr1	vector	mayor half axis of the ellipsis
rr2	vector	minor half axis of the ellipsis

defines a rectangular, elliptic cylinder starting at point vv. The cylinder axis direction and height are given by vector hh. The major and minor half axes of the ellipsis are given by the vectors rr1 and rr2.

TRC k vv hh r1 r2;

k	integer	body reference number
vv	vector	midpoint of the bottom surface
hh	vector	height vector
r1	real	radius at vv (bottom surface)
r2	real	radius at vv+hh (top surface)

defines a truncated, rectangular cone starting at point vv with radius r1. Axis direction and length are defined by vector hh. r2 gives the radius at the end of the axis (hh).

ELL kv vv1 vv2 b;

k	integer	body reference number
vv1	vector	location of focus f1
vv2	vector	location of focus f2
b	real	length of the major axis

defines an ellipsoid.

BOX k vv hh1 hh2 hh3;

k	integer	body reference number
vv	vector	location of one corner
hh1	vector	direction and length of the 1st edge
hh2	vector	direction and length of the 2nd edge
hh3	vector	direction and length of the 3rd edge

defines a box with 3 pairs of parallel surfaces. Starting from one corner, 3 vectors are used to define the direction and length of the edges of the box. hh1, hh2 and hh3 must be orthogonal.

WED k vv hh1 hh2 hh3;

k	integer	body reference direction
vv	vector	location of one corner (from which heights are defined)
hh1	vector	direction and length of 1st basis edge
hh2	vector	direction and length of 2nd basis edge
hh3	vector	height vector of the prisma

defines a wedge. A wedge is a rectangular prisma with a rectangular triangle used as basis surface. vv denotes the location of the rectangular corner of the wedge, hh1 and hh2 describe the orientation and size of the basic triangle and hh3 the height of the prisma. hh1, hh2 and hh3 must be orthogonal.

RPP kxmin xmax ymin ymax zmin zmax;

k	integer	body reference number
xmin	real	minimum x coordinate
xmax	real	maximum x coordinate
ymin	real	minimum y coordinate
ymax	real	maximum y coordinate
zmin	real	minimum z coordinate
zmax	real	maximum z coordinate

defines a rectangular (coordinate-axis) parallel epiped (brick).

The following commands define semi-infinite bodies.

P k uu d;

k	integer	body reference number
uu	vector	normal direction of the plane
d	real	distance from coordinate origin

defines a plane in space using Hesse form. All points lying beyond this plane (looking into normal direction) are inside the body.

Special planes are:

PX k d;
PY k d;
PZ k d;

k	integer	body reference number
d	real	distance from coordinate origin
uu	-	is defaulted to the x, y or z direction, respectively

To simplify the preparation of input we also defined a shifted Hesse form.

PS k vv uu d;

k	integer	body reference number
vv	vector	shift vector
uu	vector	normal direction of the plane
d	real	distance from vv

Circular cylinders of infinit length have been implemented as:

```
C       k vv u r;
CX      k vv r;
CY      k vv r;
CZ      k vv r;
        k     integer    body reference number
        vv    vector     any point on the cylinder axis
        uu    vector     the direction of the cylinder axis
                         (may be defaulted by the command
                         verb to x, y or z direction)
        r     real       radius of the cylinder
```

END;
The body input must be terminated by the END command.

Commands used for geometry zone input:

```
ZONE    imed ireg code-zone [OR code-zone] [...] [GO subgo];
        imed  integer    medium number
                         -1 for black holes
                         <-1 to suspend assignment to a
                         subsequent sub-geometry
        ireg  integer    region number
                         if <0, 3 digit part of a 9 digit
                         compound region number
        code-zone one or more integer
                         body reference numbers
                         if >0, all points of the code-zone
                                lie within the body
                         if <0, all points of the code-zone
                                lie outside the body
        OR    keyword    logical operator to join code-zones
                         together to one input zone
        GO    keyword    indicates that the zone will be sub-
                         divided into subzones
        subgeo integer   identify the zone-card set to be used
                         for subdividing the zone
```

SUBGEO;
indicate the start of a new sub-geometry (zone-card set).
Zone card sets are sequentially numbered from 1 to 10.

ENDGEO;
indicates the end of the geometry description

GEOIN in, io;

in	integer	unit from which a precompiled geometry input is read
io	integer	unit for printed output

Commands used to test the geometry description: these commands can be used when the geometry is loaded using GEOIN.

LOOKZ vv;

vv	vector	location of a point to be examined

LOOKZ will printout the point, the region and medium number and the internally used zone number.

RAY ss uu d;

ss	vector	starting location of the ray
uu	vector	direction of the ray
d	real	length of the ray

RAY performes ray-tracing, starting at location vv in direction uu to the distance d.
Position, region number, medium number and zone number is printed out at vv, at each intersection point with a geometry boundary and at the end of the ray vv+d*uu.

The following geometry-test commands can be used on an interactive operating system providing the graphic software.

PICZ ss uu vv d;

ss	vector	midpoint of the picture
uu	vector	x-direction of the picture
vv	vector	y-direction of the picture
d	real	size of the picture

PICZ generates a picture plot of a plane cut through the geometry. The lower left corner of the plot refers to the space coordinates ss-d*uu-d*vv, the upper right corner to ss+d*uu+d*vv. The zone boundaries will be plotted.

PICM ss uu vv d;
PICR ss uu vv d;
PICM plots medium boundaries, PICR the region boundaries
PICZ, PICM, PICR will prepare a picture which can be completed interactively using the following commands.

POINT n;

n	integer	number of points to be examined

The user is prompted for n points (input with the graphic cursor). At each point the zone region or medium number will be indicated.

GRNXTF;

the picture is completed and the next picture can be prepared. GRNXTF offers the picture for output on an additional device.

3.9.6 Commands Used in SIM

See also Section 3.7.1

DEFDET name, type, part, ud, ebin, abin, ir1, ir2;

name	variable name	4 character name used to identify all arrays associated with the detector
type	integer	detector type 1 - cascade yield 2 - evaporation yield 3 - total yield 4 - energy deposition 5 - scintillation light 6 - forward surface current 7 - forward surface flux 8 - tracklength volume flux 9 - energy passing surfaces
prt	real	particle type 0 proton — 6 μ^- 1 neutron — 7 deuterons 2 π^+ — 8 tritons 3 π^0 — 9 ^{3}He ions 4 π^- — 10 α 5 μ^+
ud	vector	detector reference direction
ebin	real array	energy bin limits descending [MeV]
abin	real array	angle bin limits ascending [°]
ir1	integer array	list of region numbers (from region)
ir2	integer array	list of region numbers (to region)

3.9.7 Commands Used in STATIST

The STATIST commands are described in Section 3.8.2. Here we give only a summary of the command syntax.

```
STATIN    nv, nevt;
          nv     integer     number of variables
          nevt   integer     number of events

LOAD      unit, recordid, array;
          unit   integer     unit number of submission file
          record-id name     record name
          array name         variable name

SET       dest=srs1 [*srs2] [+...];
          dest   name        destination
                 subscripted name
          srsi   name        operands
                 subscripted name
                 constant

DOT       dest=srs1*srs2 [(n1,n2,n3)];
          dest   name        destination matrix
          srsi   name        source matrices
          ni     integer     temporary dimensions

IF        srs1 symbol srs2;
          srs1   name        items to be compared
                 subscripted name
                 constant
          symbol    <        comparison operator
                    =
                    >

AND       srs1 symbol srs2;
          see above

OR        srs1 symbol srs2;
          see above

DROP;

LIST;
```

```
VETO      srs1 symbol constant;
          srs1  name
                subscripted name
          symbol  <
                  =
                  >
```

Analysis Commands:

```
STATIST   ioplot, splot, iosas;
          ioplot PRINT      plot option
                 PLOT
          splot  real       plot size in cm
          iosas  integer    unit number for SAS output file

BIN       iv, from, to, nbin, label;
          iv     integer    variable index
          from   real       lower binning limit
          to     real       upper binning limit
          nbin   integer    number of binning intervalls
          label  string     descriptive text in inverse commas

FIT       if, from, to;
          iv     integer    variable index
          from   real       lower limit for Gaussian fit
          to     real       upper limit for Gaussian fit

SCAT      ivx, ivy;
          ivx    integer    index of x-variable
          ivy    integer    index of y-variable
```

3.9.8 Commands Used for Graphic Output

CMD includes an interface to the KFA graphic software called GR software. Since this software cannot be installed at any other installation, a functional description of the GR subroutines is given in Appendix D. We, however, provide some routines to simulate a subset of the GR software on a simple line printer.

```
GRSTRT;
          turn on graphic software

GREND;
          turn off graphic software
```

```
CHHEAD   'chart-title';
         define the chart title

CHXAXS   scale,from,to,'title';

CHYAXS   scale,from,to,'title';
         define the chart axis
         scale     may be LIN or LOG for linear or logarithmic
                   scaling of the axis
         from      lower limit for the axis
         to        upper limit for the axis
                   if 'from' or 'to' is not given, it will be
                   set automatically
         "title"   text to be written at the axis

CHCURV   x,y,colour,symbol,line,'text';
         define a
         x         real array of abscissa
         y         real array of ordinates
                   given as variable name or array constant
         colour    integer value defining the colour of the
                   curve
                   1  black
                   2  red
                   3  blue
                   4  green
         symbol    integer value defining the symbol to be
                   drawn at each point x_j,y_j
                   0  no symbol
                   i  symbol number i (maximum 13)
         line      0  no lines between points
                   1  straight lines between points
         'text'    is a descriptive text which will be plotted
                   in the legend field of the chart.
                   The text appears in the same colour as the
                   curve and will be preceded by a piece of
                   line and the matching symbol.

CHBARS   x,y,colour,symbol,line,'text';
         define a bar-curve (histogram)
         x         real array of group limits
         y         real array of ordinates per group
         colour    integer value defining the colour
                   1  black
                   2  red
                   3  blue
                   4  green
```

symbol integer value defining a symbol to be placed in the group midpoints
0 no symbol
i symbol number i (maximum is 13)
line 0 no bars drawn
1 draw bars
'text' function description to be placed in the legend field of the chart

CHLGND colour,symbol,line,'text';
define a text to be placed in the legend field of the chart
colour integer value defining the text colour
1 black
2 red
3 blue
4 green
symbol integer value defining a symbol to prefixed to the text
0 no symbol
i symbol number i (maximum 13)
line integer value defining a piece of line as prefix to the text
0 no line
1 draw line
'text' text to be placed in the legend field of the chart

CHNEXT;
show current chart and clear chart-memory

CHART;
invoke a chart input panel.
The panel summarizes the above chart commands. It can be used on VM/CMS systems and uses the VM/CMS editor and system product interpreter REXX.

3.10 References Chapter 3

/1/ R. Rühle
RSYST, Modulares Programmsystem zur Reaktorberechnung
IKE-4-12 (1973)

/2/ C.E. Burgart
Capabilities of the MORSE Multigroup Monte Carlo Code in Solving Reactor Eigenvalue Problems
ORNL-TM-3662 (1971)

/3/ W.R. Nelson, H. Hirayama, D.W.O. Rogers
The EGS4 Code System
SLAC-265, December 1985

/4/ R.L. Ford, W.R. Nelson
The EGS-Code Systems: Computer Programs for the Monte Carlo Simulation of Electromagnetic Cascade Showers
SLAC-210, UC-32, June 1978

APPENDIX A
MODIFICATIONS OF THE ORIGINAL MONTE CARLO CODES USED IN HERMES

Below modifications to the original program versions contained in the HERMES system are described. The main emphasis was laid on better physics in the programs. Because these modifications are not published elsewhere, we give a detailed description here.

A.1 Modifications of HETC

A.1.1 Model for Elastic Scattering of Protons and Neutrons up to 20 GeV

(1) Introduction and Summary

Elastic scattering is usually not taken into account in HETC code calculations. While present versions of the code contain programming to allow the user to input elastic scattering cross sections (presently restricted to energies below 100 MeV and only for neutrons), such input data are not readily available. (Furthermore, the angular scattering distribution is assumed to be of the form $a+b\cdot\cos\theta$, which is very approximate.) Therefore, the elastic scattering capabilities of all present versions of the HETC code are incomplete, and almost all calculations are made with elastic scattering neglected, the assumption being that at high energies the angular change and energy loss from elastic collisions is small.

However, there are several situations related to accelerator shielding, visible energy in high energy physics calorimeters, heat deposition in materials etc. where elastic scattering effects may be important. Therefore, we have modified the HETC code to include in a general way the effects of high-energy elastic collisions to improve the physical models.

The approach used for arriving at neutron and proton high-energy elastic scattering cross sections and angular distributions for incorporation into HETC is described. Elastic cross-sections from several sources have been compared, and we have adopted neutrons values from the HILO library /1,2/ in the energy range from 15 MeV to 150 MeV, and values from the NASA library /3/ from 150 MeV to 20 GeV. For protons, cross sections from the NASA library are used above 100 MeV, and elastic scattering for protons at lower energies is neglected. An approximate expression based on the optical model is used for the scattered angular distributions. We have made optical model

calculations and comparisons with experimental data to check the validity of this approximate angular distribution, and find it to be sufficiently accurate. Also, the details of the HETC code modifications to implement elastic scattering are given.

(2) Assessment of Elastic Cross-Sections

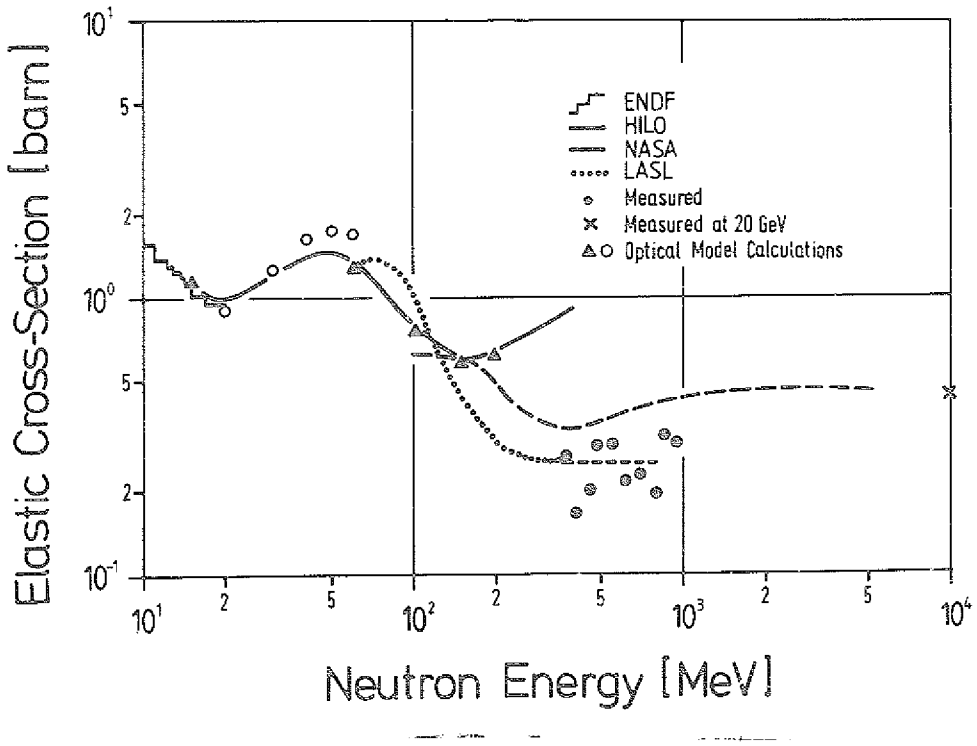


Fig. A.1: Comparison of neutron elastic cross sections for iron from various sources

Elastic cross-sections for neutrons have been collected from several sources for comparison. For example, Figure A.1 compares several sets of data for iron including: (a) Cross-sections from the low-energy (≤19.6 MeV) DNA library /4/, which is based on ENDF data. (b) Cross sections from the ORNL high-energy (≤400 MeV) HILO library /2/. These cross-sections were generated using the ORNL optical model code GENOA. (Explicit values for σ_{el} are not available from the library; these were provided to us by Dr. Alsmiller of ORNL.) (c) Cross sections from a NASA compilation for the energy range 100 MeV to 22.5 GeV /3/. These are theoretical estimates from numerical solutions of the coupled-channel Schroedinger equations. (d) Cross-sections from the LASL multigroup library /5/. (This library does not take into account elastic scattering; the elastic cross-section shown is the difference between the library values for the total and non-elastic cross sections.)

(e) Results from optical model calculations reported by Wilson /5/. (f) The measurements of Schlimmerling et al. /6/ in the ~400-1000 MeV range, and the measurements of Bellettini, et al., /7/ at 20 GeV. (g) Optical model calculations which we have made using the A-THREE code /8/ and the parameters used are also described later.

The main conclusion from Figure A.1 is that there are large differences in the data in the $\sim 10^2$-10^3 MeV range. In particular, the HILO values appear incorrect ≥150 MeV. (This is also the case for other elements. (This is meanwhile corrected by Alsmiller et al. /9/ in the HILO86 release.) To check this, we have made optical mode calculations using the A-THREE code for the same optical model parameters as used by ORNL in generating the HILO library, and we obtained essentially the same results as ORNL. Thus, this discrepancy in the HILO high-energy elastic cross sections is not attributable to the optical model code used by ORNL. The reason for the apparent error in the HILO cross sections at ≥150 MeV is probably that the optical model parameters used by ORNL, which were taken from the work of Becchetti and Greenless /10/ and based on fits to data <50 MeV are not applicable at high-energies.

The A dependence of the HILO elastic scattering cross section at high energies also differs substantially from the NASA values. For example, at 400 MeV, $\sigma_{el} \propto A^{2/3}$ for the HILO library, whereas $\sigma_{el} \propto A^{0.94}$ for the NASA library. (The NASA values are in good agreement with the measured /7/ dependence of $\sigma_{el} \propto A^{1.04}$ for energies ≥10 GeV.)

Note from Figure A.1 that the HILO and NASA cross sections agree at 150 MeV. At very high energies, the NASA cross sections are in very good agreement with the measurements of Bellettini, et al. /7/. Therefore, for incorporation into HETC to treat neutron elastic-scattering, we have made a tabulation of σ_{el} vs. E values for various A using HILO values in the energy range from 15 to 150 MeV and NASA values from 150 MeV to 20 GeV (with linear E interpolation and log-log A interpolation). The values used for both neutrons and protons are given in Tables A.1-A.3.

Table A.1: Input data used for high-energy neutron elastic cross sections (millibarns)

Energy	Element									
(MeV)	He	C	O	Al	A	Fe	Br	Ag	Ba	Pb
100	67	182	225	358	499	623	786	987	1162	1535
125	61	171	217	345	483	614	782	984	1161	1537
150	58	162	210	335	469	605	775	978	1155	1535
175	49	141	187	299	423	558	729	928	1106	1487
200	38	113	154	248	355	482	646	834	1006	1383
225	33	100	137	222	320	441	599	778	945	1316
250	30	90	125	202	292	406	558	729	892	1255
300	24	75	107	173	253	356	497	654	807	1152
400	23	70	98	161	235	331	464	611	757	1088
600	29	86	117	192	280	382	525	684	840	1184
1000	36	102	136	220	319	425	574	742	903	1254
2000	41	114	151	242	347	461	615	790	955	1314
5000	40	110	147	237	339	453	607	782	946	1306
10000	37	102	138	222	319	430	581	752	913	1268
22500	34	95	129	206	298	406	552	716	874	1223

Table A.2: Input data used for low-energy neutron elastic scattering cross sections (barns)

Energy	Element						
(MeV)	^{10}B	C	N	O	Na	Mg	Al
15	0.94	0.92	0.90	0.98	0.88	0.90	1.09
20	0.95	0.95	0.97	1.04	1.00	1.14	1.18
25	0.94	0.94	1.00	1.09	1.10	1.20	1.24
30	0.88	0.88	0.99	1.06	1.16	1.22	1.28
40	0.75	0.75	0.92	0.94	1.14	1.16	1.23
50	0.63	0.61	0.78	0.80	1.03	1.06	1.16
60	0.50	0.50	0.63	0.68	0.84	0.88	0.93
80	0.31	0.37	0.40	0.44	0.56	0.60	0.63
100	0.22	0.25	0.28	0.31	0.40	0.43	0.46

Energy	Element						
(MeV)	Si	S	K	Ca	Cr	Fe	Ni
15	0.72	0.93	1.08	0.89	1.10	1.18	1.32
20	1.00	1.08	1.24	0.94	0.95	0.98	1.00
25	1.08	1.19	1.34	1.07	1.10	1.09	1.08
30	1.23	1.25	1.31	1.25	1.30	1.27	1.24
40	1.27	1.30	1.38	1.51	1.63	1.65	1.64
50	1.18	1.23	1.28	1.53	1.77	1.80	1.83
60	1.01	1.04	1.15	1.17	1.30	1.34	1.38
80	0.67	0.73	0.82	0.85	0.96	1.01	1.05
100	0.48	0.54	0.61	0.63	0.73	0.78	0.81

Table A.3: Input data used for proton elastic collisions (millibarns)

Energy	Element									
(MeV)	He	C	O	Al	A	Fe	Br	Ag	Ba	Pb
100	67	182	225	365	524	639	811	1015	1204	1588
125	61	171	217	354	511	632	809	1013	1202	1583
150	58	162	210	342	495	622	802	1006	1196	1576
175	49	141	187	306	445	574	755	956	1054	1527
200	38	113	154	253	370	492	665	854	1036	1416
225	33	100	137	226	331	449	614	794	970	1344
250	30	90	125	204	301	412	576	742	910	1276
300	24	75	107	175	258	360	502	659	814	1158
400	23	70	98	161	236	331	464	610	575	1085
600	29	86	117	190	276	377	516	672	822	1158
1000	36	102	136	220	318	425	573	740	900	1251
2000	41	114	151	243	350	463	621	797	966	1330
5000	40	110	147	237	342	455	612	788	955	1319
10000	37	102	138	222	321	432	584	756	1009	1277
22500	34	95	129	207	298	406	553	717	876	1225

(3) Optical Model Calculations

To make predictions of σ_{el} and $d\sigma_{el}/d\Omega$, we have obtained an optical model code called "A-THREE" /8/ from Brookhaven National Laboratory and made calculations for various cases. The basic features of the code and the model parameters which have been used here are discussed briefly below.

(a) The A-THREE Optical Model Code

The A-THREE code predicts the total cross-section, elastic cross-section, and the angular distribution of the scattered particle for charged of uncharged incident particles. Basically, the code numerically solves the center-of-mass Schrödinger equation for a nuclear potential having the form

$$V(r) = V_{re}(r) + i\, V_{im}(r) + V_{so}(r)\vec{l}\,\vec{\sigma} + V_{coul}(r),$$

where the terms represent the real, imaginary, spin-orbit, and Coulomb parts of the potential. The following forms are allowed for specifying these potentials:

$$V_{re}(r) = -V_0 f_1(r) - V_1 f_2(r)$$

$$V_{im}(r) = -W_0 f_1(r) - W_1 g_1(r) - W_2 g_2(r)$$

$$V_{so}(r) = (h/m_\pi c)^2 \, V'_{so} h(r)$$

$$V_{coul}(r) = h_2(r)$$

where various functional forms for f, g, and h are allowed, such as Woods-Saxon, Gaussian, or arbitrary forms which are input point-by-point.

(b) Optical Model Parameters

The A-THREE code does not include values for the above parameters - these are supplied by the user for particular cases of interest, and are usually obtained from studies which have been made to infer optical model parameter fits from comparisons with experimental data.

We have made A-THREE code calculations using the parameters given by Becchetti and Greenless /10/. In terms of the above A-THREE variables, the Becchetti and Greenless parameters are (in MeV):

$$V_0 = 5.3 - 0.32E - 24(N-Z)/A; \quad V_1 = 0$$

$$W_0 = 0; \; W_1 = 0.22 \cdot E - 1.6; \quad W_2 = 13 - 0.25E - 12(N-Z)/A$$

$$V_{so} = 6.2$$

According to Becchetti and Greenless, if the energy and target variables are such that any of the above parameters are negative, they should be set to zero. For $f_1(r)$ and $g_1(r)$ a Woods-Saxon potential is used, and for $g_2(r)$ and $h(r)$ the derivation of a Woods-Saxon form is used - e.g.:

$$f(r,R,a) = [1 + \exp(r-R)/a]^{-1}$$

$$g(r,R,a) = 4a(df/dr)$$

For incident charged particles, a uniform charge distribution out to radius R_c is assumed for the Coulomb potential:

$$V_{coul}(r) = (Z \cdot z \cdot e^2/2R_c) \cdot [3-(r^2/R_c^2)], \text{ for } r \leq R_c$$

$$= Z \cdot z \cdot e^2/r, \text{ for } r \geq R_c$$

(Z,z are the charges of the incident particle and target).

W_2, V_{so}; and four sets of R and a in the expressions for f_1, g_1, g_2, and h.

It is important to note that the parameters given by Becchetti and Greenless are based on fits to experimental data for target nuclei having A > 40 and neutrons and protons with E < 50 MeV. However, they were used up to 400 MeV by ORNL in generating the HILO neutron cross section library. Note from the above expressions that V_0, W_1, and W_2 all become zero for E ≥ 170 MeV (using for example N, Z, and A for iron), and so both the real and imaginary terms become zero. Thus, the reason for the discrepancy in the old HILO elastic cross sections ≥ 150 MeV indicated in Figure A.1 appears to be because the optical model parameters used are not valid at such energies.

(4) Assessment of Angular Distributions for Elastic Scattering

Several approaches have been considered for obtaining the angular distributions for the elastically scattered neutrons or protons, namely: an approximate optical model distribution and a semi-empirical formula based on measurements at very high energies. While in principle the A-THREE code could be used to generate such angular distributions for use in HETC, there are two practical difficulties: (1) optical model parameters are not available for A-THREE input over the wide energy and target mass range of interest, and (2) a very large volume of data would need to be generated and processed. Therefore, the approach we have used is to test the applicability of the simple formulae by making comparisons for a small number of selected cases with A-THREE optical model calculations and, where available, experimental data. It should be noted that these simple formulae are needed only for predicting the shape of the angular distribution. That is, the absolute magnitude of the differential scattering cross sections is not needed for the Monte Carlo selections, as the normalization is provided by the σ_{el} values discussed in the previous section.

(a) Approximate Optical Model Distribution

For the simplified special case of treating the nucleus as a black disk of radius R diffracting the deBroglie wave length of the incident particle, a rather simple form for the elastic scattering differential cross section is predicted by the optical model (e.g., /11/):

$$d\sigma/d\Omega \sim R^4/\lambda\!\!\!^{-2} \left(\frac{J_1 \cdot [2 \cdot R \cdot \sin(\theta/2)/\lambda\!\!\!^{-}]}{2 \cdot R \cdot \sin(\theta/2)/\lambda\!\!\!^{-}} \right)^2$$

where

θ = center-of-mass scattering angle
J_1 = Bessel function of first kind, first order
R = $r_0 \cdot A^{1/3} + \lambda\!\!\!^{-}$
$\lambda\!\!\!^{-}$ = $\lambda\!\!\!^{-} \cdot c/p \cdot c$
$\lambda\!\!\!^{-}c$ = 1.9732×10^{-11} MeV cm
pc = $[E \cdot (E + 2m)]^{1/2}$

The value for r_0 in the above formula is somewhat of an adjustable parameter. We have used $r_0 = 1.4$ Fermis for all of the results shown here.

Figures A.2 and A.3 indicate how the angular distributions predicted by the above approximate formula vary with target nucleus and neutron energy.

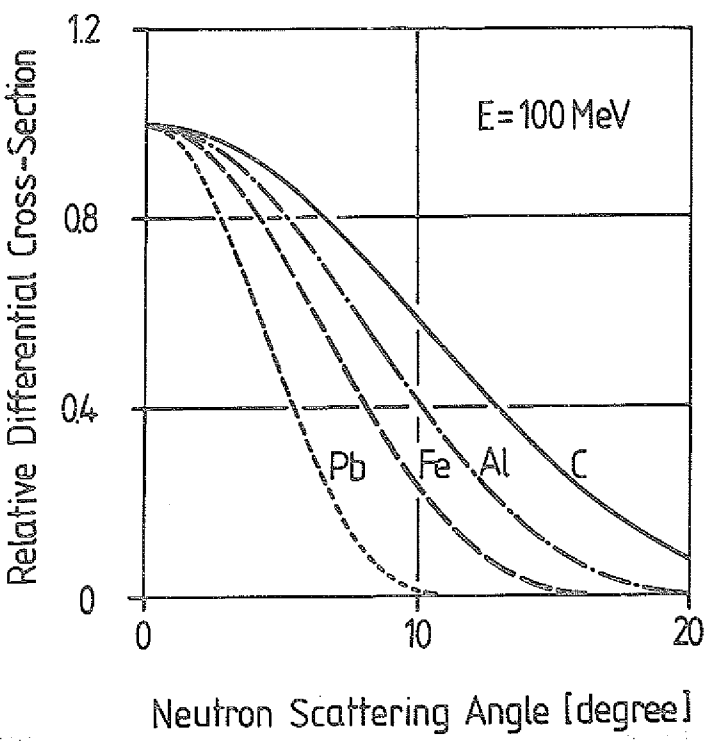


Fig. A.2: Predicted angular distributions of elastically scattered 100 MeV neutrons with various target nuclei

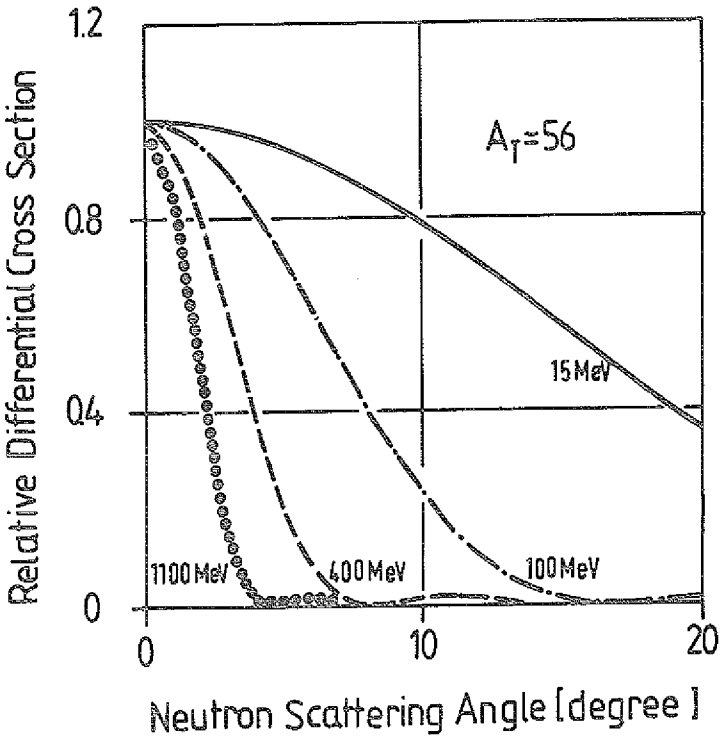
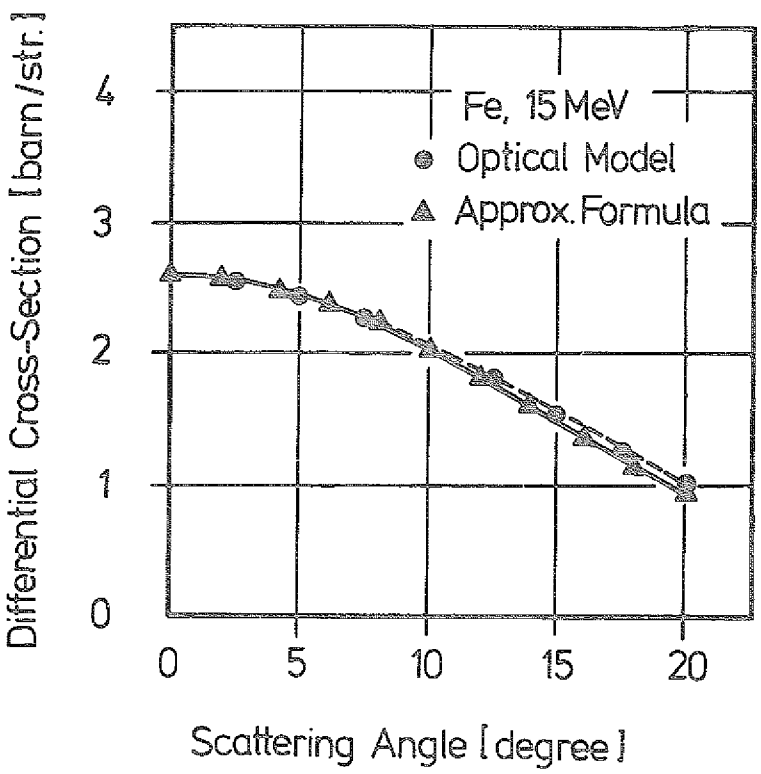


Fig. A.3: Predicted relative angular distributions of elastically scattered neutrons of various energies from iron nucleus

We have made some optical model calculations of angular distributions using the A-THREE code and the Becchetti and Greenless parameters to compare with the approximate formula. Comparisons for 15 and 100 MeV neutrons scattering on iron are shown in Figure A.4.

We have also compared the approximate angular distribution formula with the elastic scattering distributions measured by Bratenahl et al., /12/ for 84 MeV neutrons incident on Al, Cu, and Pb, and good agreement is obtained (Figures A.5-A-7).

Therefore, this approximate optical model expression for angular scattering distributions appears adequate for the energy range where the tests have been made ($\leq$ 100 MeV).



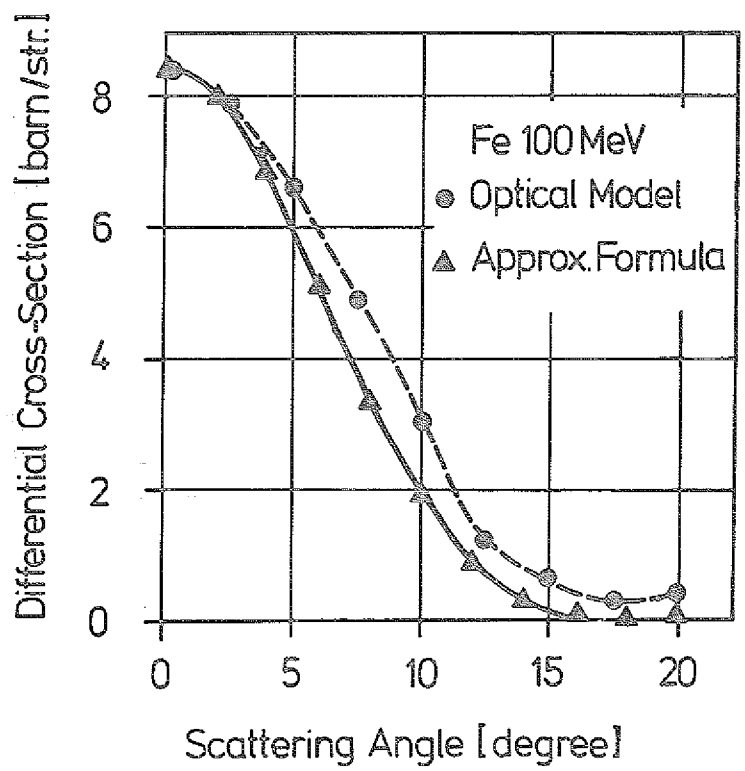


Fig. A.4: Comparison of angular distributions for 100 and 15 MeV neutrons elastically scattering from iron. Optical model results were computed using the A-THREE code and the potentials of Becchetti and Greenless. Distributions predicted by approximate formula normalization to optical model calculations at 0^{o}

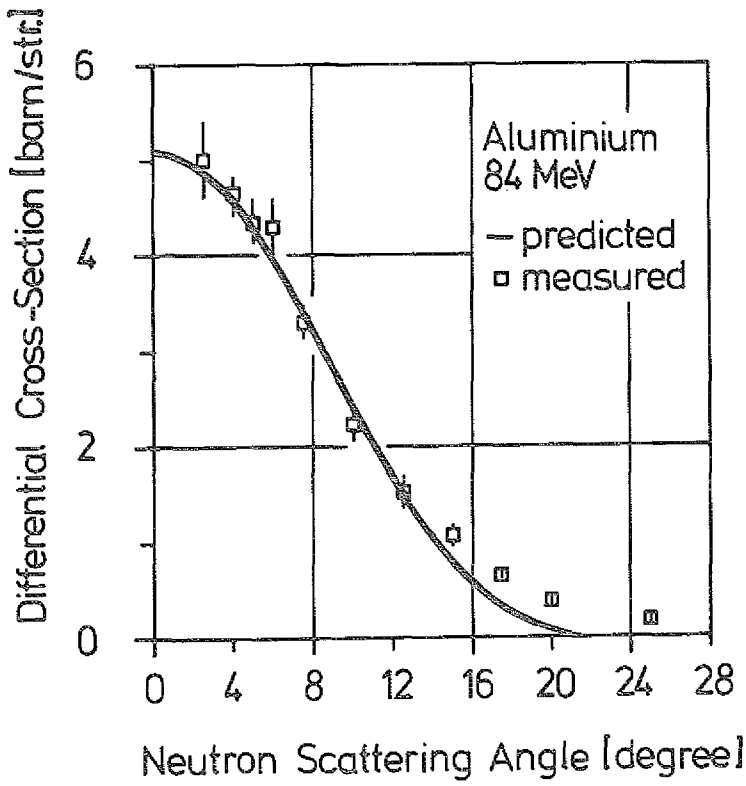


Fig. A.5: Predicted angular distribution of elastic scattering of 84 MeV neutrons compared with the measured data of Bratenahl, et al.

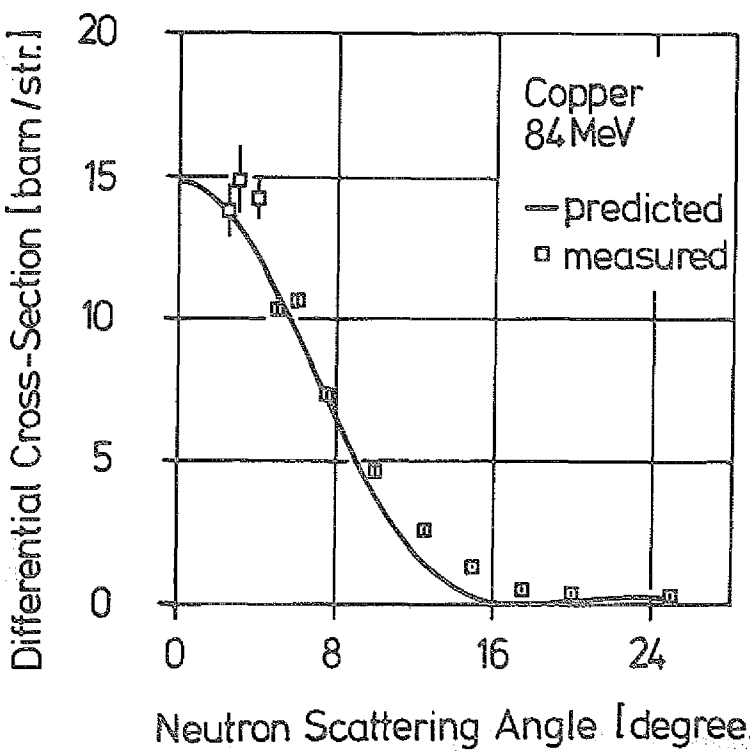


Fig. A.6: Like Figure A.5 but for copper

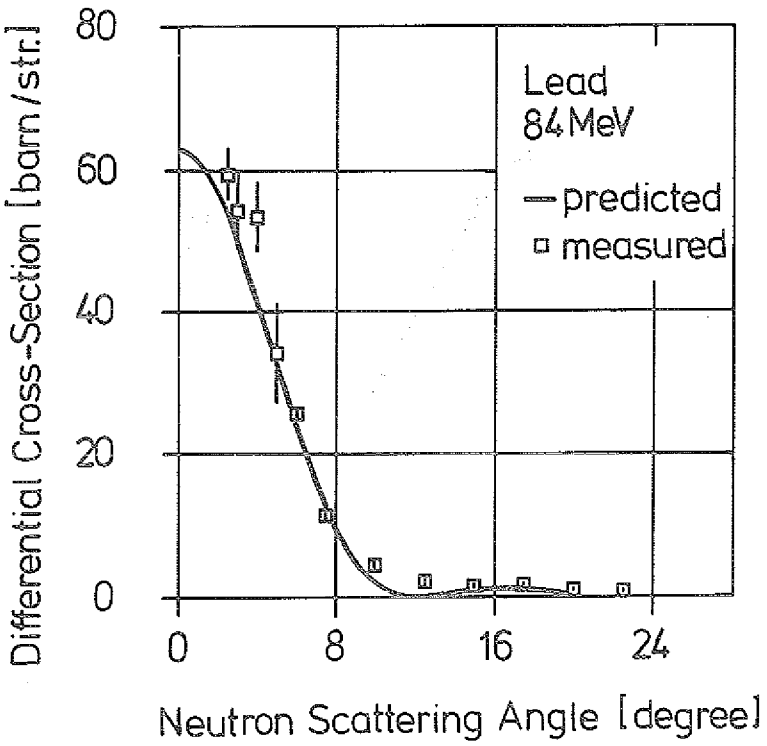


Fig. A.7: Like Figure A.6 but for lead

(b) Empirical Elastic Scattering Angular Distribution

The question arises as to whether the above angular distribution is accurate at higher (≥100 MeV) energies. Experimental data on angular distributions in the ~100 MeV to few GeV energy range are almost nonexistent. However, one series of measurements has been made by Bellettini et al. /7/ for 20 GeV protons on various target nuclei. Ranft /13/ has arrived at a semi-empirical formula to describe these data, which has the following form:

For $A < 62$,

$$d\sigma/d\Omega \sim A^{1.63}\exp(14.5 \cdot A^{0.66} \cdot t) + 1.4 \cdot A^{0.33} \cdot \exp(10t),$$

and for $A > 62$,

$$d\sigma/d\Omega \sim A^{1.63} \cdot \exp(60 \cdot A^{0.33} t) + 0.4 \cdot A^{0.40} \cdot \exp(10t),$$

where

t = momentum transfer in $(GeV/c)^2$ = $-2p^2(1-\cos\theta)$
p = momentum of scattered particle
θ = center-of-mass scattering angle.

(The total elastic cross section based on these measurements at 20 GeV is $\sigma_{el} \sim 6.38 \cdot A^{1.04}$ mb, which is in good agreement with the values of the NASA data.)

(c) Comparison of Angular Distribution Formulae

Example comparisons of the approximate optical model angular distribution with the empirical scattering formula are given in Figs. A.8-A.11 for iron, for neutron energies of 100, 250, 400, and 1100 MeV.

Comparisons show that the distributions predicted by the two formula are very similar for all energies and target nuclei. The largest difference is at low energy (100 MeV). As shown in Section A.1.1.4a) the approximate optical model formula gives good agreement with experimental data at 100 MeV. Therefore, there is some basis for adopting this formula at low energies, and since there is little difference between the two formula at high energies, we have incorporated the approximate optical model distribution into HETC for predicting scattering distributions at all energies.

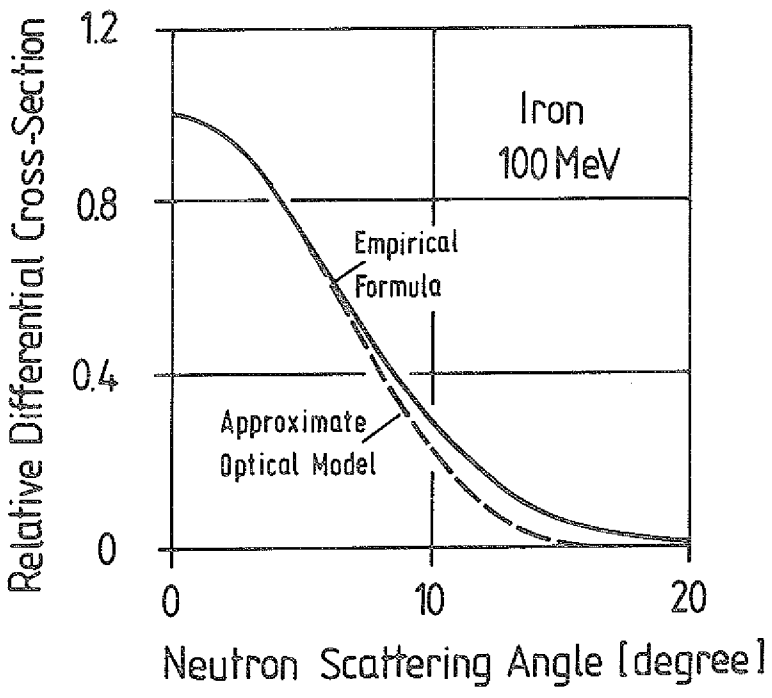


Fig. A.8: Elastic scattering angular distributions for iron, 100 MeV

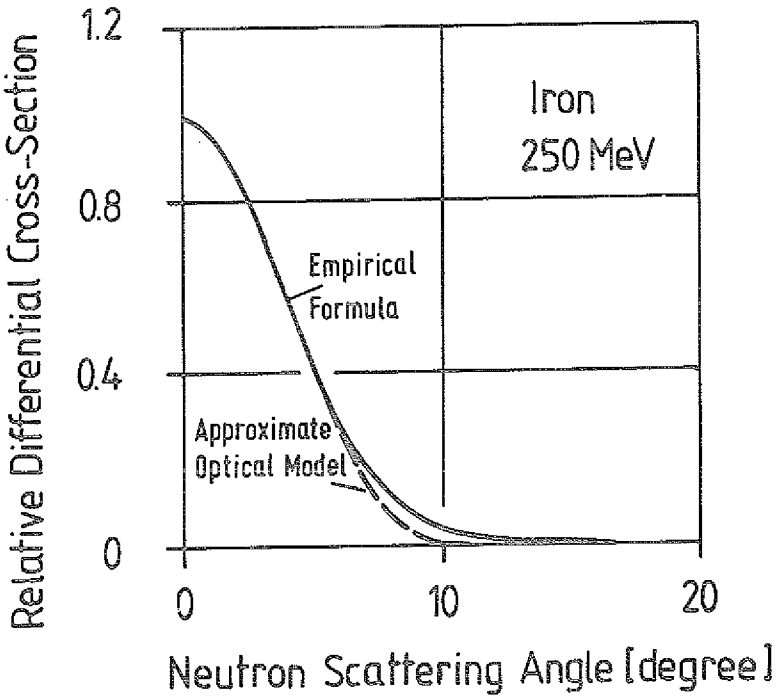


Fig. A.9: Elastic scattering angular distributions for iron, 250 MeV

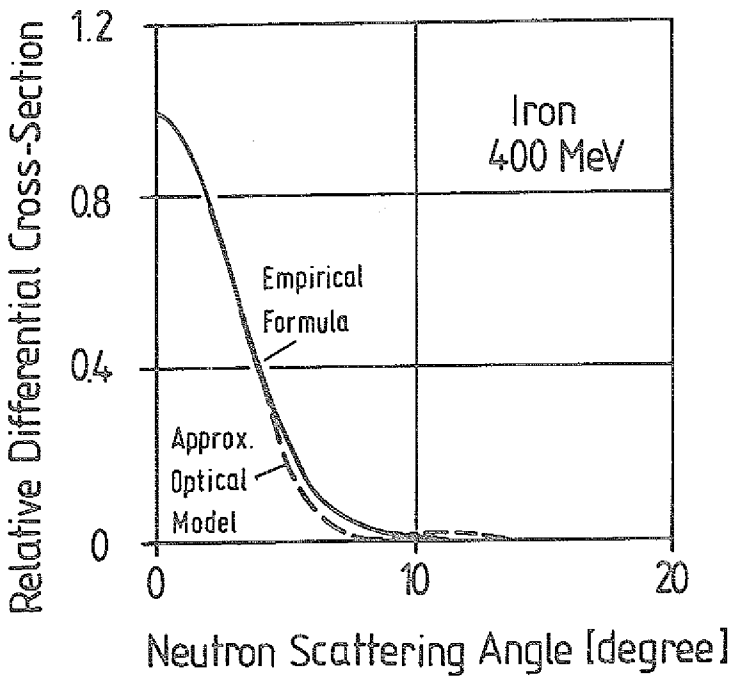


Fig. A.10: Elastic scattering angular distributions for iron, 400 MeV

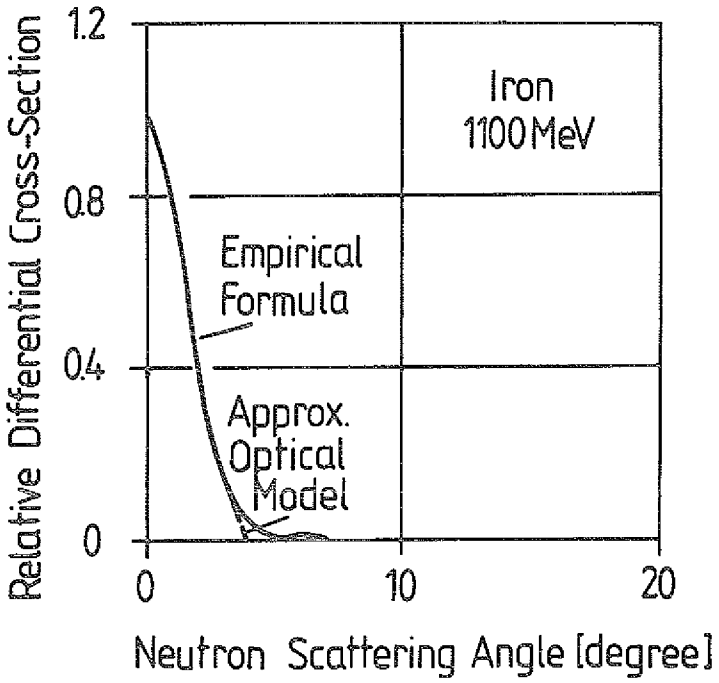


Fig. A.11: Elastic scattering angular distributions for iron, 1100 MeV

(5) Implementation of Elastic Scattering into the HETC Code

(a) Elastic Cross Sections Used

For computing elastic scattering in HETC, we have incorporated neutron cross-sections from the HILO library /2/ in the energy range from 15-100 MeV, and values from the NASA compilation /3/ at higher energies. The elastic cross section values used as HETC input are given in TABLES A.1-A.3, and the energy dependence is illustrated in Fig. A.12 for neutrons. Log-log interpolation of the data base values is used for both energy and target mass number interpolation. Fig. A.13 illustrates the target mass interpolation and extrapolation for several energies.

For protons, elastic cross-sections from the NASA compilation /3/ are used. These cross-sections are available only for ≥100 MeV, and elastic scattering by protons below 100 MeV is neglected in HETC. This is not an important approximation for most applications because protons in this energy range predominately slow down and stop due to ionization energy losses rather than undergo nuclear collisions. The proton cross section values are essentially the same as for neutrons, but separate values for protons have been incorporated.

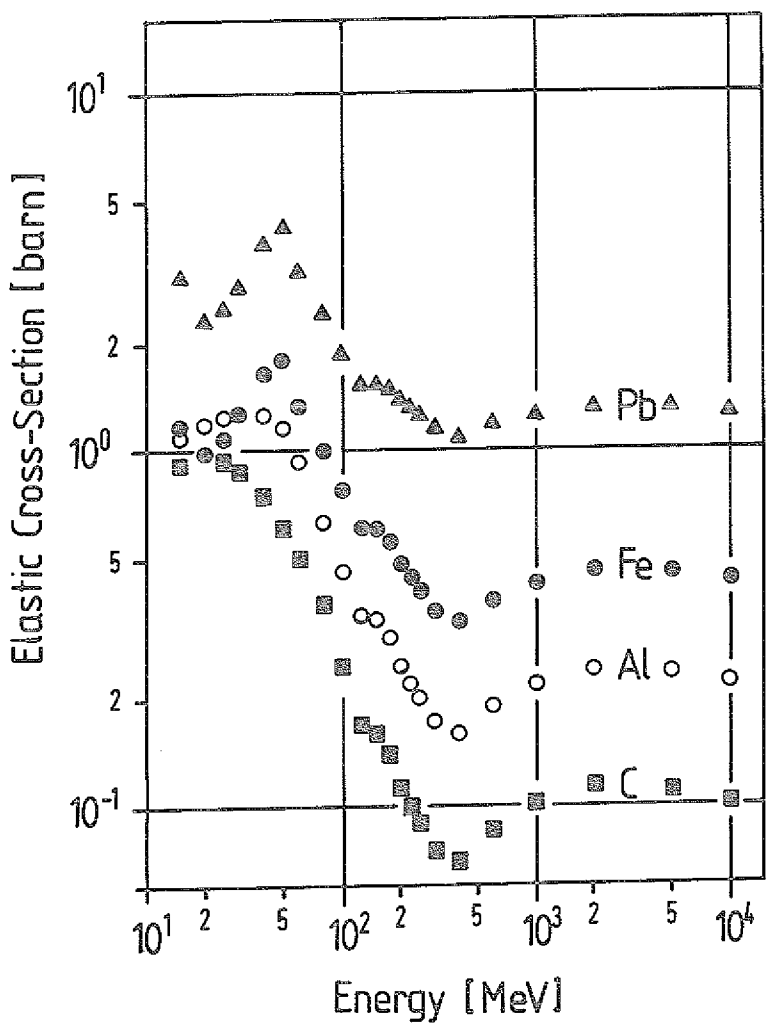


Fig. A.12: Energy dependence of neutron elastic scattering cross-sections (in barn) used as input, examples shown for carbon, aluminum, iron, and lead nuclei

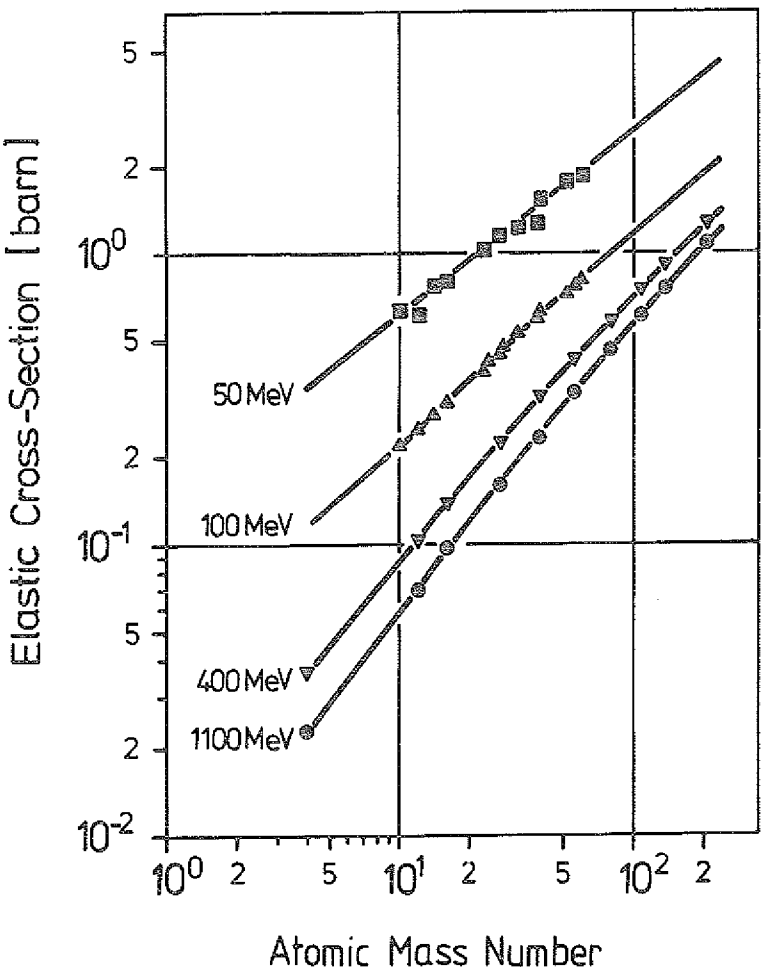


Fig. A.13: Target mass dependence of neutron elastic cross-section (barn) for several energies. The points are used in the data base, and the lines show the interpolation and extrapolation used

(b) Angular Distribution

The approximate optical model angular distribution formula discussed in Section A.1.1.4 is used for both neutron and proton scattering.

To determine the neutron or proton scattering angle, a random selection is first made of the variable x from the probability distribution function

$$f(x) \propto [J_1(x)/x]^2$$

where a series expansion is used for evaluating the Bessel function:

$$J_1(x)/x \sim 1/2 - x^2/16 + x^4/384 - x^6/18432$$

where the range of x is from 0 to the first zero of J_1, which is $x_{max} = (0.610)2\pi$. Random selections are made from a cummulative histogram of f(x) from x = 0 to x_{max}.

The angle (center-of-mass cosine) for a nucleon of energy E scattering from a nucleus of mass A is then (from Section A.1.1.4):

$$\cos\theta = 1 - x^2 \cdot 1/(2\cdot[7.095\text{x}10^{-3}\cdot A^{1/3}\cdot\sqrt{E(E+1878)} + 1]^2)$$

(c) HETC Code Modifications

The option for using elastic scattering is specified by setting a new input variable IELAS with the meaning:

IELAS = 0, don't use elastic scattering
= 1, use elastic scattering for neutrons only
= 2, use elastic scattering for neutrons and protons.

This is the only input variable relevant to elastic scattering; all cross-section values are incorporated in the code in data statements.

For neutrons, all elastic scattering collisions are "real". For protons, both "real" and "pseudo" collisions can occur for elastic collisions. Pseudo collisions are allowed for protons because the proton elastic-cross-section varies between events at different spatial points due to ionization. For proton elastic collisions, the same formalism as for non-elastic collisions is used. Thus, the path length is selected based on the maximum cross section with respect to energy. Then for a collision at the end of the path, the probability of a "real" collision is the ratio of the cross-section at the energy where the collision takes place to the maximum cross section. Using this method, the correct energy dependence of the cross section is preserved along the proton flight path.

If a real elastic collision occurs, the A and Z of the residual nucleus is set to be the same as the target nucleus, the number of "cascade" particles (NOPART) is set to 1, the evaporation particle array (NPART(I)) is zeroed, and EREC is set to the kinetic energy of the recoil nucleus. As a key to readily denote elastic scattering collisions, the excitation energy of the residual nucleus (which by definition is zero for elastic scattering) is set to -9999. Thus, for collision records, real

elastic scattering events can be identified by NCOL=2 and EX=-9999. (For pseudo collision records, no distinction is made between non-elastic and elastic collisions).

Deleted Subroutines

The following subroutines formerly used in treating elastic scattering have been removed: RELAS, CK, and SIGELS. Also, the common block ELSTIC, as well as all former input variables referring to elastic scattering, have been removed.

Modified Subroutines

INPUT: all reads of former elastic scattering removed, and calls two new subroutines ESNEUT and ESPROT (described below) added to get elastic-cross sections.

GETFLT: adds elastic cross section to non-elastic cross-section to get total cross-section for selecting flight path.

DKLOS: includes elastic cross-section to get proper total cross section for collision event selection.

CASCAD: determines whether collision is elastic; and if so, determines element struck, and calls new subroutine KINELS for kinematics calculation to get post-collision parameters.

ERUP: this subroutine usually increments a counter (NEGEX) if the residual excitation energy (EX) is negative; since the key for elastic scattering is EX=-9999, the NEGEX counter is not incremented for elastic collisions.

New Subroutines

SELCST: selects $\cos\theta$ for the elastically scattered nucleon by calling subroutine SELJ1 to select the parameter x; function FX computes $[J_1(x)/x]^2$

ESNEUT: provides σ_{el} arrays for neutrons; the values for σ_{el} from the HILO library are stored in subroutine HILONX and σ_{el} from the NASA library are stored in subroutine NASANX.

ESPROT: provides σ_{el} arrays for protons; calls subroutine NASAPX to obtain σ_{el} values based on the NASA library for protons.

KINELS: computes elastic scattering kinematics; given $\cos\theta$ (center-of-mass) for scattered nucleon, incident nucleon energy, and A of struck nucleus, this subroutine returns the scattered nucleon energy and direction cosines, and the recoil nucleus energy.

PSGELS: computes macroscopic elastic scattering cross-section for each element of medium; performs energy interpolation to get cross-section at end-of-path energy.

NSGELS: computes macroscopic cross section for neutrons, for each element in medium and total for medium.

A.1.2 Evaporation Model Modifications

The standard version of the HETC code (i.e., the version distributed by RSIC) contains version 4 of the EVAP evaporation model. The updated version described here will be refered to as EVAP-5

(1) Updated Input Data

In the evaporation model calculations, atomic masses are used in determining binding energies. These mass data (in terms of mass excesses) are stored on tape, read as input at the start of each transport calculation, and stored internally as the WAPS array, as defined in APPENDIX B.

EVAP-4 uses the evaluated 1964 Atomic Mass Table values /14/. At present the latest evaluated data are the 1977 Atomic Mass Evaluation by Wapstra and Bos /15/, and it is these data that have been put on the input data tape for EVAP-5.

In the standard EVAP-4, the WAPS (I,J) array was dimensioned WAPS (250,20), with I equal to the mass number of the nuclide J an index defining a particular isotope for a given A, and the following algorithm for retrieval:

$$J = A-2Z-J' + 10$$

$$J' = (A-1)/(1+124/A^{2/3})$$

It was found that this method did not properly represent the new data. That is the Z and A range for the above method did not cover the range of the input values. In EVAP-5, the WAPS array is dimensioned WAPS (25,11) and WAPS(I,J") denote nuclides with I=A (as before) but J"=1 represents a "starting" Z value for this A. Then WAPS (I,1) corresponds to Z_{min}, WAPS(I,2) corresponds to $Z_{min}+1$, etc. These ten Z values for each A then allow all of the Mass Table values to be contained in the WAPS array, as illustrated in Figs. A.14-A.16.

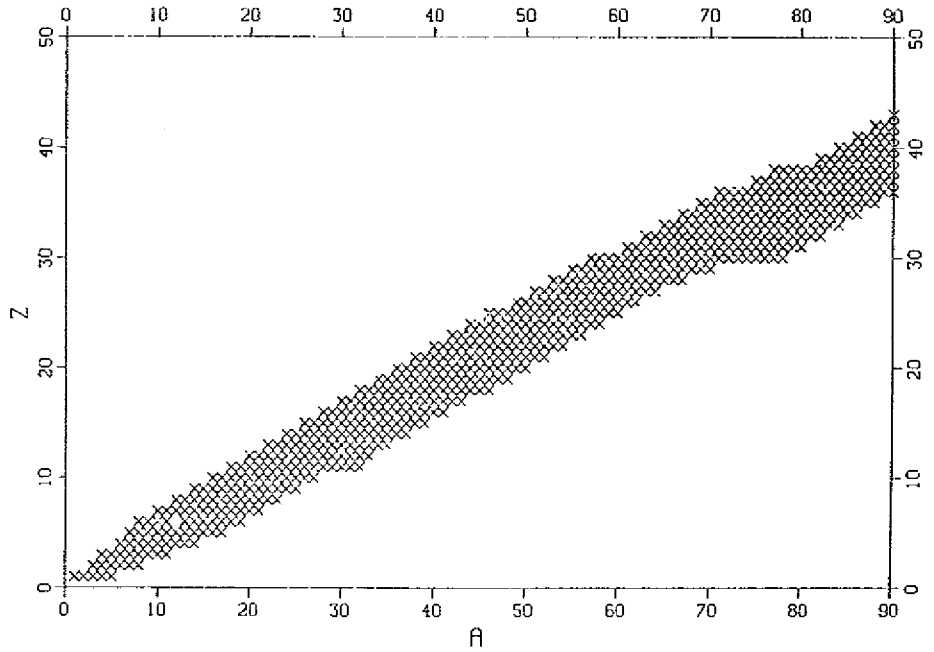


Fig. A.14: Nuclide A and Z range covered by updated input data for evaporation model. The symbols denote nuclides for which data are available and stored on the input tape. (Data for A=1-90 shown above; data for higher A in Figures A.15 and A.16)

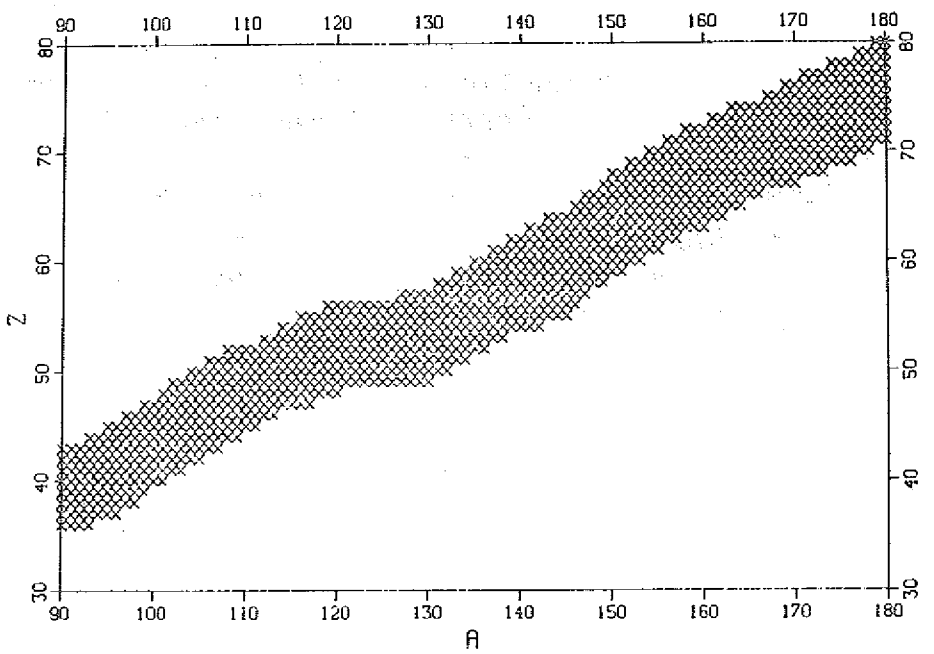


Fig. A.15: Nuclide A and Z range covered by updated input data for evaporation model. The symbols denote nuclides for which data are available and stored on the input tape. (Data for A=90-180 shown above, data for higher A in Figure A.16)

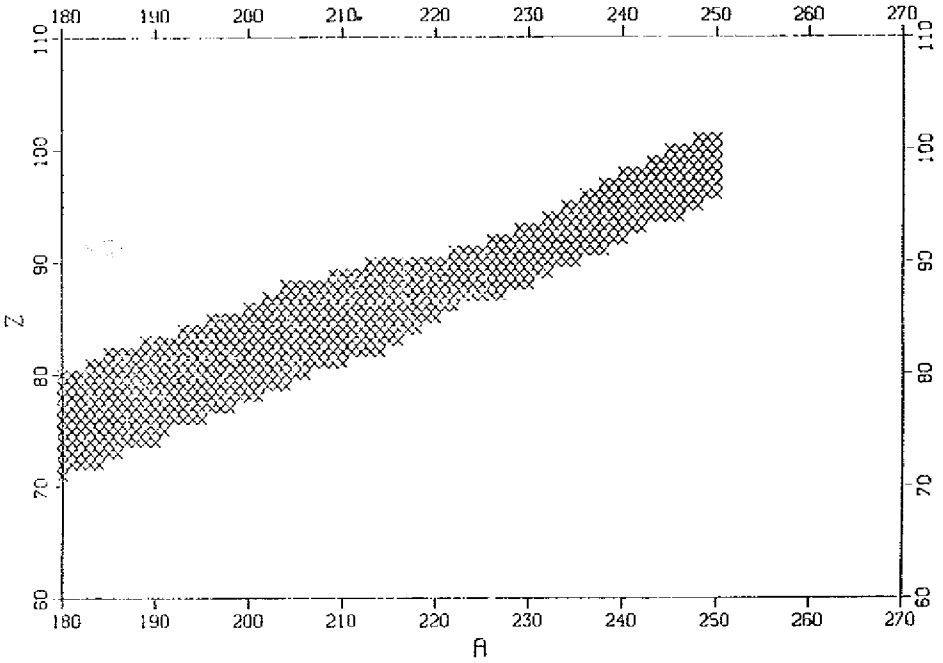


Fig. A.16: Nuclide A and Z range covered by updated input data for evaporation model. The symbols denote nuclides for which data are available and stored on the input tape (Data for A=180-250 shown above)

Another change was made in the procedure used when a nuclide mass is required that is outside of the range of the input data. The binding energy calculation involves the mass difference for two nuclides. In EVAP-4 if input data were not available for one or both nuclides, the Cameron semi-empirical mass formula (discussed in APPENDIX B) was used. Thus, in computing the mass difference, one mass could be computed from the mass formula and an input value used for the other nuclide. This can lead to what appear to be unrealistic mass differences. Thus, in EVAP-5, a consistent procedure is used - i.e., if one nuclide is outside of the range of the input data, both nuclide masses are computed using the mass formula. A new function routine,

```
FUNCTION QNRG (A1,Z1,A2,Z2)
```

computes the mass differences using this method.

(2) Level-Density Options Added

In EVAP-4 the level density parameter is computed as

$$a = A/B_0 \ (1+Y\Delta^2/A^2)$$

with B_0=8, Y=1.5, and Δ=A-2Z. The quantity in brackets differs little from unity, so the method assumes a linear mass dependence,

$$a \sim A/B_0 \ MeV^{-1}.$$

From experiments on nuclear level spacing, it is observed that the level density is strongly influenced by nuclear shell structure, with the densities for magic or nearly magic nuclei several orders of magnitude lower than for mid-shell nuclei /16/. Therefore, an input option has been added to EVAP-5 to use a method for specifying the level density parameter which takes into account shell effects.

Baba /16/ has compiled level densities from neutron resonance measurements for some 200 isotopes. These data are shown in Fig. A.17. These values (Table A.4) have been stored on the evaporation input data tape as the array APRIME (250), which is read immediately after the WAPS array. An input option allows the above method to be used, or a constant value for B_0 can be input.

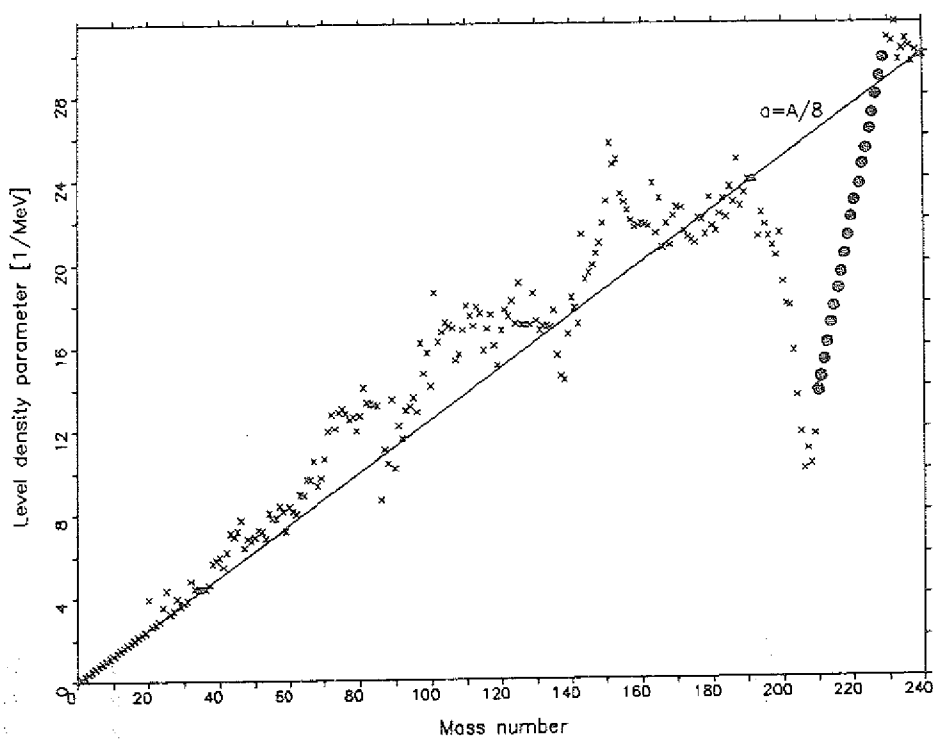


Fig. A.17: Level density parameters deduced by Baba /A.16/ from neutron resonance experiments (x symbols). The ⊙ symbol denotes our rather arbitrary interpolated values for masses not measured. The linear dependence of A/8 is usually assumed in HETC

Table A.4

Level density parameter values used as input for the evaporation model "variable B_0" option. The integer values are mass numbers and the other numbers are in the corresponding level density parameter values (in MeV^{-1}), as plotted in Fig. A.4

1	0.13	49	6.77	97	16.16	145	19.51	193	21.16
2	0.25	50	6.91	98	14.71	146	19.87	194	22.30
3	0.38	51	7.26	99	15.69	147	20.39	195	21.75
4	0.50	52	7.20	100	14.09	148	20.90	196	21.19
5	0.63	53	6.86	101	18.56	149	21.85	197	20.72
6	0.75	54	8.06	102	16.22	150	22.89	198	20.24
7	0.88	55	7.81	103	16.67	151	25.68	199	21.34
8	1.00	56	7.82	104	17.13	152	24.64	200	19.00
9	1.13	57	8.41	105	17.00	153	24.91	201	17.93
10	1.25	58	8.13	106	16.86	154	23.24	202	17.85
11	1.38	59	7.19	107	15.33	155	22.85	203	15.70
12	1.50	60	8.35	108	15.61	156	22.46	204	13.54
13	1.63	61	8.13	109	16.77	157	21.98	205	11.78
14	1.75	62	8.02	110	17.93	158	21.64	206	10.02
15	1.88	63	8.93	111	17.45	159	21.75	207	10.98
16	2.00	64	8.90	112	16.97	160	21.85	208	10.28
17	2.13	65	9.69	113	17.88	161	21.77	209	11.72
18	2.25	66	9.65	114	17.58	162	21.69	210	13.81
19	2.38	67	10.55	115	15.78	163	23.74	211	14.46
20	3.94	68	9.38	116	16.83	164	21.35	212	15.30
21	2.63	69	9.72	117	17.49	165	23.03	213	16.16
22	2.75	70	10.66	118	16.03	166	20.66	214	16.99
23	2.88	71	11.98	119	15.08	167	21.81	215	17.84
24	3.55	72	12.76	120	16.74	168	20.77	216	18.68
25	4.35	73	12.10	121	17.74	169	22.18	217	19.53
26	3.25	74	12.86	122	17.43	170	22.58	218	20.37
27	3.38	75	13.03	123	18.14	171	22.55	219	21.22
28	3.96	76	12.81	124	17.06	172	21.45	220	22.06
29	3.63	77	12.54	125	19.01	173	21.16	221	22.91
30	3.75	78	12.65	126	17.02	174	21.02	222	23.75
31	3.88	79	12.00	127	17.02	175	20.87	223	24.60
32	4.82	80	12.69	128	17.02	176	22.09	224	25.44
33	4.44	81	14.05	129	18.51	177	22.00	225	26.29
34	4.43	82	13.33	130	17.20	178	21.28	226	27.13
35	4.43	83	13.28	131	16.75	179	23.05	227	27.98
36	4.42	84	13.23	132	16.97	180	21.70	228	28.82
37	4.63	85	13.17	133	16.94	181	21.45	229	29.67
38	5.66	86	8.66	134	16.91	182	22.28	230	30.71
39	5.81	87	11.09	135	17.69	183	23.00	231	30.53
40	5.95	88	10.40	136	15.55	184	22.11	232	31.45
41	5.49	89	13.47	137	14.56	185	23.56	233	29.63
42	6.18	90	10.17	138	14.35	186	22.83	234	30.15
43	7.11	91	12.22	139	16.55	187	24.88	235	30.65
44	6.96	92	11.62	140	18.29	188	22.64	236	30.27
45	7.20	93	12.95	141	17.80	189	23.27	237	29.52
46	7.73	94	13.15	142	17.05	190	23.89	238	30.08
47	6.41	95	13.57	143	21.31	191	23.92	239	29.80
48	6.85	96	12.87	144	19.15	192	23.94	240	29.87

(3) Option for the Treatment of Emitted-Particle Angular Distribution

In the standard HETC code using the EVAP-4 model, emitted evaporation particles are assumed to be isotropic in the laboratory system. There are two effects which can cause the actual distribution to be non-isotropic: (a) for high bombardment energies, the nucleus which evaporates the particles can have rather large angular momentum, and (b) the evaporating nucleus is in movement during particle emission with a certain recoil energy. The dominate effect on emitted angular distribution is the nuclear recoil rather than angular momentum /17/. To indicate the general functional dependence and magnitude of anisotropy, an approximate relationship for the angular distribution (in lab system) of evaporated neutrons is /17/

$$W(\theta) \sim 1 + (v^*/v)\cos\theta$$

where v is the neutron velocity and v^* is the center-of-mass velocity. As an example, for 600 MeV protons incident on a lead nucleus, the angular distribution of 1-MeV neutrons then is $W(\theta)=1+0.23\cos\theta$, so the $W(0^o)/W(90^o)$ anisotropy is roughly 20% for this case, and larger for lighter nuclei.

Los Alamos has recently modified their version of HETC to take into account the recoil direction of the residual nucleus during evaporation. Evaporated particle directions are selected from an isotropic center-of-mass distribution, and this angle and the recoil direction are transformed to give non-isotropic angular distributions in the laboratory system. These modifications were kindly provided to us by. R.E. Prael of Los Alamos, and have been incorporated in the KFA HETC version as an option. This required changes to the following subroutines: MAIN, DATAHI, ERUP, RECOIL, DRES, and WTAPE. If this option is selected, the direction cosines U, V, and W are written on the history tape for each evaporated particle. We have made only a few runs using this option; it seems to work properly but has not been throughly tested. It should be noted that this option is available at present only when using EVAP-5; it is not incorporated in the RAL fission model.

(4) Option for High-Energy Fission

The fundamental basis of all of fission models is the statistical model of fission developed by Fong /18/. Basically, the assumption is that the fission process is "slow" (i.e., the nucleus exists in an equilibrium state at any time), so the pro-

bability of a particular fission mode (state of the fission fragments) is proportional to the density of quantum states at the time of splitting. From the Fong theory, the fission mode probability is expressed as a function of eleven variables: $N(A_1, A_2, Z_1, Z_2, C, D, K, E, E_1, j_1, j_2)$, where the subscripts denote the fission fragments; A, Z, and j denote mass number, charge number and angular momentum, and the remaining are energy variables (C, Coulomb; D, deformation; K, translational; E, total; and E_1, excitation).

The high-energy fission models developed differ in the approximations made in arriving at a practical implementation of the above general expression and in the physical data used. It is not the purpose here to evaluate these various approximations. Indeed, many of the approximations are interdependent, making judgement of the practical importance of particular assumptions difficult. From evaporation theory (e.g., /19/), the probability of particle emission of type i with kinetic energy E is expressed as

$$P_i(E) \propto (2S_i+1) \cdot m_i \cdot E \cdot \sigma_{ci}(E) \cdot \omega\ (E^*),$$

with S_i= spin, m_i= mass, and σ_{ci}= cross section for compound nucleus formation in the inverse reaction. The level density for excitation energy E^* is given by

$$\omega\ (E^*) = \omega_0 \cdot \exp(2(a \cdot E^*-\delta)^{1/2}),$$

where ω_0 and a are constants for a given nucleus and δ is the pairing energy. The level density parameter, a, is given by

$$a = A/B_0(1+Y(A-2Z)^2/A^2),$$

and Y~1.5. From various analyses, B_0 is in the range from about 8 to 20 MeV (e.g., /19/).

The high-energy fission model of the Rutherford and Appleton Laboratories developed by F. Atchison was implemented in the code /20/ (details in Refs. /21,22/). From the intranuclear cascade we get the high energy products plus the residual nucleus which is in a highly excited state. Next the question is whether or not it is undergoing high energy fission. If not, a particle is evaporated (i.e., a neutron, proton etc.) and the same question is asked again for the remaining, still excited nucleus. In this way all steps of de-excitation are treated. On occurence of fission, two excited nuclei are produced which then decay again by evaporation. In other words, the fission neutrons come from exactly the same processes as the other eva-

poration neutrons, except that the masses of the evaporating nuclei are lower. The problem in implementing a code in HETC which takes fission into account is, of course, that one has to make some decisions, namely whether or not fission is to occur and what will be the scission parameters of the fragments (mass, charge, recoil, excitation).

The Rutherford Appleton Laboratory fission model written by Atchison is based on several general assumptions:

- Fission competes at all stages of nuclear de-excitation, with fission probabilities that vary with the nuclear state.
- Post-fission parameters depend only on the state of the nucleus at the time of fission and not on the previous sequence of events leading to the state of the nucleus at the time of fission.
- Only binary fission occurs. While ternary and high-order fission have been observed (e.g., /23/), they occur with probabilities which are insignificant for the practical applications of interest here.
- Nucleons and charge are conserved between the fissioning nucleus and the two fission fragments. Thus, low-energy neutrons are not emitted at the time of fission, but arise either from the de-excitation of the nucleus before fission following the intranuclear cascade, or from the de-excitation of the fission fragments.

Specific assumptions used in the RAL model to determine the fission probability and post-fission parameters are given below.

(a) Fission Probability

The decision as to whether fission occurs during de-excitation is determined by randomly selecting fission with probability $P_f=(1+\Gamma_n/\Gamma_f)^{-1}$, where Γ_n and Γ_f are the neutron and fission widths, respectively.

For high-Z nuclei in the actinide region, the fission barrier is relatively constant at about 6 MeV, and P_f is not strongly dependent on excitation energy E^* (e.g., Gavron, et.al. /24/). Therefore, the model assumes $P_f=0$ for $E^* \leq 6$ MeV and P_f independent of E^* above 6 MeV, with values determined from the expression of Vandenbosch and Huizenga /25/:

$$\log (\Gamma_n/\Gamma_f) = \phi(\hat{Z})\ \hat{A} + \psi(\hat{Z})$$

Here $\hat{Z}$ and $\hat{A}$ are the charge and mass numbers of the fissioning nucleus, and ϕ and ψ are tabulated functions which depend only on Z. In the code, the above expression is used for $89 \leq \hat{Z} \leq 99$, with fission not considered for higher $\hat{Z}$.

In the sub-actinide region, the results of experiments show that P_f is strongly dependent on E* (e.g., Barashenkov, et.al. /26/), and for the RAL model Atchison has made fits to experimental data using statistical model expressions to determine P_f. Separate fits are made for neutron emission and fission to allow separate level density parameters. The expressions for neutron emission are:

$$\Gamma_n = C_1 \cdot (C_2 I_0 + C_3 A^{1/3} I_1 + A^{2/3}(C_4 I_1 + C_5 I_0))$$

$$C_1 = 0.352 \quad C_2 = 1.68 \quad C_3 = 1.93$$
$$C_4 = 0.76 \quad C_5 = -0.05$$

$$I_0 = (2a_n)^{-1} ((S_n - 1.0)\exp(S_n) + 1.0)$$

$$I_1 = (8a_n^2)^{-1} ((2S_n^2 - 6S_n + 6)\exp(S_n) + S_n^2 - 6)$$

$$a_n = (A-1)/8$$

$$S_n = 2(a_n(E^* - B'))^{1/2}$$

B' = separation energy - pairing energy

The expressions used for fission are:

$$\Gamma_f = ((S_f - 1)\exp(S_f) + 1)/a_f$$

$$S_f = 2\ (a_f(E^* - E_f))^{1/2}$$

$$E_f = C_6 - C_7(Z^2/A) + C_8(Z^2/A)^2$$

$$C_6 = B' + 321.2 \quad C_7 = 16.7 \quad C_8 = 0.218$$

$$a_f/a_n = C_9 + C_{10}\ ((Z^2/A) - C_{11})^2$$

$$C_9 = 1.09 \quad C_{10} = 0.011 \quad C_{11} = 31.09$$

The above expressions are used for $Z \leq 88$. The fit parameters for the fission barrier E_f and the level density ratio, a_f/a_n, are based on data for $Z < 85$, so the model fits are used for extrapolation to obtain the fission probability in the Z=85 to 88 region.

(b) Post-Fission Parameters

At this point, fission has occurred for a nucleus having charge $\hat{Z}$, mass $\hat{A}$, excitation energy $\hat{E}^*$, and recoil energy $\hat{E}_r$, and we desire to determine the corresponding parameters for each of the fission fragments.

The selection of the masses for the fission fragments depends on whether the fission is symmetric (a wide, single peak for the fragment mass distribution) or asymmetric (two peaks). For $\hat{Z}^2/\hat{A} \leq 35$, only symmetric fission is allowed, and the mass A_1 is selected from a Gaussian distribution of mean $A=\hat{A}/2$ and width $\sigma_A=C_{12}+C_{13}\hat{U}+C_{14}\hat{U}^2$, where $C_{12}=3.97$, $C_{13}=0.425$, $C_{14}=-2.12 \times 10^{-3}$, and $\hat{U}$ is the excitation above the fission barrier: $\hat{U}=\hat{E}^*-E_f$. This symmetric fission mass distribution is based on the systematics given by Neuzil and Fairhall /27/. If $Z>88$, the fission energy barrier is determined in the following way, based on the work of Seaborg and Vandenbosch /28/: $E_f=C_{15}+C_{16} \cdot \hat{Z}^2/\hat{A}$, where $C_{16}=-0.36$ and C_{15} has the values 18.8, 18.1, 18.1, and 18.5 for odd-odd, even-odd, odd-even, and even-even nuclei, respectively. For $\hat{Z}<88$, E_f is calculated using the expression given earlier under the fission probability calculation. With A_1 determined, the mass of the other fission fragment is $A_2=\hat{A}-A_1$.

If $\hat{Z}^2/\hat{A}>35$, competition between symmetric and asymmetric fission is allowed, with the asymmetric probability being $P_{asy}= F/(1+F)$ where $F=4870\exp(-0.36\hat{E}^*)$. For asymmetric fission, A_1 is selected from a Gaussian of mean $A=140$ and width $\sigma_A=6.5$, and then $A_2=\hat{A}-A_1$.

The charge of the first fragment Z_1 is selected from a Gaussian distribution of mean $\bar{Z}_1$ and width $\sigma_Z=2$, where $Z_1=(\hat{Z}+Z_1-Z_2)/2$, $Z_i=C_{15}A_i/(2C_{15}+A_i^{2/3})$, and $C_{15}=65.5$. Then $Z_2=\hat{Z}-Z_1$.

As an example for the fission probability computed using the RAL model for various isotopes Fig. A.18 is attached.

The total kinetic energy of the fission fragment in the center-of-mass E'_T, is selected from a Gaussian distribution having mean $\bar{E}_T=0.13Z^2/\hat{A}^{1/3}-11.4$ and width $\sigma_E=0.084\bar{E}'_T$. These relations are based on evidence of the strong correlation of fission fragment kinetic energies with the Coulomb repulsion parameter $\hat{Z}^2/\hat{A}^{1/3}$ of the fissioning nucleus (e.g., /23/), and data which suggests that the kinetic energies are narrowly distributed about $\bar{E}'_T$. The kinetic energy of each fragment, in the center-of-mass, is $E'_1=A_2E'_T/\hat{A}$, and $E'_2=E'_T-E'_1$. Isotropic emission in the center-of-mass is then assumed to obtain the kinetic energies E_1 and E_2 in the laboratory system.

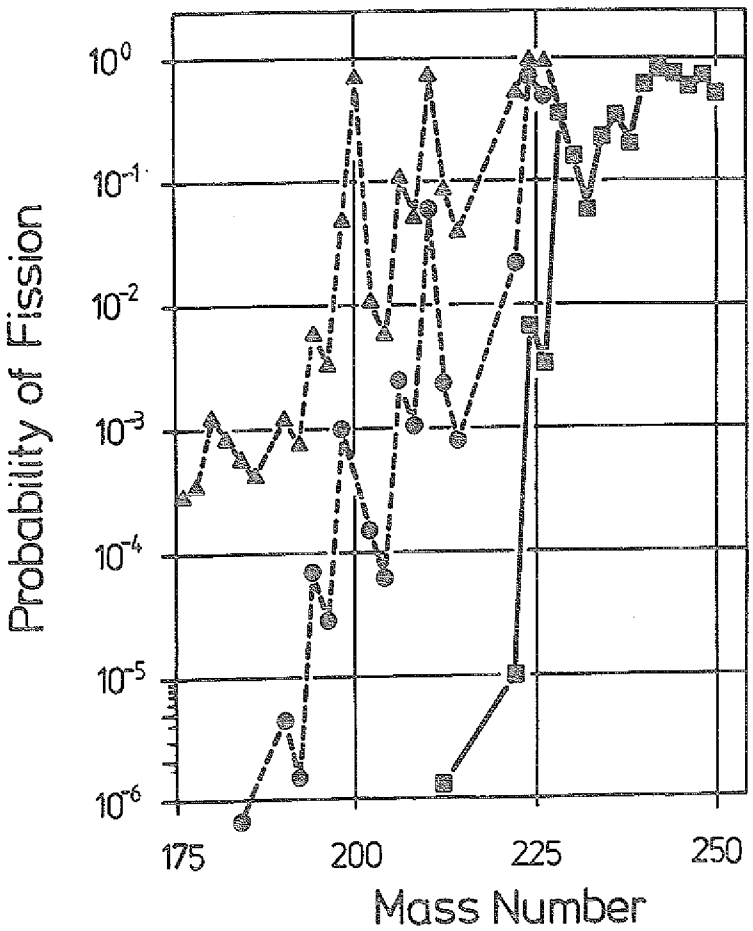


Fig. A.18: Probability of fission using RAL model for various isotopes arbitrarily selected over the range from A=175-250. The top, middle, and bottom curves are for assumed excitation energies of 100, 50, and 20 MeV, respectively. (The model assumes that the fission probability is constant for excitation energies above 6 MeV for isotopes having Z above 90)

The excitation energies of the fission fragments is then determined by an energy balance: $E_1^* = (A_1/\hat{A})(\hat{E}^* + B_1 + B_2 - \hat{B} - E_T')$ and $E_2^* = E_1^* A_2/A_1$, where B denotes binding energies.

A.1.3 Thick-Target Transport of Low-Mass Heavy-Ion Beams

The standard version of the HETC code allows protons, neutrons, π^+, π^-, μ^+, or μ^- as source particles. Previously, modifications were made (for operation on CDC computes) to treat "light" heavy ion beams having 2<A<10 /29/. The programming for this capability has been converted for operation on IBM computers and incorporated in the HETC-KFA version.

The basic theory is described in Ref. /29/, and only a short summary is given below. The key assumption is that projectile particles can be treated as a cluster of nucleons, and nonelastic interactions computed as the sum of the effects of individual computed using the same intranuclear-cascade evaporation model as used for nucleons and pions. This assumption becomes worse as the A of the projectile increases, because for heavier projectiles a cascade can be induced in the projectile particle as well as in the target nucleus. Thus, the model is expected to be applicable for d, t, He, and alpha beams. The A at which the model becomes invalid is not well defined. The programming for the model allows beams up to A=10.

The basic procedure used when a nonelastic collision occurs is as follows (see also Ref. /29/):

(a) The energy of each nucleon of the projectile is set to $E_N=(E_i-B_i)/A_i$, where E and B are the kinetic and binding energies of the ion. (These binding energies are set internally for A<4, and must be specified as input for A>4).

(b) A configuration for the nucleus of the ion is specified.

(c) Impact parameters and a cascade-evaporation calculation is performed sequentially for each nucleon of the cluster.

(d) Collisions with hydrogen target nuclei are computed using the same p-p and p-n cross-sections as used by the intranuclear cascade code.

(e) All atomic processes (ionization energy loss, ranges, etc.) are scaled from relations for protons.

Semi-empirical formulas are used for total ion-nucleus cross-sections. There are no pseudo collisions as in the case of nucleon and pion transport. The additional subroutines for heavy particle transport are indicated in Ref. /29/.

Some results of calculations using this method are given in Ref. /29/ for a few cases: (a) neutron production for 160 MeV deuterons incident on thin targets of various materials, (b) energy deposition in a thick aluminum target for 1-GeV alpha particles, and (c) energy deposition in a thick U-238 target from 330 MeV deuterons. From these cases, the model appears to give reasonably good predictions, but it has not been extensively tested.

A.1.4 Miscellaneous Updates

(1) Corrections of the Charged Particle Slowing Down Algorithm in Range Calculations

In the former HETC-KFA version the charged particle energy loss is calculated by interpolation from a predefined energy range table.

At the beginning of a flight path r=R(E) gives the range of the particle until cutoff energy will be reached. At the end of a flight path $EC=R^{-1}$ (r-path) gives the remaining energy. If the particle passes from one material to another, a new range is chosen based on the material being entered and the energy at the medium boundary.

Both the range and the final energy are interpolated from the range table which has been setup in 200 logarithmic steps of E. Only the proton range is tabulated, whereas for $\pi^{\pm}$ and $\mu^{\pm}$ the range is scaled using the relation

$$R_i(E_i) = (m_i/m_p) \cdot Z_p^2/Z_i^2 \cdot R_p \cdot ((m_p/m_i)E_a)$$

$$\sigma^2(R_i(E_i)) = (m_i/m_p) \cdot \sigma^2 \cdot [R_p(E_p(m_p/m_i))]$$

where m_p, Z_p and R_p are the mass, charge and range-function of a proton, and m_i, Z_i, R_i and E_i are the mass, charge, range-function and energy of any particle of interest. (Ranges are calculated using the code SPAR /37/.)

Both the scaling as described above and the logarithmic interpolation of the range tables (especially in invers direction) caused the amplification of numerical errors of the tabulated data. Furthermore the integration scheme used to calculate the range from dx/dE was rather simple. Thus for applications where small path lengths are frequently used (such as sampling calorimeters) the numerical uncertainties could cause perceptible errors in the energy loss.

Therefore, we have implemented separate range tables for $\pi^{\pm}$ and $\mu^{\pm}$ to avoid scaling. We changed the interpolation above 150 MeV to linear interpolation. This seems to fit better the shape of the energy range curve and we avoid the precission loss due to the usage of the log function. In the logarithmic part of the table we stored the logarithm of the range along with range itself to speedup the interpolation routine. At last we changed the integration algorithm and use now the DCADRE function of the IMSL /30/.

In practice these changes have solved the problem so far. Although in future releases of HERMES this procedure will be changed again to implement user selected and tested function setups and offer the slowing down for other particles.

(2) Range Straggling

In some applications involving low-energy charged particle sources in which the fraction of the beam particles that slow down and stop from ionization energy losses rather than undergo nuclear collision is significant, it is necessary to take into account the statistical fluctuations in energy loss. These fluctuations result in a variable range distribution (i.e., range "straggling"). In the standard version of HETC only mean ranges and average energy losses are computed. In the HETC-KFA-2 version energy-loss fluctuations and range straggling are incorporated for the primary beam particles.

The straggled range distribution is taken to be Gaussian about the mean range with a variance given by /31/:

$$\sigma^2 R_i(E \to E') = 4\pi e^4 Z_i^2 n \int_{E'}^{E} \frac{(1-1/2\beta^2) \cdot K(E)}{(1-\beta^2) \cdot (1+(2m_e/m_i)\gamma)} (S_i(E))^{-3} dE$$

where $\sigma^2 R_i(E \to E')$= the variance of the range distribution for a particle of type i slowing down from kinetic energy E to E',

e = the electron charge,
Z_i = the charge fo the particle slowing down,
n = the electron density of the stopping medium,
K = the binding correction factor,
$\beta^2 = [(E^*+1)^2-1]/(E^*+1)^2$,
$E^* = E/m_i c^2$,
m_e = the electron mass,
$\gamma = (1-\beta^2)^{-1/2}$,
S_i = the stopping power.

The factor K takes into account the binding effect of the atomic electrons at low E.

Ranges are chosen from the distribution

$$p(R_i)dR_i = \frac{1}{\sigma^2 R_i \sqrt{2\pi}} \cdot \exp-\left(\frac{(R_i-R_i)^2}{2\sigma^2 R_i}\right) dR_i$$

where R_i is the mean range.

(3) Low-Energy Transport Cutoffs

An option has been added to allow different cutoff energies for ionization and nuclear collisions for charged particle transport. For protons the input parameter ELOP was used as the energy cutoff for both nuclear collisions and ionization. Now, ELOP is for nuclear collisions only, and a new input parameter, EMIN(1), is used for the proton ionization energy cutoff. New input parameters, EPICUT and EMUCUT, have been added as cutoff energies for charged pions and muons, respectively. Thus, the ionization cutoffs are independent for different charged particles, whereas formerly the pion and muon cutoffs were fixed relative to the proton cutoff specified.

The EMIN array in labeled common /COMON/ now contains the ionization energy cutoffs for charged particles and the neutron collision cutoff. The collision cutoff for protons, ELOP, is now passed through the new common /ECUTP/.

(4) Coulomb Scattering

In the versions of HETC distributed by RSIC there was a problem in that the Coulomb scattering subroutine SPRD did not properly update certain variables at material boundary crossings. This problem was corrected already in HETC/KFA-1 /32/.

(5) Treatment of Pion Decay

Neutral Pion Decay:

Neutral pions (π^0) have a very short half-life and are assumed to decay at the collision site where they are created. Only the source distribution is provided in HETC. The photons from π^0-decay can be obtained either in EGS4, or in STATIST taking into account the $\gamma\gamma$- and the Dalitz-decay channels.

Charged Pion Decay:

For charged pions "in flight" (e.g., before coming to rest due to ionization energy loss), both decay and nuclear collisions are taken into account. π^+-particle which come to rest are assumed to decay or undergo nuclear capture, depending on the setting of the input option (the choice depends upon the density of the target material).

Pion decay in-flight is determined by defining a "macroscopic decay cross section", which analogeous to the macroscopic cross section used for nuclear collisions. If the option is specified that π^--particle become captured when stopped, the capture products are computed using the INC model, with the initial excitation corresponding to the rest-mass energy of 139.6 MeV. The main properties are given in Table A.5.

Table A.5: Properties of pions and muons

(1) Decay Properties

particle	mean lifetime τ_0 [s]	$c\tau_0$ [m]	decay model
π^+	2.6×10^{-8}	7.8	$\pi^+ \rightarrow \mu^+ \quad \nu_\mu$
π^-	2.6×10^{-8}	7.8	$\pi^- \rightarrow \mu^- \quad \nu_\mu$
μ^+	2.2×10^{-6}	~660.0	$\mu^+ \rightarrow e^+ \quad \nu_e \quad \nu_\mu$
			$\mu^- \rightarrow e^- \quad \nu_\mu \quad \nu_e$
π^0	0.87×10^{-16}	$\sim 10^{-8}$	$\pi^0 \rightarrow \gamma\gamma$ (98.799%)
			$\pi^0 \rightarrow \gamma e^+ e^-$ (1.198%)

(2) Decay Cross Sections

$\Sigma_D(E) = 1/\lambda_{decay}$ (macroscopic decay cross section)

with

$\lambda_{decay} = \pi \cdot \tau = \pi \cdot \tau_0 \cdot \gamma$ (decay mean path)

$(\tau = \gamma \cdot \tau_0,\ \gamma = [1-(\pi/c)^2]^{-1/2})$

The mean decay time in the rest frame is $\tau_0=2.6\times10^{-8}$ s for pions and 2.2×10^{-6} s for muons. According to Table A.5 the mean-free-path for decay can be written

for pions,

$$L^{\pi}_{decay} = 7.8[(E/139.6+1)^2-1]^{1/2} \quad [m]$$

and for muons

$$L^{\mu}_{decay} = 660[(E/105.7+1)^2-1]^{1/2} \quad [m]$$

(The production and transport of neutrinos is not included in the present version of HETC. This extension will be made in a next HERMES release).

The original coding of HETC does not allow charged pion decay to occur explicitly. An option is included to allow analog π-decay. In this context analog decay of charged pions in-flight means, that the decay path length - see above - is sampled from a distribution function using the velocity and the mean life-time of the pion. If the decay path length is exhausted before reaching a collision point, the pion is discarded and a muon is produced. Weighted decay of charged pions - in the original coding of HETC - means the statistical weight of the pion is reduced along the flight path length by the decay probability during that flight. The weight assigned to the created muon corresponds to the weightloss of the pion.

Weighted decay will improve the statistical error of the produced muons and should be used if mean values are important, whereas analog decay should be used if event-by-event fluctuations will be considered.

A.2 Modification of MORSE-CG

The base program source used is MORSE-CG in Ref. /33/.

A.2.1 Particle source

(1) Fixed point source

NSTRT identical particles are started in one run. The characteristic parameters for one particle, starting point, direction and age are defined on Card D1, starting weight of all particles is given on Card C.

(2) HETC Neutron Source

All neutrons, generated by the present HETC are saved on the HERMES submission file by their parameters, name, energy, direction, location and weight. HETC creates an amount of neutrons varying from batch to batch. MORSE starts neutrons as found on file instead of using NSTRT.
For more detailed information about submission file see 3.4 Structure of Submission Tapes.

A.2.2 Cross-Section Libraries for MORSE

There are three types of cross-sections MORSE accepts:

(1) Library with ANISN structure, preceded by a special head-record, for instance EPR /34/.
The first three lines of an ANISN structured library are formed by σ_{ab}, $\nu\sigma_f$, σ_{tot}; cross-section data contain the factor (2L+1).

(2) ANISN-formatted libray, e.g. HILO /2/,AMPX-created data.
Cross section matrix as in (1) preceded by an ANISN-standard format header record.

(3) Library, created by the program system RSYST, e.g. 53-, 60-, 99-group structured library /35/.

- An RSYST-created library always consists of five head records, containing σ_f, σ_{tr}, σ_{ab}, $\nu\sigma_f$, σ_{tot}, followed by a complete cross-section matrix, that is not multiplied by (2L+1). MORSE ignores the first 2 head records and multiplies the matrix data by (2L+1).
The position of σ_{g-g} that separates the upscatter matrix (line 6 to IHS-1) from the downscatter matrix (IHS to ITBL) is given by IHS; no structure with IHS=0 can be used in MORSE.
(See input description MORSE-CG, Section 3.3).

A.2.3 Changes of Partly Analogous Simulation in MORSE

MORSE does not use analog collision kernels. This means that no decision is made on the collision type. Each collision is taken to represent elastic scattering, inelastic scattering, absorption, fission and n,γ process at a time. The final state of a collision is computed as a compound of the final states of the distinct collision types.

This means, the statistical weight of the incident particle is multiplied by the non-absorption probability including the multiplicity of n,xn collisions. The final group and direction is selected from the cross-section set which also represents the superposition of elastic and inelastic cross sections.

Fission neutrons are not included in the scatter matrix of the cross section because those would dominate the spectrum. Thus, fission neutrons are generated as secondary particles. Their statistical weight was derived from the differential fission probability table. The amount of fission particles used was taken from the FWLO array of the MORSE input.

γ's have been generated in a similar way; the γ-weight was set to the generation probability $\nu_\gamma * p(n,\gamma)$ and the number of γ's was taken from the GWLO (the γ weight table).

This method of simulated Monte-Carlo results in correct mean value estimates of flux and collision rates. On the other hand it will not create physical particle histories rather than statistical representatives of classes of histories having the same physical properties. Fluctuations are normally reduced, speeding up the code.

However, if fluctuations should be measured themselves one has to use a higher degree of analogism with the physical behaviour of particle histories. Therefore, we have changed the algorithm of γ generation and fission neutron generation using $\nu * p_{fiss}$ and $\nu * p_{n,\gamma}$ to find the weight of secondaries to be generated. Then we divide this weight into portions of FWLO or GWLO, respectively. Setting FWLO and GWLO to one will then result in the generation of the physically correct amount of fission neutrons and γ's. Setting the russian roulette weight and the splitting weight to one will have the same effect for absorption and n,xn scattering.

Although, these changes adjust the number of secondary particles with respect to the distinct collision type, the collision remains a superposition of different possible types. This problem cannot be solved without separating the cross-sections into the various collision channels which in effect would mean, that we have to use a completely new Monte-Carlo program with completely new cross-section data.

A.2.4 Available Estimators

Six different estimaters are available in the MORSE release:
- Volume detector: volume-flux and volume-light
- point detector
- Surface detector: surface flux, surface current and surface energy current

- Volume detectors:

(1) Volume flux detector

The volume flux in energy group E is calculated by

$$\phi(E)_{Vol} = f/NM \cdot \sum_{j=1}^{M} \sum_{i=1}^{N_j} (WT_i * ETATH_i)$$

with

f	global normlization factor
NM	number of source particles started in all batches
M	number of bathes
N_j	number of events in batch j
WT_i	weight of neutron i before collision
$ETATH_i$	distance neutron i has to travel within the same medium (usually called as track length)
Vol	Volume

There is the probability to estimate energy-, time-, time- and energy-, or angle- and energy dependent values, with a normalization to ΔE, Δt, and $\Delta\Omega$. To get a certain response

$$R_V = \sum_{g=1}^{NE} \phi(E)_{Vol} \cdot Res_g$$

the user has to specify response functions and multiply them with the determined flux $\phi(E)_{Vol}$.

(2) Volume Light Detector

The volume light detector is used to measure scintillation light induced by neutron scattering. Only scattering with ^1H is taken into account. Thus the detector measures the light generated by recoil protons. At each scattering point the detector decides whether the neutrons were scattered at ^1H or not, using the differential hydrogen scattering probability

$$P_{1H} = \frac{\sigma_{sc}\ (1H)\ *\ N_{1H}(med)}{\Sigma_{tot}(med)}$$

(med = medium in which scattering takes place.)

The neutron is assumed to generate a recoil proton with energy uniformly distributed between zero and the neutron energy. The generated proton is assumed to be stopped within the scintillator.
Using Birk's law /36/ we can calculate the light response of the proton using ranges calculated via the SPAR code /37/

$$L_p(E_p) = \int_0^{E_p} \frac{dL_p}{dE_p}\, dE = \int_0^{E_p} \frac{S^*}{1+kB(dE/dx)_p}\, dE$$

where S is the scintillation efficiency and kB a quenching factor
Folding $L_p(E_p)$ with the distribution function of E_p for a given neutron energy E_n will result in the mean scintillation effect of th neutron

$$L_n(E_n) = \frac{\int_0^{E_n} L_p(E_p)dE}{\int_0^{E_n} dE}$$

$L_n(E_n)$ is calculated for each neutron group boundary. For simplicity $L_n(E_n)$ is considered to be linear in E for a given energy group. Thus for group g we can use

$$L_g = (L_n(E_g) + L_n(E_{g+1})) /2$$

as the mean light response of a neutron in group g. Consequently, the visible energy induced by neutrons of energy group g is calculated as

$$E_{Lg} = f/NM \sum_{j=1}^{M} \sum_{i=1}^{N_j} WT_i * L_g$$

with
- f = global normalization factor
- NM = number of source particles started in all batches
- M = number of bathes
- N_j = number of events in batch j
- WT_i = weight of neutron i before collision
- L_g = light response as described above

To get the volume light response over the total range

$$R_L = \sum_{g=1}^{NE} (E_{Lg} \cdot Rres_g)$$

the user has to specify response functions res_g.
An example of the light response for neutrons is given in Appendix E.

- Point Detector

The point detector calculations performed by MORSE is using the "next-event" estimator which scores, from each collision point (collided) or source point (uncollided), the probability of the next event being at the dx x in energy group g is calculated as

$$\phi(E,r) = f/NM \sum_{j=1}^{M} \sum_{i=1}^{N_j} \frac{(WT_i)_j * e^{-\mu_{ij}} * P_{ij}}{(x_{ij}-x_p)^2+(y_{ij}-y_p)^2+(z_{ij}-z_p)^2}$$

with $(WT_i)_j$ = weight of the particle leaving event i in
= batch j

μ_{ij} = number of mean free path between event
= site and detector

p_{ij} = probability, per steredian, for a par-
= ticle to be scattered into the detector
= direction
= in case of uncollided flux calculation,
= p_{ij} is assumed as $1/4\ \pi$

x_p, y_p, z_p = coordinates of detector point

x_{ij}, y_{ij}, z_{ij} = coordinates of event point

NM = number of source particles started in all
= batches

M = number of batches

N_j = number of events in batch j

f = global normalisation factor

r = coordinates of the detector

MORSE outputs for all detectors the energy dependent flux as well as the uncollided and the total response using response functions res_g

$$R_p = \sum_{g=1}^{NE} (\phi(E,r) \cdot Res_g)$$

More detail informations about the subroutines SDATA, RELCOL and EUCLID is given in the MORSE manual /33/.

Calculations with point detector are extremely time consuming. To diminish time, the user should specify regions, that are valid for the estimation, i.e., collisions, which do not occur inside of these regions, will be disregarded. It has to be emphasized that the user should exclude only such regions which will not significantly contribute to the flux at the detector.

For detail information about additional input for point detector see Section 3.3 MORSE Input Description.

- Surface Detector

(1) Surface Flux Detector

Surface flux in energy group g is calculated by

$$\phi(E)_{Surf} = f/NM \cdot \sum_{j=1}^{M} \sum_{i=1}^{N_j} (WT_i/abs(cos_i))_g$$

with f = global normalisation factor
NM = number of source particles started in all batches
M = number of batches
N_j = number of events in batch j
cos_i = cosine of angle between direction of flight and the normal to the passed surface
WT_i = weight of neutron before collision
Surf = surface of the detector

The surface is defined by its regions on both sides. All particle passing this surface are counted disregarding direction of flight. The flux is not normalized to the surface. Total flux is calculated in cases of response function input.

(2) Surface Current Detector

the surface current is computed as

$$J_g = f/NM \cdot \sum_{j=1}^{M} \sum_{i=1}^{N_j} (WT_i)_g$$

(3) Surface Energy Current Detector

The surface energy current is computed as

$$J = f/NM \cdot \sum_{j=1}^{M} \sum_{i=1}^{N_j} (WT_i * E_i)_g$$

with E_i energy of neutron i uniformly distributed between E_g and E_{g+1}.

The surface response for all surface detectors is calculated, if response functions Res_g are specified.

A.3 Modifications of EGS4

The EGS4 code is from the physical point of view adopted to the HERMES system as it is. Only the implementation, input-output- and the geometry interface is changed. This is described above in Section 3.4. It is assumed here that the user is familiar with EGS4 physics, otherwise he should read the EGS4 user's manual /38/ and associated literature /39-40/ where a very detailed description of the physics models is given.

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APPENDIX B
DESCRIPTION OF INPUT DATA USED BY THE EVAPORATION MODEL IN THE HETC CODE

B.1 Theory and Historical Background

The basic evaporation model theory used in the original HETC code /1/ is that of Weisskopf /2/, with much of the method of implementation based in the work of Dostrovsky, et al. /3-5/. The evaporation model used in HETC is an evolution of an evaporation code called EVAP, originally written by Dresner /6/ with a series of revisions by Guthrie /7, 8/; the nature of these revisions are indicated in TABLE B.1.

Table B.1
Basic Differences in EVAP Series of Evaporation Model Codes

	Evaporation Code	Comments
1	EVAP /6/	original code
2	EVAP-2 /7/	only 6 types of evaporated particles considered instead of 19 in EVAP updated nuclear masses allows ^{8}Be as a residual nucleus to split immediately into two α particles recycles (up to a max. of 10 times) if get kinetic energy selected greater than allowed by excitation energy
3	EVAP-3 /7/	like EVAP-2 except effects of kinetic energies of recoil nuclei taken into account
4	EVAP-4 /8/	identical to EVAP-3 except for "improved-termination" scheme for particle emission

These "stand-alone" EVAP codes have been incorporated as subroutines (and used in conjunction with the cascade model) to treat high-energy nuclear collisions in the thick-target radiation transport code HETC, and its predecessors NMTC and NTC, as indi-

cated in TABLE B.2. Various updates have been made for the nuclear mass data used, and this is also indicated in TABLE B.2.

Table B.2
Overview of Nuclear Data Input Used in the EVAP Series of Evaporation Model Codes

Evaporation Code	Transport Code Used in	Nuclear Mass Data Used
1 EVAP	NTC /9/	(a) from tables compiled by Wapstra (1955) /11/ and Huizenga (1955) /12/ for bases where measured masses exist (b) semi-empirical formula of Cameron (1957) /13/ for nuclei not measured
2 EVAP-2 and EVAP-3	NMTC /10/	(a) Mattauch, et al. (1965) /14/ tabulation of binding energies (b) Cameron semi-empirical mass formula /13/ for nuclei not tabulated by Mattauch et al. (c) "shell-plus-pairing" energy corrections for Z or N < 13 from Peele and Aebersold /15/ rather than from Cameron
3 EVAP-4	HETC /1/ (RSIC Version)	same nuclear data as EVAP-2 and EVAP-3
4 EVAP-4' (unpublished)	HETC (some versions)	updated nuclear masses from Wapstra and Gove (1971) /16/

The evaporation data input described in this paper corresponds to that used by EVAP-4, which is the form of the evaporation model used in the version of HETC distributed by the Radiation Shielding Information Center (RSIC).

B.2 Comments on Calculational Method

Some of the input data for the evaporation model consists of pre-computed functions which are used in various steps of the calculation. To define the meaning of these, and other input data, we briefly summarize here some of the steps of the evaporation calculation.

The probability $P_i(E)$ that a nucleus excited to energy U will emit a particle of type i having kinetic energy E is assumed to be expressed as

$$P_i(E) \propto g_i \cdot m_i \cdot E \cdot \sigma_{ci}(E) \cdot \omega(E^*), \qquad (B.1)$$

where g_i is the number of spin states, m_i is the emitted particle mass, σ_{ci} is the inverse cross section (i.e., the compound nucleus formation cross section corresponding to bombarding the residual nucleus with particles of type i and energy E), E^* is the excitation energy of residual nucleus ($E^*=U-Q-E$, where Q is the binding energy of particle i), and ω is the density of energy levels of the residual nucleus.

The form for ω used is

$$\omega\ (E^*) \propto \exp[2 \cdot [a \cdot (E^*-\delta)]^{1/2}] \qquad (B.2)$$

where δ is the pairing energy and

$$a = A/B_0 \cdot (1+Y\Delta^2/A^2),$$

with A=mass number, B_0=8 MeV, Y=1.5, Δ=A-2Z, and Z=charge number. (Since Eqs. (B.1) and (B.2) are always involved in ratios in the computations, constants have been omitted.) (see updates in Appendix A, Section A.1.2).

The inverse cross section is taken to be the geometric cross section modified by an empirical expression to take into account energy dependence, and a Coulomb barrier correction for charged particle emission. For neutrons,

$$\sigma_{cn}(E) = \pi \cdot R^2 \cdot \alpha(1+\beta/\alpha) \qquad (B.3.1)$$

$$\alpha = 0.76 + 1.93 \cdot A^{-1/3} \qquad (B.3.2)$$

$$\alpha\beta = 1.66 \cdot A^{-2/3} - 0.05 \qquad (B.3.3)$$

$$R = 1.7 \cdot A^{1/3} \qquad (B.3.4)$$

with R in units of fermions (1 fm=10^{-13} cm). For charged particle emission,

$$\sigma_{ci}(E) = \pi \cdot R^2 \cdot (1+C_i) \cdot (1-k_i V_i/E),$$

for $E>k_i \cdot V_i$, and zero otherwise. Here V_i is the Coulomb barrier calculated from the classical electrostatic expression and the factor k_i is inserted to take into account in an approximate way barrier penetration effects. The numerical values used for C_i and k_i are mainly those chosen by Dostrovsky, et al. /4/ to give a good fit to continuum-theory cross sections. Values for protons and alpha particles are given in Table B.3, and the others are determined from the following relations:

$$k_d = k_p+0.06 \qquad C_d = C_p/2$$

$$k_t = k_p+0.12 \qquad C_{H-3} = C_p/3$$

$$k_t = k_\alpha-0.06 \qquad C_t = C_\alpha=0$$

The expression used for Coulomb barrier is

$$V_i = Z_i \cdot Z \cdot e^2/(R+R_i) \qquad (B.4)$$

where e is the electron charge and R_i is zero for protons and 1.2 fm for all other particle types.

Table B.3
Parameters Used for Computing Inverse
Charged-Particle Cross Sections

Z	K_p	C_p	k_α
10	0.36	0.08	0.77
20	0.51	0.00	0.81
30	0.60	-0.06	0.85
40	0.66	-0.10	0.89
50	0.68	-0.10	0.93
60	0.69	-0.10	0.97
>70	0.69	-0.10	1.00

The first step in computing particle emission from an initial nucleus having A, Z, and U is to determine the total (over all energy) emission probability for each particle type which is

$$P_i = P_i/\left(\sum_{i=1}^{6} P_i\right), \quad \text{with}$$

$$P_i = g_i \cdot m_i \cdot \int E \cdot \sigma_{ci}(E) \cdot \omega \cdot (U - Q_i - \delta - E) dE$$

where the upper limit of the integration is $U-Q_i-\delta$ and the lower limit is $k_i \cdot V_i$. (This equation is applicable, of course, only if emission is energetically possible -- i.e., if $U > k_i \cdot V_i + Q_i + \delta$. Otherwise, $P_i = 0$).

Based on the work of Dostrovsky, et al. /3/, this integral is performed analytically. The result (within a common numerical factor) is:

for neutrons,

$$P_i = A^{2/3} \cdot \alpha \cdot (I_1(S) + \beta \cdot I_0(S)) \cdot e^S, \qquad \text{(B.5.1)}$$

and for charged particles,

$$P_i = (g_i \cdot m_i / 2) \cdot (1 + C_i) A^{2/3} \cdot I_1(S) \cdot e^S \qquad \text{(B.5.2)}$$

where

$$S = 2 \cdot (a \cdot (U - k_i V_i - Q_i - \delta))^{1/3} \qquad \text{(B.5.3)}$$

$$I_0(S) = (2a)^{-1} (S - 1 + e^{-S}) \qquad \text{(B.5.4)}$$

$$I_1(S) = (8a^2)^{-1} (2S^2 - 6S + 6 + e^{-S} \cdot (S^2 - 6)) \qquad \text{(B.5.5)}$$

The kinetic energy selection for the evaporated particle is based on the equation

$$N(E_i) dE_i = T_2^{-2} \cdot W_i \cdot \exp(-W_i / T_i) dE_i$$

where $W_i = E_i - k_i V_i$ and $T_i = 1/2 \langle W_i \rangle$. The Monte Carlo selection of E_i is realized by setting

$$E_i = 2T_i \cdot X + k_i V_i$$

where X is selected from the distribution $(x \cdot \exp(-x))$, which is equivalent to setting X equal to one-half the sum of two random numbers on the interval (0,1). The expression for T_i, is, for neutrons,

$$T_i = 1/2 \cdot [I_2(S) + \beta \cdot I_1(S)] \; / \; [I_1(S) + \beta \cdot I_0(S)] \qquad \text{(B.6.1)}$$

and for charged particles,

$$T_i = 1/2 \cdot I_2(S) / I_1(S), \quad \text{where} \qquad \text{(B.6.2)}$$

$$I_2(S) = (32a^3)^{-1} (8S^3 - 48S^2 + 120S - 120 + e^{-S} \cdot [S^4 - 12S^2 + 120]) \qquad \text{(B.6.3)}$$

After a particle is evaporated, the procedure is repeated with updated nucleus parameters:

$$A' = A-A_i; \qquad Z' = Z-Z_i; \qquad U' = U-Q_i-E_i$$

B.3 Description of Evaporation Model Input Data

The HETC code requires an input data tape in which the first part consists of data used by the intra-nuclear-cascade model, and the second consists of data used in the evaporation model calculation. The input data arrays for the evaporation model are listed in TABLE B.4 (in the order in which they appear on the data tape), and are discussed below.

The arrays P0, P1 and P2 are pre-computed functions which are used in evaluating the S dependence of the functions I_p, I_1, and I_2 (Eqs. (B.5.4), (B.5.5), and (B.6.3)), and are defined as follows:

$$P0 = 1/2\cdot[(S-1)\exp(S)+1]\exp(-50)$$

$$P1 = 1/8\cdot[(2S^2-6S+6)\exp(S)+S^2-6]\exp(-50)$$

$$P2 = (4/32)\cdot[8S^3-48S^2+120S-120+\exp(-S) \cdot$$

$$\cdot (S^4-12S^2+120)] / [2S^2-6S+6+(S^2-1)\exp(-S)]$$

The values stored on tape have been computed for S=0.0 through S=100.0 in steps of 0.1, for a total of 1001 values for each array. Over this S range, the expressions in the brackets for P0 and P1 can vary over many orders of magnitude; hence, an arbitrary normalization factor of exp(-50) is included.

For all variables dependent on the evaporation particles (Items 4 through 8 in Table B.4) the order assumed is neutrons, protons, deuterons, tritons, helium-3, and alpha particles. Thus, IA=1, 1, 2, 3, 3, 4, and IZ=0, 1, 1, 1, 2, 2.

The RHO array contains values for the radii of evaporated particles (corresponding to R_i of Eq. (B.4)) in units of 1.7 fermions. Thus, RHO(J)=0.0 for J=1 or 2, and RHO(J)=0.70588 for J=3 through 6.

Table B.4
Definition of Input Data for HETC Evaporation Model

	Array	Dimension	Definition
1	P0	1001	pre-computed functions
2	P1	1001	used in evaluating
3	P2	1001	I_0, I_1, and I_2 (see text)
4	IA	6	mass numbers of possible evaporation particles
5	IZ	6	charge number of possible evaporation particles
6	RHO	6	radius of evaporation particles
7	OMEGA	6	(not used)
8	EXMASS	6	mass excess values (in MeV) of evaporation particles
9	CAM2	130	shell-plus-pairing energies for nuclei having charge number 1 through 130
10	CAM3	200	shell-plus-pairing energies for nuclei having neutron number 1 through 200
11	CAM4	130	pairing energies for nuclei having charge numbers 1 through 130
12	CAM5	200	pairing energies for nuclei having neutron numbers 1 through 200
13	T	3,7	constants for computing inverse cross sections (see text)
14	RMASS	297	RMASS = $A^{1/3}$, for A = 1 through 295
15	ALPH	297	ALPH = 0.76 + 1.93 $A^{-1/3}$ for A = 1 through 295
16	BET	297	BET = $(1.66A^{-2/3} - 0.05)$/ALPH, for A = 1 through 295
17	WAPS	250,20	atomic mass data in terms of mass excess values (in MeV); WAPS(I,J) corresponds to a nuclide with mass number I=A, J=isobar index (see text)

The EXMASS array contains mass excess values in MeV units for the evaporated particles, which are used in computing the Q values of Eq. (B.5.3) in the following way. Let M(Z,A) denote the mass of an excited nucleus which evaporates a particle of mass m, leaving a residual nucleus of mass M'(Z',A'), so

$$Q = M'(Z',A') + m - M(Z,A)$$

In terms of mass excess, M(Z,A) A+ΔM(Z,A), etc., where ΔM denotes the mass excess. Therefore, Q can be written as

$$Q = \Delta M'(Z',A') - \Delta M(Z,A) + \Delta m$$

where Δm=EXMASS is the mass excess of the emitted particles. The numerical values stored are from the binding energies given in the 1964 Mass Tables /B.14/, converted to mass excess values as described in Ref. /7/.

The CAM array contain shell and pairing energy corrections, which are terms in the semi-empirical atomic mass formula of Cameron /13/. This formula is used to compute the mass excess of all nuclei for which data are not available from mass tables (as discussed later in connection with the WAPS array). The formula used is that given in Eq. (B.1) of Cameron's 1957 paper /13/:

$$\Delta M(A,Z) = [8.367A-0.783Z+E_V+E_S+E_C+E_X] + S(Z,N) + P(Z,N)$$

Expressions for the terms E_V (volume energy), E_S (surface energy), E_C (Coulomb energy), and E_X (Coulomb exchange energy), which are functions of only Z and A, are given in Cameron's paper. In HETC, the quantity above in brackets corresponds to FUNCTION CAM(A,Z). The terms S and P are empirically determined corrections to the reference mass formula to take into account shell effects and "pairing" energie (i.e., the extra stability of nuclei with "paired" neutrons and protons). It is assumed that S and P can be written as independent functions of the neutron (N=A-Z) and proton numbers:

$$S(Z,N) = S(Z) + S(N); \qquad P(Z,N) = P(Z) + P(N)$$

The input data arrays correspond to:

$$CAM2 = S(Z) + P(Z); \qquad CAM3 = S(N) + P(N)$$

$$CAM4 = P(Z); \qquad CAM5 = P(N)$$

In the code, these arrays are used in the mass formula,

$$\Delta M(Z,A) = \text{ENERGY}(A,Z) \quad \text{(code variable name)}$$

$$= \text{CAM}(A,Z) + \text{CAM2}(Z) + \text{CAM3}(A-Z)$$

and for the pairing energies alone (e.g., Eq. (B.5.3)),

$$\delta = P(Z) + P(N)$$

or in the code variable names,

$$\text{CORR} = \text{CAM4}(Z) + \text{CAM5}(A-Z).$$

The numerical input values for CAM2(Z) and CAM3(N) for Z=13 through 130 and N=13 through 200 are those given in Table 1 of Cameron's 1957 paper. For Z=1 through 12 and N=1 through 12, the values given in Table 2 of Peele and Aebersold (15/ are used. For CAM4(Z) and CAM5(N), the values for Z=13 through 130 and N=13 through 200 correspond to (the negative of) the values in Table 1 of Cameron's 1958 paper, and the values for lower Z and N are (the negative of) the values given in Table 4 of Peele and Aebersold.

The T array contains values for the parameters used in computing inverse cross sections. The numerical values in this array are the same as given previously in Table B.3, with $T(1,J)=k_p$, $T(2,J)=k_\alpha$, and $T(3,J)=C_p$. The index J=1, 7 denotes the values evaluated at the seven charge number intervals given in Table B.3.

The next three arrays contain values for A-dependent functions evaluated at A=1 through 295. RMASS is used in computing the target nucleus radius, Eq. (B.3.4), and ALPH and BET correspond to α and β as defined in Eqs. (B.3.2) and (B.3.3). It should be noted that while these arrays are dimensioned 297, the values on tape for array locations 296 and 297 are not meaningful.

The WAPS array contains atomic mass data in terms of mass excess values in MeV units. WAPS(I,J) correspond to a nuclide with mass number I=A and J is an isobar index, which is defined as

$$J = A - 2Z - J' + 10, \quad \text{with}$$

$$J' = (A - 1)/(1 + 124/A^{2/3})$$

where J and J' are integers.

For the data tape used with the EVAP-4 version of the evaporation model, the atomic mass data on tape are taken from the 1964 Atomic Mass Table /B.14/. For locations in the WAPS array where values are not available from the 1964 tables, they have been generated and stored in the WAPS array using the Cameron formula /13/. It should be noted that while the WAPS array is dimensioned 20 for each A, the J and J' algorithms for storage and retrieval are such that only 10 values are meaningful for each A. Values needed for A and Z outside of this range are computed by the code using the Cameron formula.

B.4 References Appendix B

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APPENDIX C
PROBLEM INDEPENDENT INPUT TO THE CASCADE MODEL

C.1 Introduction

HETC needs problem independent data for the intranuclear cascade- and evaporation model calculations. The purpose here is to describe the input data used by the intranuclear cascade model. (The sources of the data described here are not discussed; they have been given by Bertini /1/.)

The nuclear-data input tape contains 5 records of information used by the intranuclear cascade model, followed by 13 records of data pertaining to the evaporation model (Table C.1). In this chapter, we define these first 5 records; the evaporation model data arrays are defined in Appendix B.

Table 1. Nuclear model data arrays used as input to the HETC code. Records 1 - 5 are for the intranuclear cascade model, Records 6 - 18 for the evaporation model.

Record No.	No. Words	Arrays
1	600	CRSC(1)...CRSC(600)
2	600	CRSC(601)...CRSC(1200)
3	600	CRSC(1201)...CRSC(1800)
4	600	CRSC(1801)...CRSC(2400)
5	29849	DCLN(80), DCIN(115), PPAC(19), POAC(19), FMXSN(161), FMXDN(130) FMXSP(117), PDCI(60), PDCH(55), DCHN(143), DCHNA(36), DCHNB(60), PSPCL(158), PDPCL(130), SPCLN(158), DPCLN(130), FSLN(176), FRINN(161), DMIN(101), PPSCL(117), PNSCL(117), PMSCL(117), PNNSL(117), PCFSL (234), FRIPN(117), PNMI(101), PNFSL(234), PNEC(126), PNNEC(126), PMXC(126), PMEC(126), PPEC(126), PEC(176), ECN(176), PPDC(6426), PMDD(6426), PMDX(6426), PNDD(6426)
6	3003	P0(1), P1(1), P2(1)...P0(1001), P1(1001), P2(1001)
7	12	IA(1)...IA(6), IZ(1)...IZ(6)
8	12	RHO(1)...RHO(6), OMEGA(1)...OMEGA(6)
9	6	EXMASS(1)...EXMASS(6)
10	130	CAM2(1)...CAM2(130)
11	200	CAM3(1)...CAM3(200)
12	130	CAM4(1)...CAM4(130)
13	200	CAM5(1)...CAM5(200)
14	21	((T(I,J),J=1,7), I=1,3)
15	297	RMASS(1)...RMASS(297)
16	297	ALPH(1)...ALPH(297)
17	297	BET(1)...BET(297)
18	5000	((WAPS(I,J),I=1, 250), J=1,20)

In Section C.2 the input data arrays are defined, and some are displayed graphically in Section C.3.

C.2 Definition of Input Arrays

A brief description of each input data array is given in Table C.2 and some further comments are given below.

Table 2. Definition of input data arrays for intranuclear cascade model.

Array No.	Array Name	No Words	Description	Energy Range (MeV)	ΔE(MeV) for Tabulation
1.	CRSC	600	CRSC (1) through CRSC (600) contains the following nuclear data for A = 1 through 60: (a) mass number, A; (b) radial boundaries (3) defining nuclear regions, (c) nucleon density per nucleon for each region, and (d) Fermi energy per nucleon for each region.	---	---
2.	CRSC	600	CRSC (601) through CRSC (1200) contains nuclear data like Record 1 for A = 61 through 120.	---	---
3.	CRSC	600	CRSC (1201) through CRSC (1800) contains nuclear data like Record 1 for A = 121 through 180.	---	---
4.	CRSC	600	CRSC (1801) through CRSC (2400) contains nuclear data like Record 1 for A = 181 through 239. (Data included for A = 240 to fill record, but not meaningful.)	---	---
5.	DCLN	80	neutron-proton differential cross section (energy dependence of coefficients for angular distributions)	0 - 300	20
6.	DCIN	115	same meaning as Record 5	300 - 740	20
7.	PPAC	19	π^+ - p absorption cross sections (in cm^2)	0 - 360	20

Table 2. Definition of input data arrays for intranuclear cascade model (con't)

Array No.	Array Name	No. Words	Description	Energy Range (MeV)	ΔE(MeV) for Tabulation
8.	POAC	19	π^0 - p absorption cross section (in cm^2)	0 - 360	20
9.	FMXSN	161	maximum value of pion mass distribution vs. relative kinetic energies for nucleon-nucleon single production reactions	300 - 2500	20
10.	FMXDN	130	pion mass sampling distribution for nucleon-nucleon double pion production	920 - 3500	20
11.	FMXSP	117	like record 9 but for pion-nucleon single pion production	180 - 2500	20
12.	PDCI	60	proton-proton differential cross sections, tabulated at 440, 590, 650, 800, and 1000 MeV	440 - 1000	--
13.	PDCII	55	proton-proton differential cross sections, tabulated at 1000, 1400, 2170, 2900, and 4400 MeV	1000 - 4400	--
14.	DCIIN	143	per cent scattering in backward direction for neutron-proton differential cross sections	660 - 3500	20
15.	DCIINA	36	neutron-proton differential cross sections in forward direction tabulated at 630, 1540, 2560, and 3520 MeV	630 - 3520	--

Table 2. Definition of input data arrays for intranuclear cascade model (con't)

Array No.	Array Name	No. Words	Description	Energy Range (MeV)	ΔE(MeV) for Tabulation
16.	DCHNB	60	neutron-proton differential cross sections in backward directions, tabulated at 630, 2040, 2200, 2850, and 3500 MeV	630 - 3500	--
17.	PSPCL	158	proton-proton single pion production cross sections (in cm^2)	360 - 3500	20
18	PDPCL	130	proton-proton double pion production cross sections (in cm^2)	920 - 3500	20
19.	SPCLN	158	neutron-proton single pion production cross sections (in cm^2)	360 - 3500	20
20.	DPCLN	130	neutron-proton double pion production cross sections (in cm^2)	920 - 3500	20
21.	FSLN	176	probability of producing two isobars in nucleon-proton double pion production	0 - 3500	20
22.	FRINN	161	tabulated values of integrals for isobar sampling as a function of nucleon-nucleon relative kinetic energies	300 - 3500	20
23.	DMIN	101	tabulated values of integrals for isobar sampling for nucleon-nucleon collisions as a function of the variable R, for R values from 0.0 to 1.0 in steps of 0.01	--	--

Table 2. Definition of input data arrays for intranuclear cascade model. (con't)

Array No.	Array Name	No. Words	Description	Energy Range (MeV)	ΔE(MeV) for Tabulation
24.	PPSCL	117	π^+ - proton single pion production cross sections (in cm^2)	180 - 2500	20
25.	PNSCL	117	π^0 - proton single pion production cross sections (in cm^2)	180 - 2500	20
26.	PMSCL	117	π^- - proton single pion production cross sections (in cm^2)	180 - 2500	20
27.	PNNSL	117	π^0 - neutron single pion production cross section (in cm^2)	180 - 2500	20
28.	PCFSL	234	final states for π^- - proton single production	180 - 2500	20
29.	FRIPN	117	like Record 22 but for pion-nucleon collisions	180 - 2500	20
30.	PNMI	101	like Record 23 but for pion-nucleon collisions	--	--
31.	PNFSL	234	final states for π^0 - proton single pion production	180 - 2500	20
32.	PNEC	126	π^0 - proton elastic scattering cross sections (in cm^2)	0 - 2500	20
33.	PNNEC	126	π^0 - neutron elastic scattering cross sections (in cm^2)	0 - 2500	20

Table 2. Definition of input data arrays for intranuclear cascade model. (con't)

Array No.	Array Name	No. Words	Description	Energy Range (MeV)	ΔE(MeV) for Tabulation
34.	PMXC	126	π^- - proton charge exchange cross sections (in cm^2)	0 - 2500	20
35.	PMEC	126	π^- - proton elastic scattering cross sections (in cm^2)	0 - 2500	20
36.	PPEC	126	π^+ - proton elastic scattering cross sections (in cm^2)	0 - 2500	20
37.	PEC	176	proton-proton elastic scattering cross sections (in cm^2)	0 - 3500	20
38.	ECN	176	neutron-proton elastic scattering cross sections (in cm^2)	0 - 3500	20
39.	PPDC	6426	cummulative sampling distribution in cosθ for π^+ - proton differential cross sections	0 - 2500	20
40.	PMDD	6426	cummulative sampling distribution in cosθ for π^- - proton differential scattering cross sections	0 - 2500	20
41.	PMDX	6426	cummulative sampling distribution in cos θ for π^- - proton differential charge exchange cross sections	0 - 2500	20
42.	PNDD	6426	cummulative sampling distribution in cosθ for π^0 - proton differential scattering cross sections	0 - 2500	20

C.2.1 The CRSC Array

The first array, CRSC, contains 10 values for each target Mass number, A, from A=1 through 240. (Values for A=240 are not meaningful, although values are stored just to complete the record). For each A, the following values are stored (where i=1,2,3):

Word Designation	Description
1	A, target mass number
2 - 4	R_i, the radial boundaries of nucleus A, dividing the nucleus into 3 regions - a central sphere and two surrounding annuli (in cm)
5 - 7	ρ_i/A, nucleon densities per nucleon for each region, divided by an arbitrary normalization factor of 10^{30} (in cm^{-3})
8 - 10	E_i^f, Fermi energy per nucleon for each region (in MeV)

The radial boundaries are defined as those radii where the nucleon density has decreased to a specified value of its central value. A continuous radial dependence of nucleon densities are assumed /2/:

$$\rho(r) = \rho_1 \cdot [\exp((r-c)/Z_1) + 1]^{-1}$$

where ρ_1=normalization factor, $c=1.07\times10^{-13} \cdot A^{1/3}$ cm, and $z_1=0.545\times10^{-13}$ cm. The R_i are then defined by $\rho(R_i)=\alpha_i \cdot \rho(0)$, with $\alpha_1=0.90$, $\alpha_2=0.20$, and $\alpha_3=0.01$.

The number of neutrons or protons in each region is assumed to be the same as for the nucleus as a whole, that is,

$n_i(N)$ = neutron density (per 10^{30}) in region i
$= (\rho_i/A) \cdot N$, and

$n_i(Z)$ = proton density (per 10^{30}) in region i
$= (\rho_i/A) \cdot Z$

In the Fermi gas model, where the nucleus is considered as a collection of free nucleons, the Fermi momentum of particles bound in volume Ω is conventionally written as (e.g., /3/),

$$P_f = (3\pi^2)^{1/3} \cdot h/2\pi \cdot (A/\Omega)^{1/2}$$

and the corresponding kinetic energy is $E^f=(P_f)^2/2M$. The input nucleon densities correspond to $\rho_i/A=1/\Omega$, and the input Fermi energies (per nucleon) correspond to

$$\hat{E}^f_i = E^f/A = (3h^3\rho_i/8\pi)/2M$$

The Fermi energies of neutrons and protons in each region then are

$$E^f_i(N) = \hat{E}^f_i \cdot (A-Z)^{2/3} \quad \text{and} \quad E^f_i(Z) = \hat{E}^f_i \cdot Z^{2/3}$$

C.2.2 Differential Cross-Section Data

The differential cross section data are represented in one of three formats: (a) as expressions of the form $A+B(\cos\theta)^n$ where the coefficients are input data, (b) as tabulated values corresponding to the areas under the angular distribution in $\Delta\cos\theta$ intervals, or (c) as tabulated cummulative frequency distributions in $\mu=\cos\theta$. The method used for each cross section is given in Table C.3.

Table 3. Methods used in representing differential scattering cross sections.

Cross Sections	Energy (MeV)	Method	Array
$\frac{d\sigma}{d\Omega}$(n-p)	0-300	(a) forward scattering: $A_F + B_F (\cos\theta)^3$ (b) backward scattering: $A_B + B_B (\cos\theta)^6$	DCLN
	300-740	(a) forward scattering: $A_F + B_F (\cos\theta)^3$ (b) backward scattering: $A_B + B_B (\cos\theta)^6$	DCIN
	660-3520	tabulated values for $\Delta\mu$ intervals, $\mu \geq 0$	DCHNA
	660-3520	tabulated values for $\Delta\mu$ intervals, $\mu \leq 0$	DCHNB
$\frac{d\sigma}{d\Omega}$(p-p)	0-500	(assumed isotropic in center-of-mass)	---
	440-1000	tabulated values for $\Delta\mu$ intervals	PDCI
	1000-4400	(as above)	PDCH
$\frac{d\sigma}{d\Omega}(\pi^+$-p)	0-2500	cummulative frequency distributions in μ, determined from phase shift analysis	PPDC
$\frac{d\sigma}{d\Omega}(\pi^-$-p)	0-2500	(as above)	PMDD
$\frac{d\sigma}{d\Omega}(\pi^0$-p)	0-2500	(as above)	PNDD
$\frac{d\sigma}{d\Omega}(\pi^-$-p c.e.)	0-2500	(as above)	PMDX

For n-p scattering, forward and backward scattering are treated separately, with the per cent of scattering in the backward direction specified by the DMHN data array. For p-p scattering, the angular distribution is assumed symmetric about μ=0.

The pion-proton scattering and charge exchange cross sections are based on the phase shift data of /4/ and the formalism given by Bertini /5/. At each energy, values of μ defined by

$$R = \int_{-1}^{\mu} p(\mu)d\mu$$

are tabulated corresponding to R=0 to 1 in steps of 0.02.

C.2.3 Data for the Isobar Model

For single pion production collisions produced by an incident particle having relative kinetic energy E_r, the probability of creating an excited isobar of mass m is, according to the Sternheimer-Lindenbaum model /6/

$$P(m,E_r) = C \cdot \sigma_{3/2}(m) \cdot F(m,E_r)$$

where C is a normalization constant, $\sigma_{3/2}(m)$ is the total cross section for the pion-nucleon system (evaluated at the pion kinetic energy corresponding to the total system center-of-mass energy m), and F is the phase space available. The arrays FMXSN an FMXSP pertain to selecting from the F distribution for incident nucleons and pions, respectively. The arrays FRINN and DMIN are used in selecting from σ for nucleon-nucleon collisions, and FRIPN and PNMI are used in selecting from σ for pion-nuclear collisions.

For double pion production, the masses of the isobars are expressed as

$$P(m_1,m_2,E_r) = k \cdot \sigma_{3/2}(m_1) \cdot \sigma_{3/2}(m_2) \cdot F(m_1,m_2,E_r)$$

and the FMXDN array contains data needed in selecting from F.

The three remaining input arrays containing data used by the isobar pion production model are FSLN, PCFSL, and PNFSL, which are related to specifying final states. FSLN is the probability of two isobars in nucleon-nucleon collisions, PCFSL is for π^--proton final states, and PNFSL is for π^0-proton final states.

C.3 Plots of Input Data

Some of the input data are shown graphically in Figs. C.1 to C.8. The points shown in these graphs are the data points of the input data -- e.g., the data points vs. energy are at the energy values of the input data without any extrapolation or interpolation.

Figs. C.1 to C.3 show the contents of the CRSC input array. The total cross sections for all reactions are shown in Figs. C.4 to C.8.

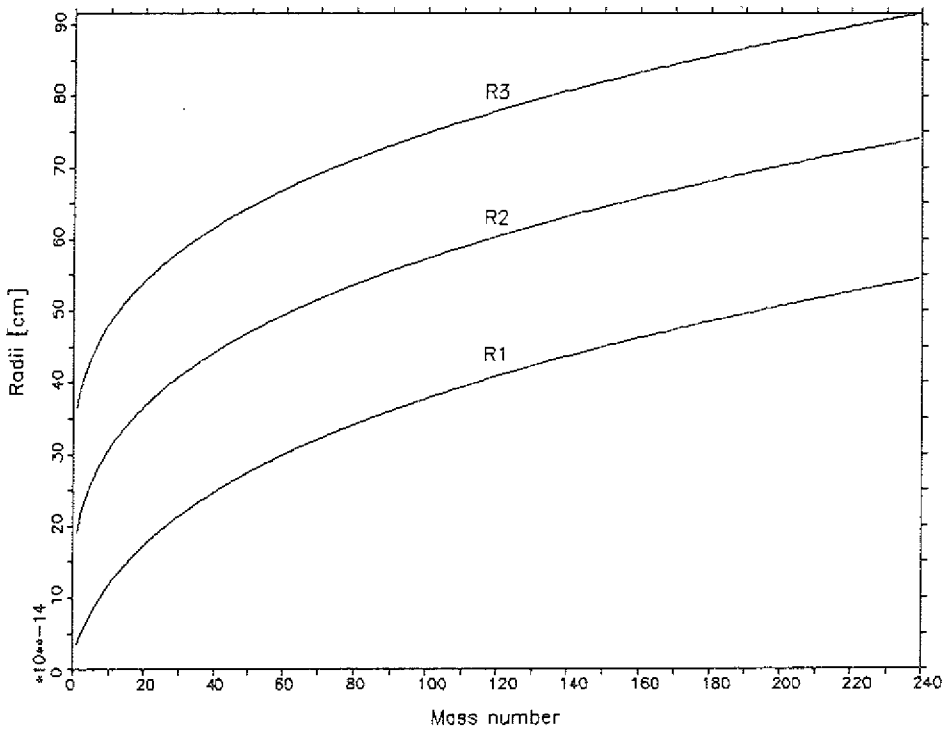

Fig. C.1: Input data (CRSC array) for radial boundaries defining regions of the nucleus. (Input values have been multiplied by 10^{13} before plotting)

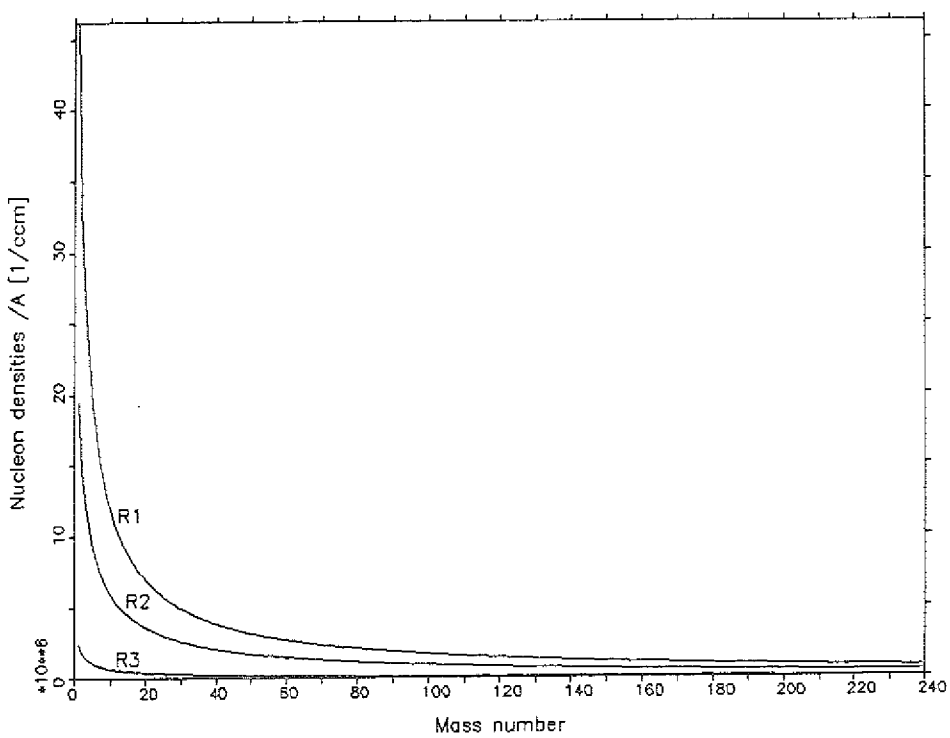

Fig. C.2: Input data (CRSC array) for nucleon density in each region of the nucleus. (The input values, and the values plotted, are divided arbitrarily by 10^{30})

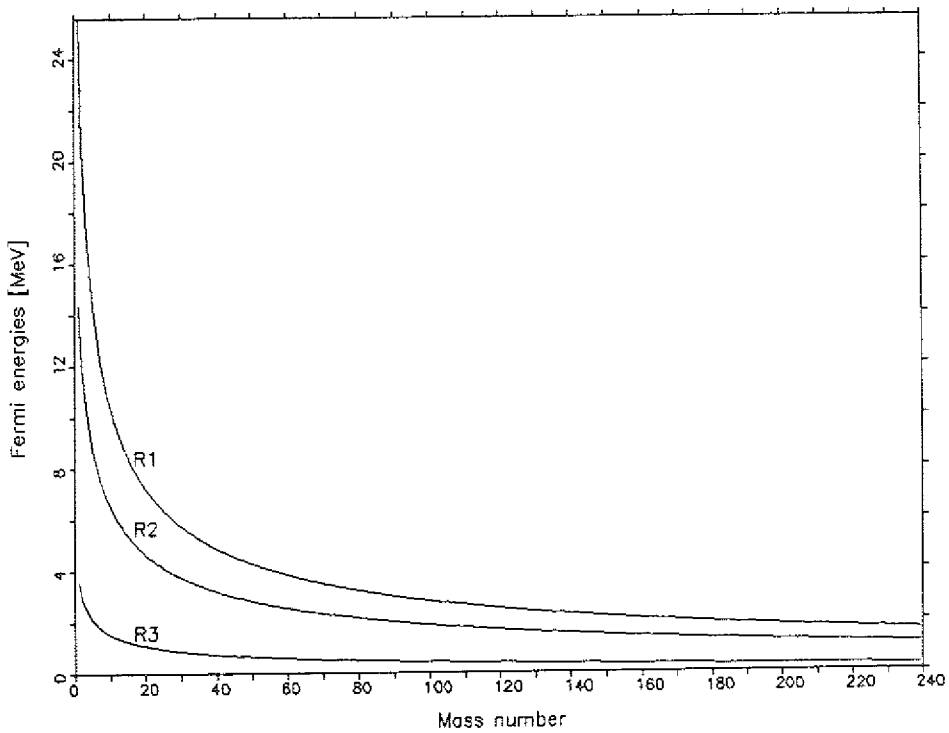

Fig. C.3: Input data (CRSC array) for Fermi energy per nucleon in each region of the nucleus

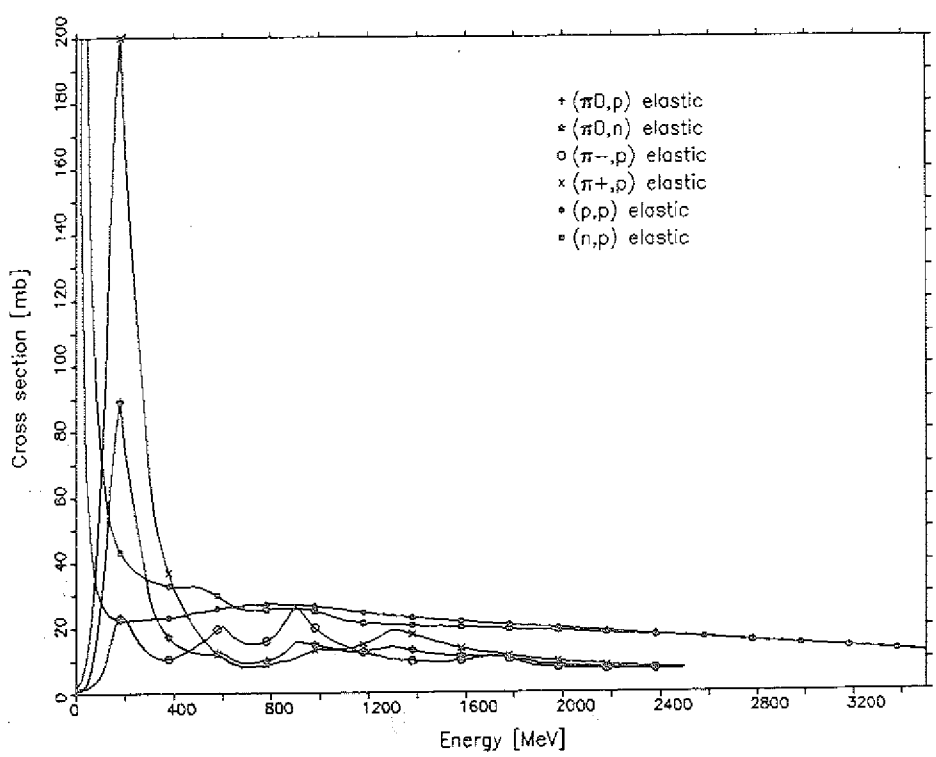

Fig. C.4: Input data used for pion-nucleon and nucleon-nucleon elastic scattering cross sections. (The low-energy region is shown expanded in Fig. C.5)

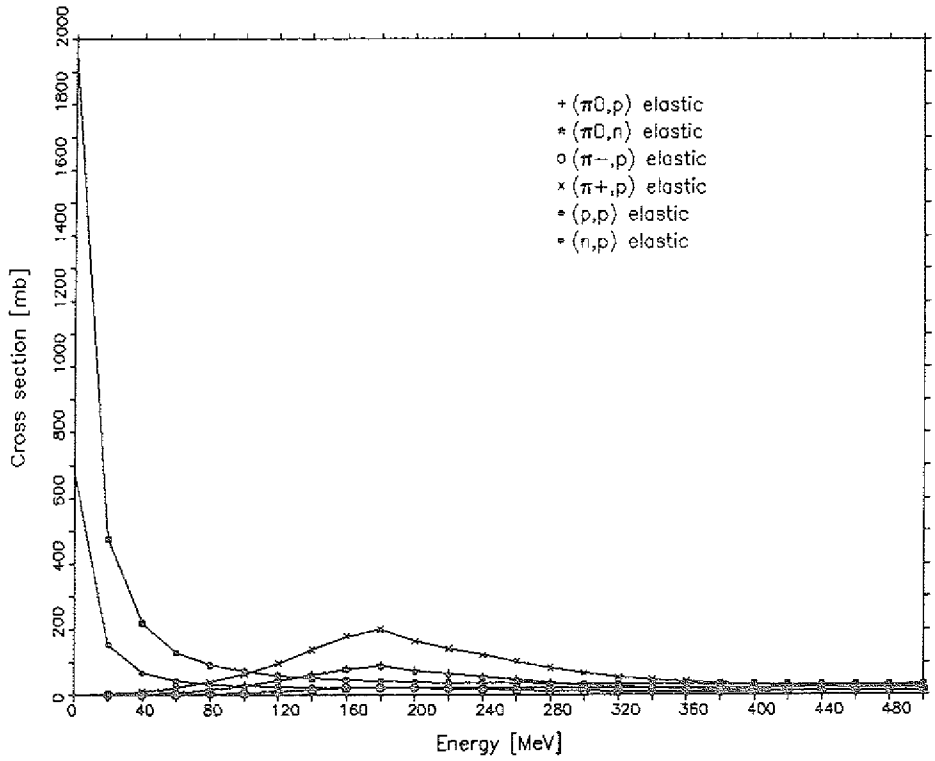

Fig. C.5: Pion-nucleon and nucleon-nucleon elastic scattering cross sections in the 0 to 500 MeV energy region

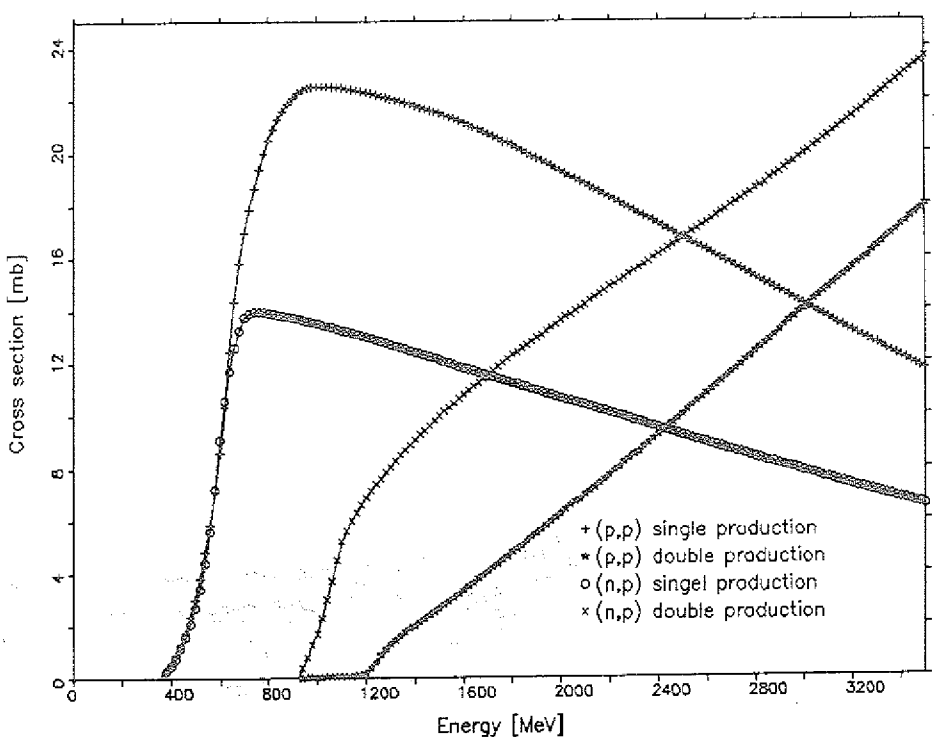

Fig. C.6: Input data used for pion production cross sections for nucleon-nucleon collisions

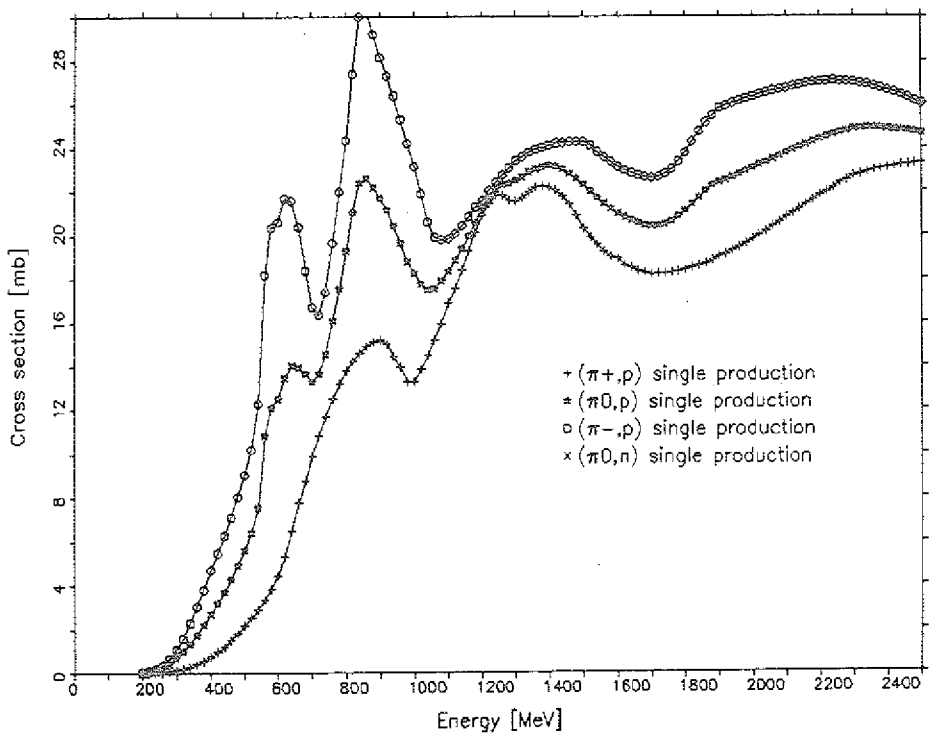

Fig. C.7: Input data used for pion production cross sections for pion-nucleon collisions

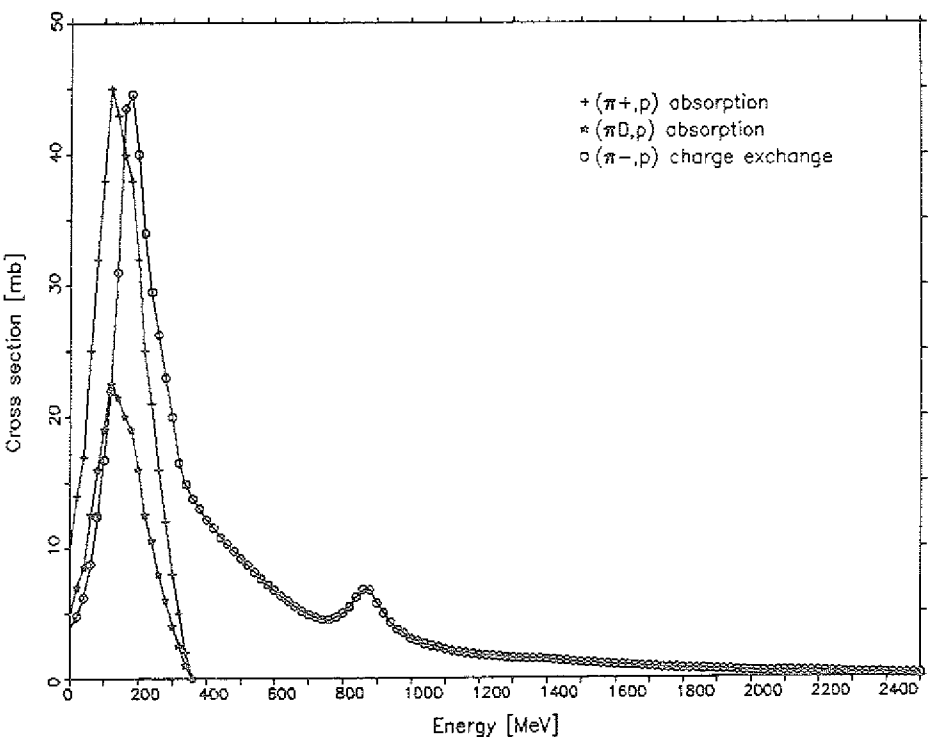

Fig. C.8: Input data used for pion absorption and charge-exchange cross sections

C.4 References Appendix C

/1/ H.W. Bertini
Intranuclear-Cascade Calculations of the Secondary Nucleons Spectra From Nucleon-Nucleus Interactions in the Energy Range 340 to 2900 MeV and Comparisons with Experiment
Phys. Rev. 188, 1711, 1969

/2/ R. Hofstadter, 28, 214, 1956

/3/ E. Segre, Nuclei and Particles, W.A. Benjamin, Inc., Reading, Mass., 1977

/4/ A. Donnachi, R.G. Kirsopp, C. Lovelace
Evidence from Pi-P Phase Shift Analysis for Nine More Possible Nucleon Resonances
CERN Report 67/1285/5-TH838, Oct. 1969

/5/ H.W. Bertini
Pion-Nucleon Differential Cross Sections in the 0 to 700 MeV Energy Region in Terms of Coulomb Scattering Amplitude, Coulomb Phase Shifts, and Nuclear Phase Shifts up to 1 = 4"
ORNL-4197, January 1968

/6/ R.M Sternheimer, S.J. Lindenbaum
Extension of the Isobaric Nucleon Model for Pion Production in Pion-Nucleon Nucleon-Nucleon, and Antinucleon-Nucleon Interactions
Phys. Rev. 123, 333, 1961

APPENDIX D
USER INTERFACING

D.1 Graphic Software Interface

The CMD command interpreter used by the HERMES system includes an interface to the KFA graphic software called the GR Software. The GR software is used to produce a series of viewgraphs. As this software is not portable it is necessary for the user, if he wants to use the graphic tools of HERMES, to provide a software which can be invoked by the following subroutine calls and performs the described functions.

The first call must be

```
CALL GRSTRT(35,8)
```

now unit 8 is used for plot output until

```
CALL GREND
```

terminates the graphic software. Whenever a viewgraph has been generated

```
CALL GRNXTF
```

displays the viewgraph on the terminal and/or plotter. The graphic memory is cleared and the GR Software is ready for the next viewgraph.

Scaling:
The dimension of a viewgraph is assumed to be 28.7*39.5 cm.

```
CALL GRSCLC(XLL,YLL,XUR,YUR)
```

defines a window with lower left corner at XLL, YLL and upper right corner XUR, YUR all measured in cm.

```
CALL GRSCLV(XA,YA,XB,YB)
```

defines the matching user values for the lower left and the upper right corners of the cm frame. The cm units refer to a plotter device with scaling factor 1, other devices need a scaling factor ≠1 to fit 28.7*39.5 to the possible device coordinates. This may be included in the device driver software or can be set by calling

```
CALL GRFCTR(FACTOR)
```

Routines for simple drawing primitives are:

```
CALL GRJMP(X,Y)
```

move the pen to point X,Y (of the user value frame) without drawing

```
CALL GRDRW(X,Y)
```

draw a line from current position to X,Y

```
CALL GRJMPS(X,Y,ISY)
```

move the pen to X,Y without drawing and then draw symbol number ISY

```
CALL GRDRWS(X,Y,ISY)
```

draw a line from current pen position to X,Y and then draw symbol number ISY.

Polylines can be plotted with

```
CALL GRLN(X,Y,N)
```

move the cursor to X(1),Y(1) and draw lines to X(i),Y(i) for i=2 to N.

```
CALL GRCHN(X,Y,N,ISY)
```

draw polyline with symbol number ISY at each X(i), Y(i).
Text may be included with

```
CALL GRTXT(X,Y,LEN,Text)
```

at position X,Y. Additional routines are available to define drawing and text attributes:

```
CALL GRNWPN(IPEN)
```

selects a new pen. This can be used to define colours e.g.

With

```
CALL GRFONT(ifont)
```

a character font can be selected and with

```
CALL GRCHRC(height,angle,intens)
```

the height of characters (in cm), the text angle and intensity can be selected. Finally,

```
GSTXAL(IA,4)
```

selects the text alignment as

```
IA=1  right justified
IA=2  centered
IA=3  left justified.
```

The subroutines described above form part of the low level graphics offered in the GR Software. Some additional routines of the second level are used by CMD as well. This second level provides automatic linear and logarithmic scaling and, therefore, needs FORTRAN unit number 4 to store data until all user data is available and automatic scaling can be done. We use the routines KURVEF and GRBLD.

```
CALL KURVEF(X,Y,N,ISTYLE)
```

defines a polyline or polymarker to be drawn and stores it on unit 4. X(N) and Y(N) are real arrays containing the coordinate data. ISTYLE defines how to draw the curves.

```
ISTYLE=(2*IPEN-1)*100+ISY
```

where ISY is the symbol number 1 to 13 or -1 for no symbol. IPEN denotes the colour of the curve. Thus, KURVEF can be used for polylines and polymarkers.

```
CALL GRBLD(XCM,YCM,IXSC,IYSC,XMIN,XMAX,YMIN,YMAX,KEY)
```

reads all data stored by KURVEF and draws all curves in one (or more) frames.

The parameters of GRBLD decide the appearance of the picture,

XCM,YCM are the lengths of x and y axis in cm coordinates.
On the first call GRBLD issues a
CALL GRSCLC(3.,35,3+XCM,3.5+YCM) and
CALL GRSCLV(0.,0.,XCM,YCM).
If XCM,YCM are given negative the lower left corner of the cm frame remains as it has been set by the user before calling GRBLD, and the upper right corner is set to (lower+left)+(XCM,YCM).

```
IXSC      set the axis scaling
IYSC         2   linear scale
           102   linear scale with grid lines
            -2   logarithmic scale
          -102   logarithmic scale with grid lines
             0   no axis (data is linear)

XMIN      value frame used for user data
XMAX      666. - use automatic minimum or maximum
YMIN
YMAX

KEY       number of curves plotted in one frame.
          666    all curves, GRNXTF is called automatically
          -666   all curves, GRNXTF is not called
          use -666 to combine GRBLD with text drawing etc.
```

Some routines included in CMD extend the graphic interface providing some useful techniques of calling graphic for special purposes.

```
GRHEAD(TEXT)
          writes a chart title

GRXLAB(TEXT)
          writes a title at the x axis

GRYLAB(TEXT)
          writes a title at the y axis

GRLAB3(HEAD,XLAB,YLAB)
          writes the chart title and titles for the x and
          y axis

GRLGND(IPEN,ISY,ILIN,LTXT,TXT)
          add a line of text (of length LTXT) to the legend
          field of the chart using pen (colour) IPEN and pre-
          fixes the text optionally by a piece of line
          (if ILIN=1) and a symbol ISY

GRCURV(X,Y,N,IPEN,ISY,ILIN,LTXT,TXT)
          combines a call of KURVEF(X,Y,N,ISTYLE)
          with a call of GRLGND(IPEN,ISY,ILIN,LTXT,TXT)

GRHIST(X,Y,NY,ISTYLE)
          constructs a curve from X(0:N) and Y(N) data group
          entries and invokes KURVEF
```

GRBARS(X,Y,NY,IPEN,ISY,ILIN,LTXT,TXT)
combines a call to GRHIST with a call to GRLGND

GRFCMD
finally compiles the graphic commands and calls the appropriate graphic routines.

D.2 Interfacing of User Provided Monte-Carlo Evaluation Codes

Interfacing for user written particle sources and analysis programs is possible, however, it has to be done in FORTRAN level.

The STATLIB subroutine package may provide programming aid for design of user detectors. For further details contact the authors.

APPENDIX E
SAMPLE PROBLEMS

Three examples of different HERMES use are given in this section. The necessary input is completely given following the guide for HERMES operation of Section 3.1. The sample outputs are reported as excerpts, because of their enormous length. They are given in full size on the HERMES distribution file.

E.1 Sample Problem I

High Energy Calorimeter

This is a simplified geometrical setup of a test calorimeter experiment, which is shown in detail in Fig. E.1 in a 9 tower multilayer structure. The simplified CG version is shown in Fig. E.2, where the 8 outer towers are considered as one, surrounding the central tower. The layer structure is also shown in this figure. A π^- beam of 5 GeV was assumed to hit the central tower in z-direction.

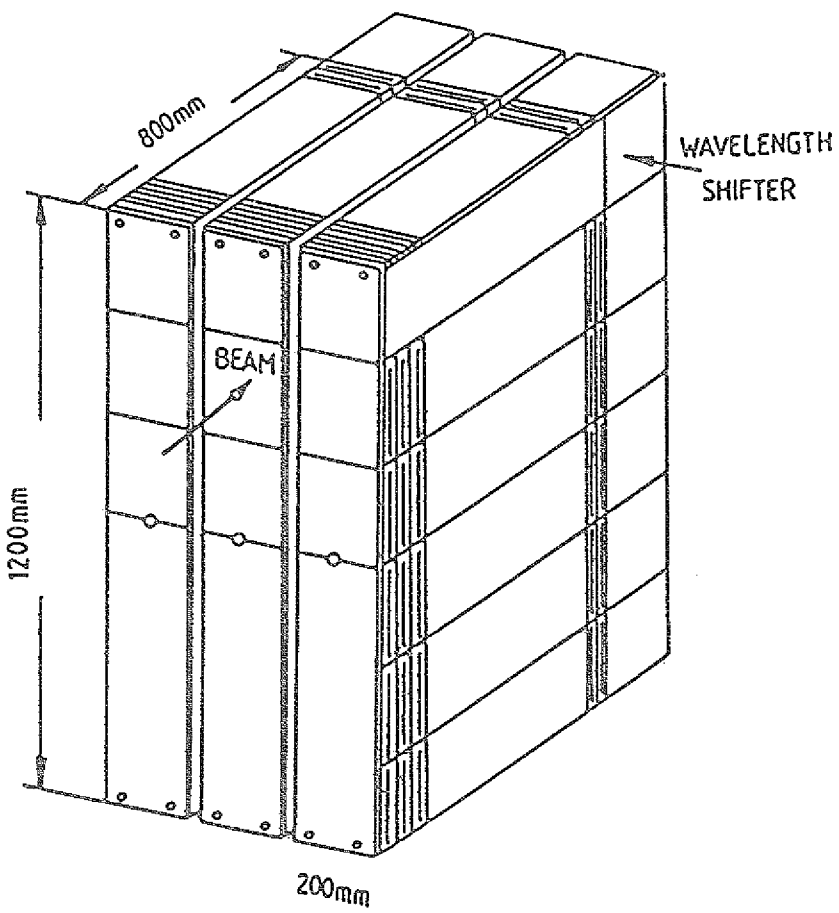

Fig. E.1: Experimental Setup

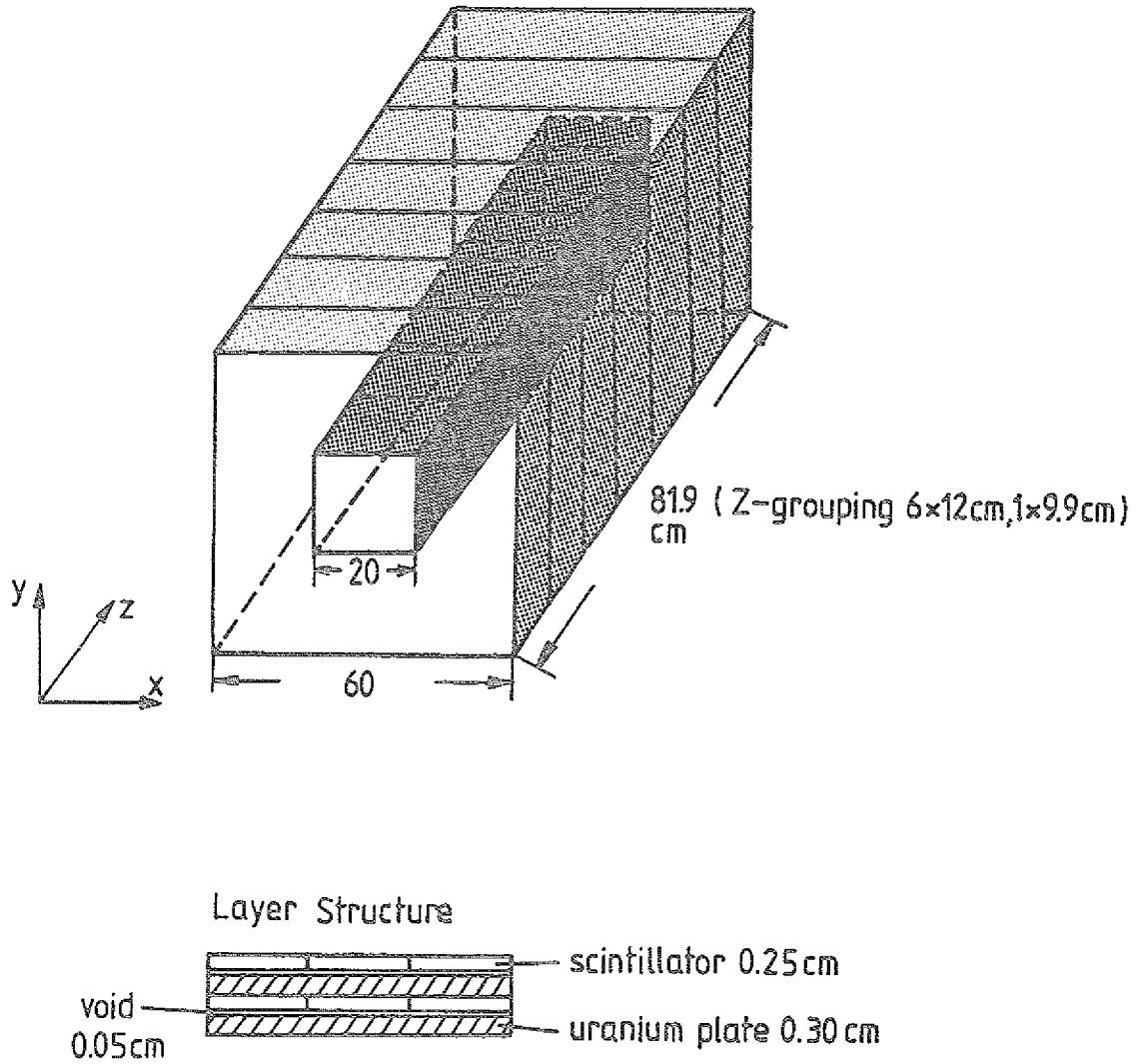

Fig. E.2: Geometrical Setup

E.1.1 Input Files for Sample Problem I

(1) Geometry Description in CMD Language

```
  GEOCMP 412 435 435 4600 16000;
 / Define z structure body data
 / IB0 body reference numbers
  INTEGER IB0(410);
  DATA IB0=<1000 A 59 1 2000 A 59 1 3000 A 59 1
            4000 A 59 1 5000 A 59 1 6000 A 59 1
            7000 A 48 1 8000> ;
 / ZB  thickness of 409 z layers
  REAL ZB(410);DATA ZB=<0. 0.3 0.05 0.25 Q 135 3  0.3 >;
 / Accumulate thicknesses to get coordinates
  ZB(2:410)=ZB(1:409)+ZB(2:410);
 / Start body input with z structure
  FOR I=1,410;
    PZ  IB0(I) ZB(I);
  ENDFOR;
 / Add two bodies to define the x-y-structure
  RPP 500 -10. 10. -10. 10. -10. 90.;
  RPP 501 -30. 30. -30. 30. -10. 90.;
  END;
/ Start ZONE INPUT with course structure
  ZONE -2 -1  500                    +1000 -8000 GO 2; / Central tower
  ZONE -2 -2  501 -500               +1000 -8000 GO 2; / Outer towers
  ZONE -1  3 -501                    +1000 -8000;      / Side void
  ZONE -1  4                         -1000 ;           / Front void
  ZONE -1  5                               +8000 ;     / Rear void
 / Next define subgeometry data
 /   low bounds of z-slabs are defined in IB0(1:409)
 /   high bounds are defined by exclusion of bodies IB0(2:410)
  INTEGER IB1(409); IB1=-IB0(2:410);     / copy exclusion to IB1
 /   define slab medium numbers
  INTEGER IM0(409);DATA IM0=<1 6666 2 Q 135 3 1>;
 /   define slab region number
 /     all U will be region 1
 /     all intermedium voids will be region 2
 /     scintillator regions will be numbered as
 /               Itower * 1000000 + Iz * 1000
  INTEGER IR0(409);
  DATA IR0=< 1 2 -1 Q 19 3
             1 2 -2 Q 19 3
             1 2 -3 Q 19 3
             1 2 -4 Q 19 3
             1 2 -5 Q 19 3
             1 2 -6 Q 19 3
             1 2 -7 Q 15 3
             1 >;
 / now setup subgeometry zones as defined above
  SUBGEO;
  FOR I=1,409;
    ZONE IM0(I) IR0(I) IB0(I) IB1(I);
  ENDFOR;
 / End of geometry compillation
  ENDGEO;
 / Load geometry object file from unit 22;
  GEOIN;
 / Return to terminal input  for test
  UNIT 5;
```

(2) Input to HETC and SIM

```
//REW031H1 JOB ($$ACCOUNT$),'TEST1-HET',TIME=(64),REGION=3000K,
//     CLASS=C,MSGCLASS=A
/*JOBPARM  L=15
/*PASSWORD $MVS
/*ROUTE  PRINT CMS
//HET EXEC GFORTV,NAME=HETKFA2,DS='REW031.HERMES'
//G.FT20F001 DD DSN=REW071.HET86.BERT,DISP=SHR,LABEL=(,,,IN)     BERTP
//G.FT21F001 DD  DSN=REW031.HETSUB.TEST1,DISP=SHR                IOSUB
//G.FT22F001 DD  DSN=REW031.HETDET.TEST1,DISP=SHR                IOSIM
//G.FT96F001 DD  DUMMY                                           IODUM
//G.FT25F001 DD *                                                INGEO
$INCLUDE TEST1 GEO-O
/*
//G.SYSIN DD *
   / request detector output for each batch to unit 22
 SIMIO IOSIM 22;
  / load geometry object file from unit 25, print log. on unit 6
 GEOIN 25,6;
   / define detectors
   /   1. scintillation light in any SCSN38 region
 DEFDET EVIS,5,,,,,< 1001000 A 6 1000   2001000 A 6 1000 >;
   /   2. energy deposition all regions
 DEFDET EDEP,4;
   /   3. energy leakage into side,front and rear void
 DEFDET ELOS,9,,,,,,<3 4 5>;
RUN;   / return to het primary input
 &RUN
    MAXCAS= 1,  MAXBCH=1000,
    EMIN(1)=1., EMIN(2)=14.9, ELOP=20., EPICUT=2.23, EMUCUT=1.69,
    IBERTP=-20, IOSUB=21, NHSTP= 0,  INGEO= 0, IOGEO= 6,
    IELAS=2, ISTRAG=0, IANG=0, IFISS=1,KEYDK=1,

    MXMAT=2,

    NEL(1)=2, DENH(1)=0., KB(1)=0.,
      ZZ(1,1)=92., A(1,1)=238., DEN(1,1)= 4.7932E-2,
      ZZ(2,1)=92., A(2,1)=235., DEN(2,1)= 1.4607E-4,

    NEL(2)=1, DENH(2)=4.8295E-2, KB(2)=8.5E-3,
      ZZ(1,2)= 6., A(1,2)= 12., DEN(1,2)= 4.8295E-2,

     TIPSR=4., ESR= 5000. , EMAX=5000.,
     XSR=0.,YSR=0.,ZSR=0.001, USR=0.,VSR=0.,WSR=1.,
 &END
EXIT;
/*
```

(3) Input to MORSE

```
//REW101$$ JOB ($$ACCOUNT$),TEST1,TIME=(128),REGION=6000K,CLASS=C
/*PASSWORD $MVS
/*JOBPARM L=20
/*ROUTE PRINT CMS
//  EXEC  LGFORTV
//L.LOAD DD DSN=REW031.HERMES,DISP=SHR
//L.SYSIN DD *
  INCLUDE LOAD(MORSE)
  INCLUDE LOAD(CGL2)
  ENTRY MORSCG
//G.FT50F001 DD DSN=REW031.HETSUB.TEST1,DISP=SHR,LABEL=(,,,IN)
//G.FT20F001 DD DSN=REW031.EPRLIB,DISP=SHR,LABEL=(,,,IN)
//G.FT21F001 DD DSN=REW101.TEST1.MORDET.IBM,DISP=SHR
//G.SYSIN DD *
  HERMES TEST1       14 DETEKTOREN    CARD A
  0  0 32 6                                  /                  CARD A2
 113 2500  450 1 100 21 100 121 0 0 58   3 0/                  CARD B
  1 1 0 0 1.0E+0 1.0E-4 1.0E+4 1.0E-7 .6293E+6 /                    CARD C
   0. 0. 0. 0.  0. 0. 0.                  /                  CARD D
  50    21                                 /                  CARD D2
  /   ENERGIES (EV)                                          CARD F
 0.149E+08 0.135E+08 0.122E+08 0.111E+08 0.100E+08 0.905E+07 0.819E+07 /
 0.741E+07 0.670E+07 0.607E+07 0.549E+07 0.497E+07 0.449E+07 0.407E+07 /
 0.368E+07 0.333E+07 0.301E+07 0.273E+07 0.247E+07 0.223E+07 0.202E+07 /
 0.183E+07 0.165E+07 0.150E+07 0.135E+07 0.122E+07 0.111E+07 0.100E+07 /
 0.907E+06 0.821E+06 0.743E+06 0.672E+06 0.608E+06 0.550E+06 0.498E+06 /
 0.450E+06 0.408E+06 0.369E+06 0.334E+06 0.302E+06 0.273E+06 0.247E+06 /
 0.224E+06 0.202E+06 0.183E+06 0.166E+06 0.150E+06 0.136E+06 0.123E+06 /
 0.111E+06 0.865E+05 0.674E+05 0.525E+05 0.409E+05 0.318E+05 0.248E+05 /
 0.193E+05 0.150E+05 0.117E+05 0.912E+04 0.710E+04 0.553E+04 0.431E+04 /
 0.335E+04 0.261E+04 0.203E+04 0.158E+04 0.123E+04 0.961E+03 0.749E+03 /
 0.583E+03 0.454E+03 0.354E+03 0.275E+03 0.214E+03 0.167E+03 0.130E+03 /
 0.101E+03 0.789E+02 0.614E+02 0.479E+02 0.373E+02 0.290E+02 0.226E+02 /
 0.176E+02 0.137E+02 0.107E+02 0.832E+01 0.648E+01 0.504E+01 0.393E+01 /
 0.306E+01 0.238E+01 0.186E+01 0.144E+01 0.113E+01 0.876E+00 0.683E+00 /
 0.532E+00 0.414E+00 0.140E+08 0.120E+08 0.100E+08 0.800E+07 0.750E+07 /
 0.700E+07 0.650E+07 0.600E+07 0.550E+07 0.500E+07 0.450E+07 0.400E+07 /
 0.350E+07 0.300E+07 0.250E+07 0.200E+07 0.150E+07 0.100E+07 0.400E+06 /
 0.200E+06 0.100E+06                     ;                E 0 CARD F
000035FA731A                             /                  CARD H
 1 1 0 0 0  3 121 0                      /                  CARD I
   0 0 0 0 0 0 1.0E+0 1.00E+0 1.0E+0 0.0E+0 /               CARD J
  -1                                     /                E 0 CARD J
 0 1 0 0                                 /                  CARD L
 F 1. ;                    FISSION WEIGHTS FWLO(MXREG)      CARD M
                         / FISSION SPEC. FSE(NMTG,MEDIA)    CARD N
 .4122E-04 .1133E-03 .2770E-03 .6091E-03 .1218E-02 .2233E-02 .3791E-02 /
 .6003E-02 .8930E-02 .1256E-01 .1679E-01 .2145E-01 .2632E-01 .3113E-01 /
 .3564E-01 .3961E-01 .4289E-01 .4536E-01 .4696E-01 .4771E-01 .4766E-01 /
 .4689E-01 .4551E-01 .4363E-01 .4133E-01 .3886E-01 .3618E-01 .3342E-01 /
 .3065E-01 .2793E-01 .2531E-01 .2282E-01 .2048E-01 .1830E-01 .1630E-01 /
 .1446E-01 .1280E-01 .1129E-01 .9941E-02 .8732E-02 .7654E-02 .6698E-02 /
 .5852E-02 .5105E-02 .4448E-02 .3871E-02 .3365E-02 .2923E-02 .2536E-02 /
 .4959E-02 .3458E-02 .2403E-02 .1666E-02 .1153E-02 .7967E-03 .5498E-03 /
 .3791E-03  R 64 0.0 R 121 0.0 /
 .4122E-04 .1133E-03 .2770E-03 .6091E-03 .1218E-02 .2233E-02 .3791E-02 /
 .6003E-02 .8930E-02 .1256E-01 .1679E-01 .2145E-01 .2632E-01 .3113E-01 /
 .3564E-01 .3961E-01 .4289E-01 .4536E-01 .4696E-01 .4771E-01 .4766E-01 /
 .4689E-01 .4551E-01 .4363E-01 .4133E-01 .3886E-01 .3618E-01 .3342E-01 /
 .3065E-01 .2793E-01 .2531E-01 .2282E-01 .2048E-01 .1830E-01 .1630E-01 /
 .1446E-01 .1280E-01 .1129E-01 .9941E-02 .8732E-02 .7654E-02 .6698E-02 /
 .5852E-02 .5105E-02 .4448E-02 .3871E-02 .3365E-02 .2923E-02 .2536E-02 /
 .4959E-02 .3458E-02 .2403E-02 .1666E-02 .1153E-02 .7967E-03 .5498E-03 /
```

```
 .3791E-03  R 64 0.0 F 0.      ;                              E O CARD N
R 100 1. R 21 0. Q 2 121 ;    GAMMA PROB.'S GWLO(NMTG,MXREG)    CARD O
MATERIALIEN  EPR WQ PS VON FT20                                 CARD XA
 100 100 21 21 121 124 4  3 4  5 6 3  0/                       CARD XB
 0 0 0 0 0 0 0 20 0 0 0 0  0 0        /                         CARD XC
  64 A 5 1 127 A 5 1  / C     H
 262 A 5 1 253 A 5 1  ; U238  U235                              CARD XD
    1    3  4.7932E-2         U238                               CARD XF
    1   -4  1.4607E-4       + U235
    2    2  4.8295E-2         H
    2   -1  4.8295E-2       + C
    3   -2  4.8295E-2         H
ANALYSIS INPUT                                                 CARD AA
   14  100  121    0    0    1    0  100  1 1/                   CARD BB
 VL
F 0. ;                                                         CARD CCX
F 0. ;                                                          CARD CCY
F 0. ;                                                          CARD CCY
1001000 A 6 1000 2001000 A 6 1000;
F 3 ;
                                                               CARD DD
 / VISIBLE ENERGY IN SCSN38 ; 7X INNER, 7X OUTER, 7X OUTER TOWER EXTRA
  R 100 1. /
   F 0. ;
                                                              CARD GG
    1 A 120 1 ;                                               CARD HH

 1                        / NUMBR
 14 1. 0.0085 1 4.8295E-2 / NDETEC S KB NEL DENH
 /                        /ID = REGION NUMBERS
1001000 A 6 1000 2001000 A 6 1000;
 F 6. ;        ZZ
 F 12. ;       A
 F 4.8295E-2 ; DEN
//G.FT32F001 DD *
        412       435       435      4600      16000          0          0
          4         0
          0 1.000E+00
  PZ  1000     0.000
  PZ  1001     0.300
  PZ  1002     0.350
  PZ  1003     0.600
  PZ  1004     0.900
  PZ  1005     0.950
  PZ  1006     1.200
  PZ  1007     1.500
  PZ  1008     1.550
  PZ  1009     1.800
  PZ  1010     2.100
  PZ  1011     2.150
  PZ  1012     2.400
  PZ  1013     2.700
  PZ  1014     2.750
  PZ  1015     3.000
  PZ  1016     3.300
  PZ  1017     3.350
  PZ  1018     3.600
  PZ  1019     3.900
  PZ  1020     3.950
  PZ  1021     4.200
  PZ  1022     4.500
  PZ  1023     4.550
  PZ  1024     4.800
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PZ	1025	5.100
PZ	1026	5.150
PZ	1027	5.400
PZ	1028	5.700
PZ	1029	5.750
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PZ	1032	6.350
PZ	1033	6.600
PZ	1034	6.900
PZ	1035	6.950
PZ	1036	7.200
PZ	1037	7.500
PZ	1038	7.550
PZ	1039	7.800
PZ	1040	8.100
PZ	1041	8.150
PZ	1042	8.400
PZ	1043	8.700
PZ	1044	8.750
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PZ	1053	10.550
PZ	1054	10.800
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PZ	1056	11.150
PZ	1057	11.400
PZ	1058	11.700
PZ	1059	11.750
PZ	2000	12.000
PZ	2001	12.300
PZ	2002	12.350
PZ	2003	12.600
PZ	2004	12.900
PZ	2005	12.950
PZ	2006	13.200
PZ	2007	13.500
PZ	2008	13.550
PZ	2009	13.800
PZ	2010	14.100
PZ	2011	14.150
PZ	2012	14.400
PZ	2013	14.700
PZ	2014	14.750
PZ	2015	15.000
PZ	2016	15.300
PZ	2017	15.350
PZ	2018	15.600
PZ	2019	15.900
PZ	2020	15.950
PZ	2021	16.200
PZ	2022	16.500
PZ	2023	16.550
PZ	2024	16.800
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PZ	2026	17.150
PZ	2027	17.400
PZ	2028	17.700
PZ	2029	17.750
PZ	2030	18.000
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PZ	2032	18.350
PZ	2033	18.600
PZ	2034	18.900
PZ	2035	18.950
PZ	2036	19.200
PZ	2037	19.500
PZ	2038	19.550
PZ	2039	19.800
PZ	2040	20.100
PZ	2041	20.150
PZ	2042	20.400
PZ	2043	20.700
PZ	2044	20.750
PZ	2045	21.000
PZ	2046	21.300
PZ	2047	21.350
PZ	2048	21.600
PZ	2049	21.900
PZ	2050	21.950
PZ	2051	22.200
PZ	2052	22.500
PZ	2053	22.550
PZ	2054	22.799
PZ	2055	23.099
PZ	2056	23.149
PZ	2057	23.399
PZ	2058	23.699
PZ	2059	23.749
PZ	3000	23.999
PZ	3001	24.299
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PZ	4021	40.198
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PZ	4023	40.548
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PZ	4026	41.148
PZ	4027	41.398
PZ	4028	41.698
PZ	4029	41.748
PZ	4030	41.998
PZ	4031	42.298
PZ	4032	42.348
PZ	4033	42.598
PZ	4034	42.898
PZ	4035	42.948
PZ	4036	43.198
PZ	4037	43.498
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PZ	4041	44.148
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PZ	5031	54.297
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PZ	5054	58.797
PZ	5055	59.097
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PZ	6014	62.747
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PZ	6016	63.297
PZ	6017	63.347
PZ	6018	63.597
PZ	6019	63.897
PZ	6020	63.947
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PZ	6022	64.497
PZ	6023	64.547
PZ	6024	64.797
PZ	6025	65.097
PZ	6026	65.147
PZ	6027	65.397
PZ	6028	65.697
PZ	6029	65.747
PZ	6030	65.997
PZ	6031	66.297
PZ	6032	66.347
PZ	6033	66.597
PZ	6034	66.897
PZ	6035	66.947
PZ	6036	67.197
PZ	6037	67.497
PZ	6038	67.547
PZ	6039	67.797
PZ	6040	68.097
PZ	6041	68.146
PZ	6042	68.396
PZ	6043	68.696
PZ	6044	68.746
PZ	6045	68.996
PZ	6046	69.296
PZ	6047	69.346
PZ	6048	69.596
PZ	6049	69.896
PZ	6050	69.946
PZ	6051	70.196
PZ	6052	70.496
PZ	6053	70.546
PZ	6054	70.796
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PZ	6056	71.146
PZ	6057	71.396
PZ	6058	71.696
PZ	6059	71.746
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PZ	7008	73.546
PZ	7009	73.796
PZ	7010	74.096
PZ	7011	74.146
PZ	7012	74.396
PZ	7013	74.696
PZ	7014	74.746
PZ	7015	74.996
PZ	7016	75.296
PZ	7017	75.346
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PZ	7019	75.896
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PZ	7021	76.196
PZ	7022	76.496
PZ	7023	76.546
PZ	7024	76.796
PZ	7025	77.096
PZ	7026	77.146
PZ	7027	77.396
PZ	7028	77.696
PZ	7029	77.746
PZ	7030	77.996
PZ	7031	78.296
PZ	7032	78.346
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PZ	7038	79.546
PZ	7039	79.796
PZ	7040	80.096
PZ	7041	80.146
PZ	7042	80.396

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  PZ  7043     80.696
  PZ  7044     80.746
  PZ  7045     80.996
  PZ  7046     81.296
  PZ  7047     81.346
  PZ  7048     81.596
  PZ  8000     81.896
  RPP  500   -10.000     10.000   -10.000     10.000   -10.000     90.000
  RPP  501   -30.000     30.000   -30.000     30.000   -10.000     90.000
  END
   -2   -1     500    1000  -8000GO     2
   -2   -2     501    -500   1000  -8000GO     2
   -1    3    -501    1000  -8000
   -1    4   -1000
   -1    5    8000
  777
    1    1    1000   -1001
 1000    2    1001   -1002
    2   -1    1002   -1003
    1    1    1003   -1004
 1000    2    1004   -1005
    2   -1    1005   -1006
    1    1    1006   -1007
 1000    2    1007   -1008
    2   -1    1008   -1009
    1    1    1009   -1010
 1000    2    1010   -1011
    2   -1    1011   -1012
    1    1    1012   -1013
 1000    2    1013   -1014
    2   -1    1014   -1015
    1    1    1015   -1016
 1000    2    1016   -1017
    2   -1    1017   -1018
    1    1    1018   -1019
 1000    2    1019   -1020
    2   -1    1020   -1021
    1    1    1021   -1022
 1000    2    1022   -1023
    2   -1    1023   -1024
    1    1    1024   -1025
 1000    2    1025   -1026
    2   -1    1026   -1027
    1    1    1027   -1028
 1000    2    1028   -1029
    2   -1    1029   -1030
    1    1    1030   -1031
 1000    2    1031   -1032
    2   -1    1032   -1033
    1    1    1033   -1034
 1000    2    1034   -1035
    2   -1    1035   -1036
    1    1    1036   -1037
 1000    2    1037   -1038
    2   -1    1038   -1039
    1    1    1039   -1040
 1000    2    1040   -1041
    2   -1    1041   -1042
    1    1    1042   -1043
 1000    2    1043   -1044
    2   -1    1044   -1045
    1    1    1045   -1046
 1000    2    1046   -1047
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1	1	1048	-1049
1000	2	1049	-1050
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1000	2	1052	-1053
2	-1	1053	-1054
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1000	2	1055	-1056
2	-1	1056	-1057
1	1	1057	-1058
1000	2	1058	-1059
2	-1	1059	-2000
1	1	2000	-2001
1000	2	2001	-2002
2	-2	2002	-2003
1	1	2003	-2004
1000	2	2004	-2005
2	-2	2005	-2006
1	1	2006	-2007
1000	2	2007	-2008
2	-2	2008	-2009
1	1	2009	-2010
1000	2	2010	-2011
2	-2	2011	-2012
1	1	2012	-2013
1000	2	2013	-2014
2	-2	2014	-2015
1	1	2015	-2016
1000	2	2016	-2017
2	-2	2017	-2018
1	1	2018	-2019
1000	2	2019	-2020
2	-2	2020	-2021
1	1	2021	-2022
1000	2	2022	-2023
2	-2	2023	-2024
1	1	2024	-2025
1000	2	2025	-2026
2	-2	2026	-2027
1	1	2027	-2028
1000	2	2028	-2029
2	-2	2029	-2030
1	1	2030	-2031
1000	2	2031	-2032
2	-2	2032	-2033
1	1	2033	-2034
1000	2	2034	-2035
2	-2	2035	-2036
1	1	2036	-2037
1000	2	2037	-2038
2	-2	2038	-2039
1	1	2039	-2040
1000	2	2040	-2041
2	-2	2041	-2042
1	1	2042	-2043
1000	2	2043	-2044
2	-2	2044	-2045
1	1	2045	-2046
1000	2	2046	-2047
2	-2	2047	-2048
1	1	2048	-2049
1000	2	2049	-2050
2	-2	2050	-2051
1	1	2051	-2052
1000	2	2052	-2053
2	-2	2053	-2054
1	1	2054	-2055
1000	2	2055	-2056
2	-2	2056	-2057
1	1	2057	-2058
1000	2	2058	-2059
2	-2	2059	-3000
1	1	3000	-3001
1000	2	3001	-3002
2	-3	3002	-3003
1	1	3003	-3004
1000	2	3004	-3005
2	-3	3005	-3006
1	1	3006	-3007
1000	2	3007	-3008
2	-3	3008	-3009
1	1	3009	-3010
1000	2	3010	-3011
2	-3	3011	-3012
1	1	3012	-3013
1000	2	3013	-3014
2	-3	3014	-3015
1	1	3015	-3016
1000	2	3016	-3017
2	-3	3017	-3018
1	1	3018	-3019
1000	2	3019	-3020
2	-3	3020	-3021
1	1	3021	-3022
1000	2	3022	-3023
2	-3	3023	-3024
1	1	3024	-3025
1000	2	3025	-3026
2	-3	3026	-3027
1	1	3027	-3028
1000	2	3028	-3029
2	-3	3029	-3030
1	1	3030	-3031
1000	2	3031	-3032
2	-3	3032	-3033
1	1	3033	-3034
1000	2	3034	-3035
2	-3	3035	-3036
1	1	3036	-3037
1000	2	3037	-3038
2	-3	3038	-3039
1	1	3039	-3040
1000	2	3040	-3041
2	-3	3041	-3042
1	1	3042	-3043
1000	2	3043	-3044
2	-3	3044	-3045
1	1	3045	-3046
1000	2	3046	-3047
2	-3	3047	-3048
1	1	3048	-3049
1000	2	3049	-3050
2	-3	3050	-3051
1	1	3051	-3052
1000	2	3052	-3053

2	-3	3053	-3054
1	1	3054	-3055
1000	2	3055	-3056
2	-3	3056	-3057
1	1	3057	-3058
1000	2	3058	-3059
2	-3	3059	-4000
1	1	4000	-4001
1000	2	4001	-4002
2	-4	4002	-4003
1	1	4003	-4004
1000	2	4004	-4005
2	-4	4005	-4006
1	1	4006	-4007
1000	2	4007	-4008
2	-4	4008	-4009
1	1	4009	-4010
1000	2	4010	-4011
2	-4	4011	-4012
1	1	4012	-4013
1000	2	4013	-4014
2	-4	4014	-4015
1	1	4015	-4016
1000	2	4016	-4017
2	-4	4017	-4018
1	1	4018	-4019
1000	2	4019	-4020
2	-4	4020	-4021
1	1	4021	-4022
1000	2	4022	-4023
2	-4	4023	-4024
1	1	4024	-4025
1000	2	4025	-4026
2	-4	4026	-4027
1	1	4027	-4028
1000	2	4028	-4029
2	-4	4029	-4030
1	1	4030	-4031
1000	2	4031	-4032
2	-4	4032	-4033
1	1	4033	-4034
1000	2	4034	-4035
2	-4	4035	-4036
1	1	4036	-4037
1000	2	4037	-4038
2	-4	4038	-4039
1	1	4039	-4040
1000	2	4040	-4041
2	-4	4041	-4042
1	1	4042	-4043
1000	2	4043	-4044
2	-4	4044	-4045
1	1	4045	-4046
1000	2	4046	-4047
2	-4	4047	-4048
1	1	4048	-4049
1000	2	4049	-4050
2	-4	4050	-4051
1	1	4051	-4052
1000	2	4052	-4053
2	-4	4053	-4054
1	1	4054	-4055
1000	2	4055	-4056
2	-4	4056	-4057
1	1	4057	-4058
1000	2	4058	-4059
2	-4	4059	-5000
1	1	5000	-5001
1000	2	5001	-5002
2	-5	5002	-5003
1	1	5003	-5004
1000	2	5004	-5005
2	-5	5005	-5006
1	1	5006	-5007
1000	2	5007	-5008
2	-5	5008	-5009
1	1	5009	-5010
1000	2	5010	-5011
2	-5	5011	-5012
1	1	5012	-5013
1000	2	5013	-5014
2	-5	5014	-5015
1	1	5015	-5016
1000	2	5016	-5017
2	-5	5017	-5018
1	1	5018	-5019
1000	2	5019	-5020
2	-5	5020	-5021
1	1	5021	-5022
1000	2	5022	-5023
2	-5	5023	-5024
1	1	5024	-5025
1000	2	5025	-5026
2	-5	5026	-5027
1	1	5027	-5028
1000	2	5028	-5029
2	-5	5029	-5030
1	1	5030	-5031
1000	2	5031	-5032
2	-5	5032	-5033
1	1	5033	-5034
1000	2	5034	-5035
2	-5	5035	-5036
1	1	5036	-5037
1000	2	5037	-5038
2	-5	5038	-5039
1	1	5039	-5040
1000	2	5040	-5041
2	-5	5041	-5042
1	1	5042	-5043
1000	2	5043	-5044
2	-5	5044	-5045
1	1	5045	-5046
1000	2	5046	-5047
2	-5	5047	-5048
1	1	5048	-5049
1000	2	5049	-5050
2	-5	5050	-5051
1	1	5051	-5052
1000	2	5052	-5053
2	-5	5053	-5054
1	1	5054	-5055
1000	2	5055	-5056
2	-5	5056	-5057
1	1	5057	-5058
1000	2	5058	-5059

```
   2   -5   5059  -6000
   1    1   6000  -6001
1000    2   6001  -6002
   2   -6   6002  -6003
   1    1   6003  -6004
1000    2   6004  -6005
   2   -6   6005  -6006
   1    1   6006  -6007
1000    2   6007  -6008
   2   -6   6008  -6009
   1    1   6009  -6010
1000    2   6010  -6011
   2   -6   6011  -6012
   1    1   6012  -6013
1000    2   6013  -6014
   2   -6   6014  -6015
   1    1   6015  -6016
1000    2   6016  -6017
   2   -6   6017  -6018
   1    1   6018  -6019
1000    2   6019  -6020
   2   -6   6020  -6021
   1    1   6021  -6022
1000    2   6022  -6023
   2   -6   6023  -6024
   1    1   6024  -6025
1000    2   6025  -6026
   2   -6   6026  -6027
   1    1   6027  -6028
1000    2   6028  -6029
   2   -6   6029  -6030
   1    1   6030  -6031
1000    2   6031  -6032
   2   -6   6032  -6033
   1    1   6033  -6034
1000    2   6034  -6035
   2   -6   6035  -6036
   1    1   6036  -6037
1000    2   6037  -6038
   2   -6   6038  -6039
   1    1   6039  -6040
1000    2   6040  -6041
   2   -6   6041  -6042
   1    1   6042  -6043
1000    2   6043  -6044
   2   -6   6044  -6045
   1    1   6045  -6046
1000    2   6046  -6047
   2   -6   6047  -6048
   1    1   6048  -6049
1000    2   6049  -6050
   2   -6   6050  -6051
   1    1   6051  -6052
1000    2   6052  -6053
   2   -6   6053  -6054
   1    1   6054  -6055
1000    2   6055  -6056
   2   -6   6056  -6057
   1    1   6057  -6058
1000    2   6058  -6059
   2   -6   6059  -7000
   1    1   7000  -7001
1000    2   7001  -7002
   2   -7   7002  -7003
   1    1   7003  -7004
1000    2   7004  -7005
   2   -7   7005  -7006
   1    1   7006  -7007
1000    2   7007  -7008
   2   -7   7008  -7009
   1    1   7009  -7010
1000    2   7010  -7011
   2   -7   7011  -7012
   1    1   7012  -7013
1000    2   7013  -7014
   2   -7   7014  -7015
   1    1   7015  -7016
1000    2   7016  -7017
   2   -7   7017  -7018
   1    1   7018  -7019
1000    2   7019  -7020
   2   -7   7020  -7021
   1    1   7021  -7022
1000    2   7022  -7023
   2   -7   7023  -7024
   1    1   7024  -7025
1000    2   7025  -7026
   2   -7   7026  -7027
   1    1   7027  -7028
1000    2   7028  -7029
   2   -7   7029  -7030
   1    1   7030  -7031
1000    2   7031  -7032
   2   -7   7032  -7033
   1    1   7033  -7034
1000    2   7034  -7035
   2   -7   7035  -7036
   1    1   7036  -7037
1000    2   7037  -7038
   2   -7   7038  -7039
   1    1   7039  -7040
1000    2   7040  -7041
   2   -7   7041  -7042
   1    1   7042  -7043
1000    2   7043  -7044
   2   -7   7044  -7045
   1    1   7045  -7046
1000    2   7046  -7047
   2   -7   7047  -7048
   1    1   7048  -8000
 999
/* E O F
```

(4) Input to NDEM (not applied in this problem)

(5) Input to PEGS

```
//REW031P1 JOB ($$ACCOUNT$),PEGS4,CLASS=C,MSGCLASS=A,REGION=2000K,
//  TIME=(4)
/*JOBPARM L=15
/*PASSWORD $MVS
/*ROUTE  PRINT CMS
//   EXEC GFORTV,NAME=PEGS4,DS='REW031.HERMES'
//G.FT06F001 DD SYSOUT=*
//G.FT07F001 DD  DSN=REW031.PEGS4.TEST1,DISP=SHR
//G.FT08F001 DD DSN=REW071.PEGS4.PEPR,DISP=SHR,LABEL=(,,,IN)
//G.FT09F001 DD DSN=REW071.PEGS4.FORM,DISP=SHR,LABEL=(,,,IN)
//G.FT10F001 DD SYSOUT=*,DCB=(RECFM=UA,LRECL=132)
//G.SYSIN DD *  FT05F001
ENER
 &INP AE=0.711,UE=5000.,AP=0.10,UP=5000., &END
COMP
 &INP NE=2, RHO=1.044,  PZ=1.,1.,
  AFACT=0.,CBAR=0.,SK=0.,X0=0.,X1=0.,IEV=0.,
 &END
SCSN38
H  C
PWLF
 &INP &END
DECK
 &INP &END
MIXT
 &INP NE=2,  RHO=19., RHOZ= 99.97,0.03, WA=238.,235.,
  AFACT=0.,CBAR=0.,SK=0.,X0=0.,X1=0.,IEV=0.,
 &END
URAN
U  U
PWLF
 &INP &END
DECK
 &INP &END
STOP
 &INP &END
/*
```

(6) Input to EGS (for π^0-processing)

```
//REW031$$ JOB ($$ACCOUNT$),'TEST1-EGS4',CLASS=C,MSGCLASS=A,
//  REGION=2000K,TIME=(128)
/*JOBPARM L=15
/*PASSWORD $MVS
/*ROUTE  PRINT CMS
//* ---------------------------------------------------------------
//*   EGS
//* ---------------------------------------------------------------
//  EXEC GFORTV,COND=(9,LT),NAME=EGS4,DS='REW031.HERMES'
//G.SYSIN    DD *
 &EGS
  IRUN=1,  MHIS=1, MBAT= 500, IXX=123456789,
  INEGS=1,IOEGS=2, INGEO=5,IOGEO=6,
  NMED=2,
  MEDNAM=  'URAN',      'SCSN38',
  ESTEPE=   0.005,        0.01,
  NREG=19,
  LSTREG= 1001000,1002000,1003000,1004000,1005000,1006000,1007000,
          2001000,2002000,2003000,2004000,2005000,2006000,2007000,
                1,      2,      3,      4,      5,
  ECUT=   7*1.511, 7*1.511, 1.511, 4*0.,
  PCUT=   7*0.100, 7*0.100, 0.100, 4*0.,
  MED=        7*2,     7*2,     1, 4*0,
  IRAYLR=                          19*0,
  IQI=-1,  EI=5.E3, XI=0.,YI=0.,ZI=0.01, UI=0.,VI=0.,WI=1.,WTI=1.,
 &END
$INCLUDE TEST1 GEO-O
/*
//G.FT01F001 DD DSN=REW031.HETSUB.TEST1,DISP=SHR      SOURCE FILE
//G.FT02F001 DD DSN=REW031.EGSPIO.TEST1,DISP=SHR      EGS DETECTOR FILE
//G.FT12F001 DD DSN=REW031.PEGS4.TEST1,DISP=SHR       HATCH INPUT
//G.FT08F001 DD DUMMY
```

(7) Input to STATIST

```
//REW031$$ JOB ($$ACCOUNT$),'TEST1-STATIST',TIME=(,30),REGION=4000K,
//    CLASS=C,MSGCLASS=A
/*JOBPARM  L=15
//* test1 statist
/*PASSWORD $MVS
/*ROUTE  PRINT CMS.REW031
//  EXEC GFORTV,DS='REW031.HERMES',NAME=STATPRT
//*             grafic workspace ( line printer grafic )
//G.FT04F001 DD UNIT=TEMP,SPACE=(TRK,(10,2)),DISP=(NEW,DELETE)
//*             grafic output    ( line printer grafic )
//G.FT08F001 DD SYSOUT=L,DEST=(CMS,REW031)
//*             submission files
//G.FT10F001 DD DSN=REW031.HETDET.TEST1,DISP=SHR
//G.FT11F001 DD DSN=REW031.MORDET.TEST1,DISP=SHR
//G.FT12F001 DD DSN=REW031.EGSPI0.TEST1,DISP=SHR
//G.SYSIN DD *
/  Test1 STATIST
/ 1)   define data arrays for STATIST analysis
/ 1.1) setup arrays to read in HET, MORSE, and EGS(pi0) detector records
 REAL EDEP(19);
 REAL FHET(14,19),FMOR(14),FPI0(19,3,5);
/ 1.2) setup arrays to keep the sums
/    over all contribution types of interest
 REAL EHET(14)   ,EMOR(14),EPI0(19)    ;
/ 1.3) setup weight arrays used to extract the contributions of interest
 REAL WHET(19)   ,WMOR(1) ,WPI0(15)    ;
 DATA WHET=< 1. 1. 1. F 0.>;
 DATA WMOR=1.;
 DATA WPI0=< R 3 1. R 3 1. R 3 1. R 3 0.  0. 1. 0.>;
/ 1.4) setup an array to sum over all scintillator regions
 REAL SCINT(19);DATA SCINT=<R 14 1. F 0.>;
/ 1.5) setup variables for final event results
 REAL EVCHG(1),EVPI0(1),EVNEU(1);
/ 2)   start event processing (7 variables 450 events)
 STATIN 7,450;
/ 2.1) load detector records from submission files
 LOAD 10,EVIS@EOB,FHET; / HET DIFFERENTIAL PULSE DISTRBUTION
 LOAD 10,EDEP@EOB,EDEP; / HET GLOBAL ENERGY DEPOSITION
 LOAD 11,R001@EOB,FMOR; / MORSE VISIBLE N ENERGY
 LOAD 12,EDEP@EOB,FPI0 ;/ EGS   VISIBLE PI0 ENERGY
/ 2.2) extract main contributions
 DOT EHET=FHET*WHET;          / EXTRACT  EVIS
 DOT EMOR=FMOR*WMOR;          / EXTRACT  EVIS
 DOT EPI0=FPI0*WPI0 (19,15,1);/ EXTRACT  EVIS
/ 2.3) sum over all scintillator regions
 DOT EVCHG=EHET*SCINT (1,14,1);
 DOT EVNEU=EMOR*SCINT (1,14,1);
 DOT EVPI0=EPI0*SCINT (1,19,1);

/ 2.4) assign V  containg 7 variables
/      for each event, V is stacked into EVENT
 SET V( 1)=EDEP(1)+EDEP(2)+EDEP(3);
 SET V( 2)=EDEP(17);
 SET V( 3)=EDEP(18);
 SET V( 4)=EVCHG(1);
 SET V( 5)=EVNEU(1);
 SET V( 6)=EVPI0(1);
 SET V( 7)=V(4)+V(5)+V(6);
/ 3)   start end of run analysis
 BIN  1,0.,5000., 50,' Edep p,pi+,pi-';
 BIN  2,0.,1000., 50,' Esub n';
 BIN  3,0.,5000., 50,' Esub pi0';
```

```
 BIN  4,0.,500.0, 50,' Evis p,pi+,pi-';
 BIN  5,0.,100.0, 50,' Evis n';
 BIN  6,0.,500.0, 50,' Evis pi0';

 BIN  7,0.,500.0, 50,' Evis p,pi+,pi-,n,pi0';
 / NOTE: FIT and SCAT require a previous call of BIN
 /       for the variables wanted.
 FIT  7;
 SCAT 1,4;
 SCAT 2,5;
 SCAT 3,6;
 STATIST PLOT;
 EXIT;
/*
```

E.1.2 Output Files Excerpt for Sample Problem I

(1) Geometry Object File on Tape

(2) Output of HETC and SIM

```
/JOB-ID = REW031H1 05/03/88 12:36:16
I:    / request detector output for each batch to unit 22
I: SIMIO IOSIM 22;
I:    / load geometry object file from unit 25, print log. on unit 6
I: GEOIN 25,6;
 NUMB. OF BODIES (NUMB)                  412
 NUMB. OF REGIONS (NUMR)                 435
 NUMBER OF CODE REGIONS (NCOD)           435
 LENGTH OF FDP ARRAY (LMXX)             4600
 LENGTH OF MA ARRAY (LMYY)             16000
 MODIFIED INPUT (LOUT)                     0
 VOLUME INPUT OPTION (IVOPT)         4 NOT USED
 BOUNDARY OPTION (MEDREG)                  0
 DEBUG OPTION (IDBGO)                      0

MACHINE EPS =  0.100000E-07


IPRINT=          0
STRETCH= 1.0000000E+00

NUMBER OF BODIES           412
LENGTH OF MA -ARRAY       2885
LENGTH OF FPD-ARRAY       4543
SUB-GEOMETRY #2
NUMBER OF INPUT ZONES     414
NUMBER OF  CODE ZONES     414
LENGTH OF INTEGER ARRAY 6619
I:    / define detectors
I:    /    1. scintillation light in any SCSN38 region
I: DEFDET EVIS,5,,,,,< 1001000 A 6 1000   2001000 A 6 1000 >;
I:    /    2. energy deposition all regions
I: DEFDET EDEP,4;
I:    /    3. energy leakage into side,front and rear void
I: DEFDET ELOS,9,,,,,,<3 4 5>;
I:RUN;    / return to het primary input
MAXBCH=1000   IBERTP=-20  EMIN(1)= 1.000E+00  ELOP  = 2.000E+01
MAXCAS=    1  IOSUB = 21  EMIN(2)= 1.490E+01  CTOFE = 0.000E+00
IRUN  =    1  NHSTP =  0  EPICUT = 2.230E+00  EMAX  = 5.000E+03
                          EMUCUT = 1.690E+00  B0    = 8.000E+00
NICOL =0  NPIDK =1  NBOGUS =1  NSEUDO=1
NSPRED=0  NWSPRD=0  ISTRAG =0  IANG  =0
IFISS =1  IBO   =1  IGEOM  =0  KEYDK =1
IELAS =2
ISEED =  123456789
LHI   =0  HIA(5)=  0.0  HIZ(5)=  0.0  HIBE(5)= 0.000E+00
/BERTTP(1): I-N-C  DATA READ FORM UNIT 20
/BERTTP(1): EVAP   DATA READ FORM UNIT 20
FISSION OPTION SELECTED
HSIGMX     0.12000E-23    0.64942E-24    0.20000E-24    0.00000E+00    0.67700E-25
THIS IS MEDIUM  1
DENH=0.000000E+00  NEL= 2  SO= 1.000E+00  KB= 0.000E+00
ZZ( 1, 1)=92.0  A( 1, 1)=238.0  DEN( 1, 1)=4.793200E-02
ZZ( 2, 1)=92.0  A( 2, 1)=235.0  DEN( 2, 1)=1.460700E-04
THIS IS MEDIUM  2
DENH=4.829500E-02  NEL= 1  SO= 1.000E+00  KB= 6.500E-03
ZZ( 1, 2)= 6.0  A( 1, 2)= 12.0  DEN( 1, 2)=4.829500E-02
 "GEOMETRIC" X-SECTIONS IN (1/CM)

  NUCLIDS:     1           2           3           4           5           6           7           8           9           10
  MEDIA
      1     1.2568E-01  3.8128E-04
      2     3.7396E-02
 MAXIMUM M-1 X-SECTIONS IN (1/CM)
```

```
  MEDIA         PROTONS     NEUTRONS          PI+          PIO          PI-
      1     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
      2     5.7954E-02   3.1364E-02   9.6590E-03   0.0000E+00   3.2696E-03
TRANSPORT X-SECTION = SUM("GEOMETRIC") + MAX. H-1 + MAX. DECAY X-SECTIONS IN (1/CM)

  MEDIA         PROTONS     NEUTRONS          PI+          PIO          PI-          MUE+          MUE-
      1     1.2626E-01   1.2626E-01   1.3329E-01   0.0000E+00   1.3329E-01   8.8943E-05   8.8943E-05
      2     9.5350E-02   6.8759E-02   5.4078E-02   0.0000E+00   4.7689E-02   8.8943E-05   8.8943E-05
SOURCE DATA:
TYP     =         4.
XYZ     =     0.000      0.000      0.001  GAUSSIAN DISTRIBUTED WITH
XYZ SIG.=     0.000      0.000      0.000  TRUNCATED TO RADIUS
  R     =     0.000                        IF R>0
UVW     =    0.0000     0.0000     1.0000  IF = 0.,0.,0. -> ISOTROPIC
 WT     =     1.000
  E     =  5000.000  GAUSSIAN DISTRBUTED WITH
  E SIG.=     0.000
M:GOMIN INGEO= 0 IOGEO= 6
```

```
--> SOR HET    IRUN=     1 ISEED=  123456789
/SUBMIT(I): IOSUB=21
/HET1(I): SKALING TURNED ON
--> SOB HET    IBAT=     1 ISEED=  123456789
/BERTTP(I): I-N-C  DATA READ FORM UNIT 20
/DRESF(I): USING 1977 WAPS DATA
--> EOB HET    IBAT=     1 ISEED= 1486727229 NHIS=     1 CPU=    27.05SEC.
  MEDIUM    SORS    CASC    SLOW    ESCP    PSEU    ABSO    BRDY    SCAT

       1       1      61       9       3      10       6     717       0       0
       2       0      17       2       2      11       1     728       0       0
    6666       0       0       0       0       1       0     722       0       0
   TOTAL       1      78      11       5      22       7    2167       0       0
/SUBMIT(I): NEUTRONS:    156, PIO:      2, NUCLEI:     24
-------------------------------------------------------------------------------
--> SOB HET    IBAT=     2 ISEED= 1486727229
--> EOB HET    IBAT=     2 ISEED= 1453333397 NHIS=     2 CPU=     2.71SEC.
/SUBMIT(I): NEUTRONS:    102, PIO:      2, NUCLEI:     22
-------------------------------------------------------------------------------
                .
                .
                .
--> EOR HET    IRUN=     1 ISEED=  606246303 NHIS= 1000 CPU= 1877.56SEC.
  MEDIUM    SORS    CASC    SLOW    ESCP    PSEU    ABSO    BRDY    SCAT

       1    1000   29539   13443    3009    6137    3474  375957       0       0
       2       0    6128    2665     696    5767     115  380467       0       0
    6666       0       0       0     145     201       0  377238       0       0
   TOTAL    1000   35667   16108    3850   12105   35891  133662       0       0
                REAL          PSEUDO          REAL          PSEUDO          PSEUDO          REAL          PSEUDO
               NONHYDROG     NONHYDROG       HYDROGEN      HYDROGEN        DECAY         ELASTIC       ELASTIC
               COLLISIONS    COLLISIONS      COLLISIONS    COLLISIONS      COLLISIONS    COLLISIONS    COLLISIONS
MEDIUM   1  0.15077E+05   0.58720E+04   0.00000E+00   0.00000E+00   0.16600E+03   0.17936E+05   0.96000E+02
MEDIUM   2  0.20560E+04   0.29300E+04   0.13570E+04   0.27060E+04   0.11300E+03   0.28300E+04   0.17000E+02


                                  PSEUDO COLLISIONS WITHIN INTERNAL VOID BY PARTICLES OF

        TYPE 1          TYPE 2          TYPE 3          TYPE 4          TYPE 5          TYPE 6          TYPE 7

      0.15000E+02     0.16200E+03     0.30000E+01     0.00000E+00     0.21000E+02     0.00000E+00     0.00000E+00
**** COLLISION INFORMATION FOR NUCLEONS ABOVE     3495.0   MEV AND CHG. PIONS ABOVE     2495.0   MEV.****
                REAL          PSEUDO          REAL          PSEUDO          PSEUDO          REAL          PSEUDO
               NONHYDROG     NONHYDROG       HYDROGEN      HYDROGEN        DECAY         ELASTIC       ELASTIC
               COLLISIONS    COLLISIONS      COLLISIONS    COLLISIONS      COLLISIONS    COLLISIONS    COLLISIONS
MEDIUM   1  0.10020E+04   0.52100E+03   0.00000E+00   0.00000E+00   0.85000E+02
MEDIUM   2  0.89000E+02   0.23000E+03   0.10000E+02   0.15000E+02   0.64000E+02
--> NEGEX=  35   LOWAZ=  27     NWTC=   4
/SUBMIT(I): NEUTRONS:114132, PIO:  1136, NUCLEI: 16528
```

MEDIUM	SOURCE-FRACTION	%ERR		
1	1.000E+00	0.00		
2	0.000E+00	0.00		
VOID	0.000E+00	0.00		
MEDIUM	INELASTIC C./SOURCE	%ERR	ELASTIC C. /SOURCE	%ERR
1	1.160E+01	1.41	1.803E+01	1.65
2	3.298E+00	2.11	2.847E+00	2.42
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	ABSORPTION /SOURCE	%ERR	FISSION /SOURCE	%ERR
1	3.474E+00	2.06	6.965E+00	1.52
2	1.150E-01	9.44	0.000E+00	0.00
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	P FLUX (CM)	%ERR	N FLUX (CM)	%ERR
1	1.165E+01	2.68	1.550E+02	1.59
2	9.859E+00	2.66	1.283E+02	1.59
VOID	1.954E+00	2.70	2.568E+01	1.60
MEDIUM	PI+ FLUX (CM)	%ERR	PI- FLUX (CM)	%ERR
1	4.166E+00	5.89	1.915E+01	2.26
2	3.478E+00	5.90	1.581E+01	2.28
VOID	6.936E-01	5.89	3.161E+00	2.27
MEDIUM	MU+ FLUX (CM)	%ERR	MU- FLUX (CM)	%ERR
1	3.633E-02	98.78	7.024E-03	87.26
2	2.987E-02	99.23	8.303E-04	100.00
VOID	6.348E-03	93.58	1.661E-04	100.00
MEDIUM	P YIELD	%ERR	N YIELD	%ERR
1	1.773E+01	1.55	1.487E+02	1.29
2	3.882E+00	2.49	4.918E+00	2.43
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	PI+ YIELD	%ERR	PIO YIELD	%ERR
1	8.671E-01	4.35	1.404E+00	2.98
2	1.159E-01	10.78	1.361E-01	10.74
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	PI- YIELD	%ERR		
1	2.027E+00	2.70		
2	2.061E-01	8.42		
VOID	0.000E+00	0.00		
MEDIUM	MU+ YIELD	%ERR	MU- YIELD	%ERR
1	1.093E-03	100.00	2.053E-03	70.68
2	9.814E-04	100.00	0.000E+00	0.00
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	D YIELD	%ERR	T YIELD	%ERR
1	3.821E+00	2.66	4.217E+00	2.37
2	6.372E-02	14.75	1.018E-02	33.42
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	HE3 YIELD	%ERR	HE4 YIELD	%ERR
1	4.940E-01	6.68	8.091E+00	2.42
2	1.386E-02	34.17	1.749E+00	4.39
VOID	0.000E+00	0.00	0.000E+00	0.00

W:RSYS: NO RSYST-TAPE AVAILABLE

```
VISIBLE ENERGY DEPOSITION
DETECTOR NAME =     EVIS
DEPOSITION-TYPE= P
    REGION     ENERGY       %ERR

   1001000 1.457E+01      5.411
   1002000 1.678E+01      4.327
   1003000 1.184E+01      5.053
   1004000 7.719E+00      6.175
   1005000 5.026E+00      7.894
   1006000 3.029E+00     10.484
   1007000 1.538E+00     13.804
   2001000 8.957E-01     13.449
   2002000 1.816E+00      9.900
   2003000 2.824E+00      7.871
   2004000 2.996E+00      7.359
   2005000 2.663E+00      7.943
   2006000 1.808E+00      9.862
   2007000 1.187E+00     12.326
DEPOSITION-TYPE= PI+
    REGION     ENERGY       %ERR

   1001000 1.515E+00      8.656
   1002000 2.039E+00      7.528
   1003000 1.628E+00      8.919
   1004000 9.604E-01     10.974
   1005000 6.260E-01     12.910
   1006000 4.107E-01     17.012
   1007000 2.009E-01     20.560
   2001000 3.357E-02     51.677
   2002000 1.885E-01     26.137
   2003000 3.845E-01     20.482
   2004000 3.469E-01     21.042
   2005000 2.515E-01     24.135
   2006000 1.331E-01     29.676
   2007000 1.083E-01     37.290
DEPOSITION-TYPE= PI-
    REGION     ENERGY       %ERR

   1001000 1.194E+01      1.299
   1002000 9.155E+00      2.454
   1003000 6.180E+00      3.697
             .
             .
             .
```

```
ENERGY DEPOSITIED
DETECTOR NAME =     EDEP
    DEPOSITION-TYPE     ENERGY       %ERR

P                     8.742E+02      1.715
PI+                   1.163E+02      5.488
PI-                   5.595E+02      2.134
MU+                   1.068E+00     94.598
MU-                   2.733E-01     76.539
D                     4.305E+01      3.075
T                     4.723E+01      2.683
HE3                   9.373E+00      7.146
ALPHA                 1.597E+02      2.300
RECOIL                1.914E+03      1.537
P       LEAK          3.875E+01     13.872
N       LEAK          3.965E+02      3.062
PI+     LEAK          2.951E+01     19.617
PI-     LEAK          1.236E+02     14.707
MU+     LEAK          1.299E+00    100.000
MU-     LEAK          0.000E+00      0.000
N       SUBMIT        4.423E+02      1.294
PIO     SUBMIT        8.861E+02      3.738
EXI.    SUBMIT        1.124E+02      1.422


ENERGY ON SURFACE
DETECTOR NAME =     ELOS
  PARTICLE-TYPE= p
   REGION1    REGION2    ENERGY       %ERR

         0          3 3.663E+00     34.460
         0          4 1.006E+01     16.121
         0          5 2.503E+01     20.071
  PARTICLE-TYPE= n
   REGION1    REGION2    ENERGY       %ERR

         0          3 1.616E+02      4.099
         0          4 1.075E+02      5.486
         0          5 1.273E+02      7.871
                .
                .
                .
I:EXIT;
```

```
 HERMES TEST1       14 DETEKTOREN     CARD A

  NSTRT   NMOST    NITS   NQUIT  NGPQTN  NGPQTG   NMGP    NMTG  NCOLTP   IADJM  MAXTIM   MED1A  MEDALB
    113    2500     450       1     100      21    100     121       0       0   58.00       3       0

  ISOUR   NGPFS  ISBIAS             WTSTRT       EBOIN       EBOTG        TCUT       VELTH
      1       1       0         1.0000E+00  1.0000E-04  1.0000E+04  1.0000E-07  6.2930E+05

             XSTRT       YSTRT       ZSTRT      AGSTRT        UINP        VINP        WINP
         0.000E+00   0.000E+00   0.000E+00   0.000E+00    0.000000    0.000000    0.000000
***UNIT-NUMBER OF HERMES SUBMISSION  :    50

GROUP PARAMETERS, GROUP NUMBERS GREATER THAN  100 CORRESPOND TO SECONDARY PARTICLES
   GROUP      UPPER EDGE          VELOCITY
                 (EV)             (CM/SEC)
     1      1.4900E+07       5.2115E+09
     2      1.3500E+07       4.9576E+09
                 .
                 .
                 .
   120      2.0000E+05       2.9979E+10
   121      1.0000E+05       2.9979E+10

INITIAL RANDOM NUMBER =     35FA731A

NSPLT= 1     NKILL= 1     NPAST= 0     NOLEAK= 0     IEBIAS= 0     MXREG=  3     MAXGP=121

WEIGHT STANDARDS FOR SPLITTING AND RUSSIAN ROULETTE AND PATHLENGTH STRETCHING PARAMETERS

 NGP1  NDG NGP2  NRG1 NDRG NRG2    WTHIN1      WTLOW1      WTAVE1        XNU
   0     0    0     0    0    0  1.0000E+00  1.0000E+00  1.0000E+00  0.0000E+00

NSOUR= 0     MFISTP=  1     NKCALC= 0     NORMF= 0

FWLOW=    1.00000E+00,    1.00000E+00,    1.00000E+00,

   SOURCE DISTRIBUTION FOR FISSION NEUTRONS
GROUP      IMED=  1      IMED=  2      IMED=  3
   1    4.1220E-05    0.0000E+00    4.1220E-05
   2    1.1330E-04    0.0000E+00    1.1330E-04
                .
                .
                .
 120    0.0000E+00    0.0000E+00    0.0000E+00
 121    0.0000E+00    0.0000E+00    0.0000E+00

CWLOW(IG,MREG)

 GROUP       REGION 1       REGION 2       REGION 3
    1      1.0000E+00     1.0000E+00     1.0000E+00
    2      1.0000E+00     1.0000E+00     1.0000E+00
                .
                .
                .
   98      1.0000E+00     1.0000E+00     1.0000E+00
   99      1.0000E+00     1.0000E+00     1.0000E+00
  100      1.0000E+00     1.0000E+00     1.0000E+00

 NUMB. OF BODIES (NUMB)                  412
 NUMB. OF REGIONS (NUMR)                 435
 NUMBER OF CODE REGIONS (NCOD)           435
 LENGTH OF FDP ARRAY (LMXX)             4600
 LENGTH OF MA ARRAY (LMYY)             16000
 MODIFIED INPUT (LOUT)                     0
 VOLUME INPUT OPTION (IVOPT)         4 NOT USED
 BOUNDARY OPTION (MEDREG)                  0
```

```
 DEBUG OPTION (IDBGO)                    0

 MACHINE EPS =  0.100000E-07


 IPRINT=         0
 STRETCH= 1.0000000E+00

 NUMBER OF BODIES          412
 LENGTH OF MA -ARRAY      2885
 LENGTH OF FPD-ARRAY      4543
 SUB-GEOMETRY #2
 NUMBER OF INPUT ZONES    414
 NUMBER OF  CODE ZONES    414
 LENGTH OF INTEGER ARRAY 6619
 NGEOM= 10295,   NGLAST= 29103
```

MATERIAL IEN EPR WQ P5 VON FT20 CARD XA

```
NUMBER OF PRIMARY GROUPS (NGP)          100
NUMBER OF PRIMARY DOWNSCATTERS (NDS)    100
NUMBER OF SECONDARY GROUPS (NGG)         21
NUMBER OF SECONDARY DOWNSCATTERS (NDSG)  21
NUMBER OF PRIM+SEC GROUPS (INGP)        121
TABLE LENGTH (ITBL)                     124
LOC OF WITHIN GROUP (SIG GG) (ISGG)       4
NUMBER OF MEDIA (NMED)                    3
NUMBER OF INPUT ELEMENTS (NELEM)          4
NUMBER OF MIXING ENTRIES (NMIX)           5
NUMBER OF COEFFICIENTS (NCOEF)            6
NUMBER OF ANGLES (NSCT)                   3
RESTORE COEFF (ISTAT)                     0
ADJOINT SWITCH (FROM MORSE)               0

INPUT/OUTPUT OPTIONS
     IRDSG (AS READ)          0
     ISTR (AS STORE)          0
     IFMU (MUS)               0
     IMOM (MOMENTS)           0
     IPRIN (ANGLES,PROB)      0
     IPUN (IMPOSSIBLE COEF)   0
     CARD FORMAT (IDTF)       0
     INPUT TAPE (IXTAPE)     20
     MORSEC TAPE (JXTAPE)     0
     O6R TAPE (IO6RT)         0
     IGOPT (LAST GRP. O6R)    0
     CROSS-TAPE AUS RSYST     0
     ICRO CROSS. FOR MEDIA
     N TO G TRANSFER          0
     PRINT OF BADMOMENTS      0

     ELEMENTS FROM LIBRARY TAPE
IDENTIFIERS   64   65   66   67   68   69  127  128  129  130  131  132  262  263
             264  265  266  267  253  254  255  256  257  258
ELEMENT        1         64         121  124    0   64C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        2        127         121  124    0  127H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        3        262         121  124    0  262 P0 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        4        253         121  124    0  253U-235 1261 100N-21G GPS P8 800K INF DIL              07/25/84

STORAGE ALLOCATIONS
CROSS SECTIONS START AT     29104
LAST LOCATION USED (PERM)  148701
TEMP LOCATIONS USED        784848 TO  950000
EXCESS STORAGE (TEMP)      636147
ELEMENT        1         64         121  124    0   64C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        1         65         121  124    0   65C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        1         66         121  124    0   66C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        1         67         121  124    0   67C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        1         68         121  124    0   68C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        1         69         121  124    0   69C 1274 100N-21G GPS P8 800K                          07/25/84
ELEMENT        2        127         121  124    0  127H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        2        128         121  124    0  128H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        2        129         121  124    0  129H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        2        130         121  124    0  130H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        2        131         121  124    0  131H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        2        132         121  124    0  132H 1269 100N-21G GPS P8 800K WATER BOUND              07/25/84
ELEMENT        3        262         121  124    0  262 P0 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        3        263         121  124    0  263 P1 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        3        264         121  124    0  264 P2 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        3        265         121  124    0  265 P3 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        3        266         121  124    0  266 P4 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        3        267         121  124    0  267 P5 U-238 1262 100N-21G P8 800K MOD 17 INF DIL       07/25/84
ELEMENT        4        253         121  124    0  253U-235 1261 100N-21G GPS P8 800K INF DIL              07/25/84
```

ELEMENT	4	254	121	124	0	254U-235 1261 100N-21G GPS P8 800K INF DIL	07/25/84
ELEMENT	4	255	121	124	0	255U-235 1261 100N-21G GPS P8 800K INF DIL	07/25/84
ELEMENT	4	256	121	124	0	256U-235 1261 100N-21G GPS P8 800K INF DIL	07/25/84
ELEMENT	4	257	121	124	0	257U-235 1261 100N-21G GPS P8 800K INF DIL	07/25/84
ELEMENT	4	258	121	124	0	258U-235 1261 100N-21G GPS P8 800K INF DIL	07/25/84

MIXING TABLE

MEDIA	1	CONTAINS ELEMENT	3	WITH DENSITY	4.7932E-02
MEDIA	1	CONTAINS ELEMENT	4	WITH DENSITY	1.4607E-04
MEDIA	2	CONTAINS ELEMENT	2	WITH DENSITY	4.8295E-02
MEDIA	2	CONTAINS ELEMENT	1	WITH DENSITY	4.8295E-02
MEDIA	3	CONTAINS ELEMENT	2	WITH DENSITY	4.8295E-02

BANKS START AT 148702
LAST LOCATION USED 186201

```
ANALYSIS INPUT                                                    CARD AA

ND= 14, NNE=100, NE=121, NT=  0, NA=  0, NRESP=  1, NEX=  0, NEXND=100
IORESP=1 IOFLUX=1
DET      X               Y               Z            MED1            MED2

TO IS SET TO 0.0 IN ALL CASES

  1                                                  1001000      0.0000E+00      0.0000E+00
  2                                                  1002000      0.0000E+00      0.0000E+00
  3                                                  1003000      0.0000E+00      0.0000E+00
  4                                                  1004000      0.0000E+00      0.0000E+00
  5                                                  1005000      0.0000E+00      0.0000E+00
  6                                                  1006000      0.0000E+00      0.0000E+00
  7                                                  1007000      0.0000E+00      0.0000E+00
  8                                                  2001000      0.0000E+00      0.0000E+00
  9                                                  2002000      0.0000E+00      0.0000E+00
 10                                                  2003000      0.0000E+00      0.0000E+00
 11                                                  2004000      0.0000E+00      0.0000E+00
 12                                                  2005000      0.0000E+00      0.0000E+00
 13                                                  2006000      0.0000E+00      0.0000E+00
 14                                                  2007000      0.0000E+00      0.0000E+00
 GROUP        RESP( 1)
     1      1.0000E+00
     2      1.0000E+00
              .
              .
              .
   120      0.0000E+00
   121      0.0000E+00

        NUMBER OF PRIMARY ENERGY BINS   100
        TOTAL NUMBER OF ENERGY BINS     121
           LOWER    LOWER
BIN NO.    LIMIT    ENERGY       DELTA
           GROUP    LIMIT          E

                  1.490E+07
   1         1    1.350E+07    1.400E+06
   2         2    1.220E+07    1.300E+06
                    .
                    .
                    .
 120       120    1.000E+05    1.000E+05
 121       121    1.000E+04    9.000E+04

     NUMBER OF TIME BINS   0

     NUMBER OF ANGLE BINS   0
UPPER LIMITS OF COSINE BINS

 7375 CELLS USED BY ANALYSIS, 756424 CELLS REMAIN UNUSED.

     DETECTOR NO    1          REGION NO    1001000      NEL =  1     DENN =  0.4829500E-01     S =  1.00     KB =  0.8499999E-02
                               Z =  6.0     A =  12.0    DEN =  0.4829484E-01

     DETECTOR NO    2          REGION NO    1002000      NEL =  1     DENN =  0.4829500E-01     S =  1.00     KB =  0.8499999E-02
                               Z =  6.0     A =  12.0    DEN =  0.4829484E-01

                    .
                    .
                    .
     DETECTOR NO   13          REGION NO    2006000      NEL =  1     DENN =  0.4829500E-01     S =  1.00     KB =  0.8499999E-02
                               Z =  6.0     A =  12.0    DEN =  0.4829484E-01
```

DETECTOR NO 14 REGION NO 2007000 NEL = 1 DENH = 0.4829500E-01 S = 1.00 KB = 0.8499999E-02
Z = 6.0 A = 12.0 DEN = 0.4829484E-01

ENERGY-GROUP	LIGHT RESPONSE
1	0.3694288E+01
2	0.3236586E+01
3	0.2839274E+01
.	
.	
.	
98	0.2533569E-06
99	0.2002612E-06
100	0.2002612E-06

```
TIME REQUIRED FOR INPUT WAS   3 MINUTES 51 SECONDS .
YOU ARE USING THE DEFAULT VERSION OF STRUN WHICH DOES NOTHING.

***START BATCH     1                          RANDOM=     35FA731A

SOURCE DATA

HET-IDENTIFIKATION:       REWO     31N1     05/0     3/88     12:3     6:16


YOU ARE USING THE DEFAULT VERSION OF SOURCE WHICH SETS WATE TO DDF AND PROVIDES AN ENERGY IG.
  WTAVE        IAVE    UAVE     VAVE     WAVE        XAVE        YAVE        ZAVE        AGEAVE
 1.804E+02     19.25   0.0314   0.0012  -0.0682   -3.824E+00   8.615E-01   3.818E+01    0.000E+00

NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)     FISHN    GAMGEN REALCOLL    ALBEDO     BDRYX    ESCAPE     E-CUT TIMEKILL R R KILL R R SURV  GAMLOST   FISGEN
     156      863        97       971      5494         0     23706        22         0       191      1874      3703         0        97
TIME REQUIRED FOR THE PRECEDING BATCH WAS  22 SECONDS .

***START BATCH     2                          RANDOM=     696C252A

SOURCE DATA
  WTAVE        IAVE    UAVE     VAVE     WAVE        XAVE        YAVE        ZAVE        AGEAVE
 1.021E+02     20.15   0.0721  -0.0215   0.0527   -1.233E+00  -3.514E-01   4.547E+01    0.000E+00

NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)     FISHN    GAMGEN REALCOLL    ALBEDO     BDRYX    ESCAPE     E-CUT TIMEKILL R R KILL R R SURV  GAMLOST   FISGEN
     102      416        43       429      2572         0     11217        20         0       100       872      1783         0       140

TIME REQUIRED FOR THE PRECEDING BATCH WAS   8 SECONDS .
                .
                .
                .
***START BATCH   450                          RANDOM=     6278807E

SOURCE DATA

  WTAVE        IAVE    UAVE     VAVE     WAVE        XAVE        YAVE        ZAVE        AGEAVE
 1.832E+02     21.51   0.0559   0.0260  -0.0038    4.764E-01   2.013E+00   4.309E+01    0.000E+00

NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)     FISHN    GAMGEN REALCOLL    ALBEDO     BDRYX    ESCAPE     E-CUT TIMEKILL R R KILL R R SURV  GAMLOST   FISGEN
     157      763        62       792      4652         0     19248        23         0       165      1586      3159         0     25647

TIME REQUIRED FOR THE PRECEDING BATCH WAS  12 SECONDS .
```

/ VISIBLE ENERGY IN SCSN38 ; 7X INNER, 7X OUTER, 7X OUTER TOWER EXTRA

CARD DD

RESPONSES(DETECTOR)

DETECTOR	UNCOLL RESPONSE	FSD UNCOLL	TOTAL RESPONSE	FSD TOTAL
1	0.0000E+00	0.00000	5.5550E+00	0.05651
2	0.0000E+00	0.00000	6.6532E+00	0.05022
3	0.0000E+00	0.00000	4.9863E+00	0.05195
4	0.0000E+00	0.00000	3.5615E+00	0.06393
5	0.0000E+00	0.00000	2.3326E+00	0.08263
6	0.0000E+00	0.00000	1.2973E+00	0.10683
7	0.0000E+00	0.00000	5.1285E-01	0.15913
8	0.0000E+00	0.00000	2.3704E+00	0.05214
9	0.0000E+00	0.00000	3.7826E+00	0.04301
10	0.0000E+00	0.00000	4.0207E+00	0.03782
11	0.0000E+00	0.00000	3.4266E+00	0.04421
12	0.0000E+00	0.00000	2.5918E+00	0.05474
13	0.0000E+00	0.00000	1.8419E+00	0.06765
14	0.0000E+00	0.00000	9.0301E-01	0.10086

FLUENCE(ENERGY,DETECTOR) CARD GG

DETECTOR NO. ENERGIES	1	2	3	4	5	6	7	8	9	10
1.490E+07										
	7.037E-08	1.407E-07	1.056E-07	5.278E-08	3.518E-08	2.346E-08	5.864E-09	2.932E-08	4.691E-08	5.864E-08
	0.309	0.246	0.257	0.366	0.470	0.498	1.000	0.445	0.351	0.344
1.350E+07										
	1.162E-07	1.162E-07	6.639E-08	6.639E-08	4.426E-08	5.533E-09	0.000E+00	2.213E-08	6.639E-08	7.192E-08
	0.224	0.224	0.309	0.309	0.351	1.000	0.000	0.498	0.285	0.274
1.220E+07										
	9.177E-08	1.606E-07	9.751E-08	7.457E-08	6.883E-08	1.147E-08	1.147E-08	5.162E-08	5.162E-08	6.883E-08
	0.261	0.183	0.266	0.350	0.330	0.706	0.706	0.330	0.398	0.285
1.110E+07										
	1.456E-07	1.707E-07	9.537E-08	1.154E-07	6.023E-08	3.012E-08	3.012E-08	5.019E-08	8.031E-08	7.027E-08
	0.193	0.170	0.237	0.221	0.309	0.406	0.406	0.344	0.276	0.263

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.
.

FLUENCE(ENERGY,DETECTOR) CARD GG

DETECTOR NO. ENERGIES	11	12	13	14
2.000E+05				
	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000	0.000	0.000	0.000
1.000E+05				
	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000	0.000	0.000	0.000
1.000E+04				

EXTRA ARRAYS OF LENGTH ND

EXT1(14)

(1)	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01
(9)	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01	0.369429E+01		

EXT2(14)

(1)	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01
(9)	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01	0.323659E+01		

.
.
.

E100(14)

(1)	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07
(9)	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07	0.883867E-07		

TIME REQUIRED FOR THE PRECEDING 450 BATCHES WAS 1 HOUR 17 MINUTES 13 SECONDS .

NEUTRON DEATHS	NUMBER	WEIGHT
KILLED BY RUSSIAN ROULETTE	527385	3.12670E+05
ESCAPED	13776	1.37760E+04
REACHED ENERGY CUTOFF	0	0.00000E+00
REACHED TIME CUTOFF	53040	5.30400E+04

** NEXT RANDOM NUMBER IS 3CB08A3E

TOTAL CPU TIME FOR THIS PROBLEM WAS 73.38 MINUTES.

(4) No Output of NDEM

(5) Output of PEGS on Tape

(6) Output of EGS

```
/JOB-ID = RE403102 05/09/86 08:32:18
 IRUN=     1  MMIS=     1  MBAT=   500 NSKIP=     0
INEGS=     1 IOEGS=     2 INGEO=     5 IOGEO=     6  KMPI=    12  KMPO=     8
  IXX=  123456789
  IQI=        -1     EI= 5.000E+03    WTI= 1.000E+00
   XI= 0.000E+00     YI= 0.000E+00     ZI= 1.000E-02
   UI= 0.000E+00     VI= 0.000E+00     WI= 1.000E+00
 NMED=     2  NREG=    19
EGS SUCCESSFULLY 'MATCHED' FOR     2 MEDIA.
-------- MEDNAM --------       ESTEPE          AE          AP
URAN                        5.000E-03  7.110E-01  1.000E-01
SCSN36                      1.000E-02  7.110E-01  1.000E-01
REGION      LSTREG         MED        ECUT        PCUT      IRAYLR
     1     1001000           2  1.511E+00  1.000E-01           0
     2     1002000           2  1.511E+00  1.000E-01           0
     3     1003000           2  1.511E+00  1.000E-01           0
     4     1004000           2  1.511E+00  1.000E-01           0
     5     1005000           2  1.511E+00  1.000E-01           0
     6     1006000           2  1.511E+00  1.000E-01           0
     7     1007000           2  1.511E+00  1.000E-01           0
     8     2001000           2  1.511E+00  1.000E-01           0
     9     2002000           2  1.511E+00  1.000E-01           0
    10     2003000           2  1.511E+00  1.000E-01           0
    11     2004000           2  1.511E+00  1.000E-01           0
    12     2005000           2  1.511E+00  1.000E-01           0
    13     2006000           2  1.511E+00  1.000E-01           0
    14     2007000           2  1.511E+00  1.000E-01           0
    15           1           1  1.511E+00  1.000E-01           0
    16           2           0  0.000E+00  0.000E+00           0
    17           3           0  0.000E+00  0.000E+00           0
    18           4           0  0.000E+00  0.000E+00           0
    19           5           0  0.000E+00  0.000E+00           0
 NUMB. OF BODIES (NUMB)                  412
 NUMB. OF REGIONS (NUMR)                 435
 NUMBER OF CODE REGIONS (NCOD)           435
 LENGTH OF FDP ARRAY (LMXX)             4600
 LENGTH OF MA ARRAY (LMYY)             16000
 MODIFIED INPUT (LOUT)                     0
 VOLUME INPUT OPTION (IVOPT)           4 NOT USED
 BOUNDARY OPTION (MEDREG)                  0
 DEBUG OPTION (IDBGO)                      0

MACHINE EPS =  0.100000E-07


IPRINT=         0
STRETCH= 1.0000000E+00

NUMBER OF BODIES          412
LENGTH OF MA -ARRAY      2885
LENGTH OF FPD-ARRAY      4543
SUB-GEOMETRY #2
NUMBER OF INPUT ZONES     414
NUMBER OF  CODE ZONES     414
LENGTH OF INTEGER ARRAY 6619
EOB EGS      1    1     1 TBAT=     5.805 IXX=-1527888639
EOB EGS      1    2     1 TBAT=    23.438 IXX=   47469917
                          .
                          .
                          .
EOB EGS      1  499     1 TBAT=     9.559 IXX=  -56670779
EOB EGS      1  500     1 TBAT=     0.098 IXX=  -56670779
ENERGY DEPOSITION IN MEV WITH IARG=0
  EGS-DET    REGION          E-     %ERR        GAMMA     %ERR          E+     %ERR       SUMME     %ERR
        1   1001000   4.240E+00    12.36   0.000E+00     0.00   3.050E+00    11.94   7.290E+00    11.88
```

2	1002000	4.782E+00	10.75	0.000E+00	0.00	3.095E+00	11.22	7.877E+00	10.78
3	1003000	3.281E+00	12.94	0.000E+00	0.00	2.288E+00	14.01	5.569E+00	13.06
4	1004000	2.054E+00	17.50	0.000E+00	0.00	1.609E+00	18.16	3.663E+00	17.29
5	1005000	1.208E+00	23.15	0.000E+00	0.00	9.260E-01	25.32	2.134E+00	23.66
6	1006000	4.585E-01	27.54	0.000E+00	0.00	3.210E-01	27.82	7.795E-01	27.25
7	1007000	3.697E-01	39.54	0.000E+00	0.00	2.263E-01	39.17	5.960E-01	39.28
8	2001000	2.086E-02	33.85	0.000E+00	0.00	2.452E-02	67.01	4.537E-02	46.21
9	2002000	7.859E-02	42.23	0.000E+00	0.00	2.128E-02	62.82	9.987E-02	45.90
10	2003000	4.133E-02	46.79	0.000E+00	0.00	1.341E-02	58.56	5.474E-02	46.33
11	2004000	1.224E-01	42.94	0.000E+00	0.00	1.282E-01	40.80	2.506E-01	40.21
12	2005000	1.428E-01	33.54	0.000E+00	0.00	6.511E-02	33.40	2.079E-01	31.10
13	2006000	1.025E-01	32.77	0.000E+00	0.00	1.080E-01	39.36	2.105E-01	35.31
14	2007000	5.358E-02	57.07	0.000E+00	0.00	2.314E-02	64.41	7.672E-02	58.76
15	1	2.607E+02	5.26	0.000E+00	0.00	1.751E+02	5.29	4.354E+02	5.25
16	2	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00
17	3	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00
18	4	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00
19	5	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00
SUMME		2.776E+02	5.26	0.000E+00	0.00	1.870E+02	5.28	4.641E+02	5.25

IARG ALL REGIONS	E-	%ERR	GAMMA	%ERR	E+	%ERR	SUMME	%ERR
0	2.776E+02	5.26	0.000E+00	0.00	1.870E+02	5.28	4.641E+02	5.25
1	2.983E+02	5.29	0.000E+00	0.00	4.512E+01	5.32	3.434E+02	5.29
2	2.604E+01	5.33	1.189E-01	6.65	1.436E-01	7.20	2.630E+01	5.33
3	1.222E+00	36.10	1.289E+01	23.69	1.050E+00	43.79	1.516E+01	22.52
4	0.000E+00	0.00	4.846E+01	5.30	0.000E+00	0.00	4.846E+01	5.30

FREQUENCY OF IARG=0

EGS-DET	REGION	E-	%ERR	GAMMA	%ERR	E+	%ERR	SUMME	%ERR
1	1001000	1.165E+02	12.17	1.405E+02	12.43	6.784E+01	12.29	3.248E+02	11.99
19	5	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00
SUMME		1.680E+04	5.28	2.490E+03	5.64	8.473E+03	5.31	2.767E+04	5.30

IARG ALL REGIONS	E-	%ERR	GAMMA	%ERR	E+	%ERR	SUMME	%ERR
0	1.680E+04	5.28	2.490E+03	5.64	8.473E+03	5.31	2.767E+04	5.30
1	5.539E+02	5.29	0.000E+00	0.00	5.099E+01	5.31	6.048E+02	5.29
2	2.847E+02	5.32	1.479E+01	5.51	2.625E+00	6.09	3.021E+02	5.32
3	7.747E-02	26.33	2.128E+00	16.72	5.316E-02	27.01	2.259E+00	16.81
4	0.000E+00	0.00	4.201E+02	5.30	0.000E+00	0.00	4.201E+02	5.30

FLUX IN CM

EGS-DET	REGION	E-	%ERR	GAMMA	%ERR	E+	%ERR	SUMME	%ERR
1	1001000	2.470E+00	12.36	5.605E+01	11.79	1.785E+00	11.94		
19	5	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00		

LEAKAGE CURRENT

EGS-DET	REGION	E-	%ERR	GAMMA	%ERR	E+	%ERR	SUMME	%ERR
1	1001000	0.000E+00	0.00	0.000E+00	0.00	0.000E+00	0.00		
19	5	1.251E-02	57.63	3.156E-01	45.16	4.228E-03	70.64		

EOR EGS 1 500 500 REW03102 05/09/88 08:32:18
TOTAL TIME USED =******
MULTIPLE SCATTERING PER EVENT

TRIED	FAILED	FRACTION FAILED[%]
21251.11	3.98	0.02

(7) Output of STATIST

```
I:/  Test1 STATIST
I:/ 1)   define data arrays for STATIST analysis
I:/ 1.1) setup arrays to read in HET, MORSE, and EGS(pi0) detector records
I: REAL EDEP(19);
I: REAL FHET(14,19),FMOR(14),FPI0(19,3,5);
I:/ 1.2) setup arrays to keep the sums
I:/    over all contribution types of interest
I: REAL EHET(14)   ,EMOR(14),EPI0(19)    ;
I:/ 1.3) setup weight arrays used to extract the contributions of interest
I: REAL WHET(19)   ,WMOR(1) ,WPI0(15)    ;
I: DATA WHET=< 1. 1. 1. F 0.>;
I: DATA WMOR=1.;
I: DATA WPI0=< R 3 1. R 3 1. R 3 1. R 3 0.  0. 1. 0.>;
I:/ 1.4) setup an array to sum over all scintillator regions
I: REAL SCINT(19);DATA SCINT=<R 14 1. F 0.>;
I:/ 1.5) setup variables for final event results
I: REAL EVCHG(1),EVPI0(1),EVNEU(1);
I:/ 2)   start event processing (7 variables 450 events)
I: STATIN 7,450;
I:/ 2.1) load detector records from submission files
I: LOAD 10,EVIS@EOB,FHET; / HET DIFFERENTIAL PULSE DISTRBUTION
I: LOAD 10,EDEP@EOB,EDEP; / HET GLOBAL ENERGY DEPOSITION
I: LOAD 11,R001@EOB,FMOR; / MORSE VISIBLE N ENERGY
I: LOAD 12,EDEP@EOB,FPI0 ;/ EGS   VISIBLE PI0 ENERGY
I:/ 2.2) extract main contributions
I: DOT EHET=FHET*WHET;          / EXTRACT  EVIS
I: DOT EMOR=FMOR*WMOR;          / EXTRACT  EVIS
I: DOT EPI0=FPI0*WPI0 (19,15,1);/ EXTRACT  EVIS
I:/ 2.3) sum over all scintillator regions
I: DOT EVCHG=EHET*SCINT (1,14,1);
I: DOT EVNEU=EMOR*SCINT (1,14,1);
I: DOT EVPI0=EPI0*SCINT (1,19,1);
I:
I:/ 2.4) assign V  containg 7 variables
I:/      for each event, V is stacked into EVENT
I: SET V( 1)=EDEP(1)+EDEP(2)+EDEP(3);
I: SET V( 2)=EDEP(17);
I: SET V( 3)=EDEP(18);
I: SET V( 4)=EVCHG(1);
I: SET V( 5)=EVNEU(1);
I: SET V( 6)=EVPI0(1);
I: SET V( 7)=V(4)+V(5)+V(6);
I:/ 3)   start end of run analysis
I: BIN  1,0.,5000., 50,' Edep p,pi+,pi-';
I: BIN  2,0.,1000., 50,' Esub n';
I: BIN  3,0.,5000., 50,' Esub pi0';
I:
I: BIN  4,0.,500.0, 50,' Evis p,pi+,pi-';
I: BIN  5,0.,100.0, 50,' Evis n';
I: BIN  6,0.,500.0, 50,' Evis pi0';
I:
I: BIN  7,0.,500.0, 50,' Evis p,pi+,pi-,n,pi0';
I: / NOTE: FIT and SCAT require a previous call of BIN
I: /       for the variables wanted.
I: FIT  7;
I: SCAT 1,4;
I: SCAT 2,5;
I: SCAT 3,6;
I: STATIST PLOT;
```

```
/JOB-ID = REW03112 05/26/88 09:27:47
SOR HET       1    0    0  REW031H1 05/03/88 12:36:16
PGM MOR                   REW10102 05/17/88
g¢
SOR HET       1    0    0  REW031H1 05/03/88 12:36:16
BI-VARIATE MOMENTS        STATIST          REW03112 05/26/88 09:27:47
VARIABLE X                      MEAN(X)    STD(X)  COV(X,Y)          A
         Y                      MEAN(Y)    STD(Y)  RHO(X,Y)          B

 Edep p,pi+,pi-              1.542E+03 5.538E+02 2.310E+04 7.534E-02
 Evis p,pi+,pi-              1.214E+02 4.575E+01 9.119E-01 5.225E+00

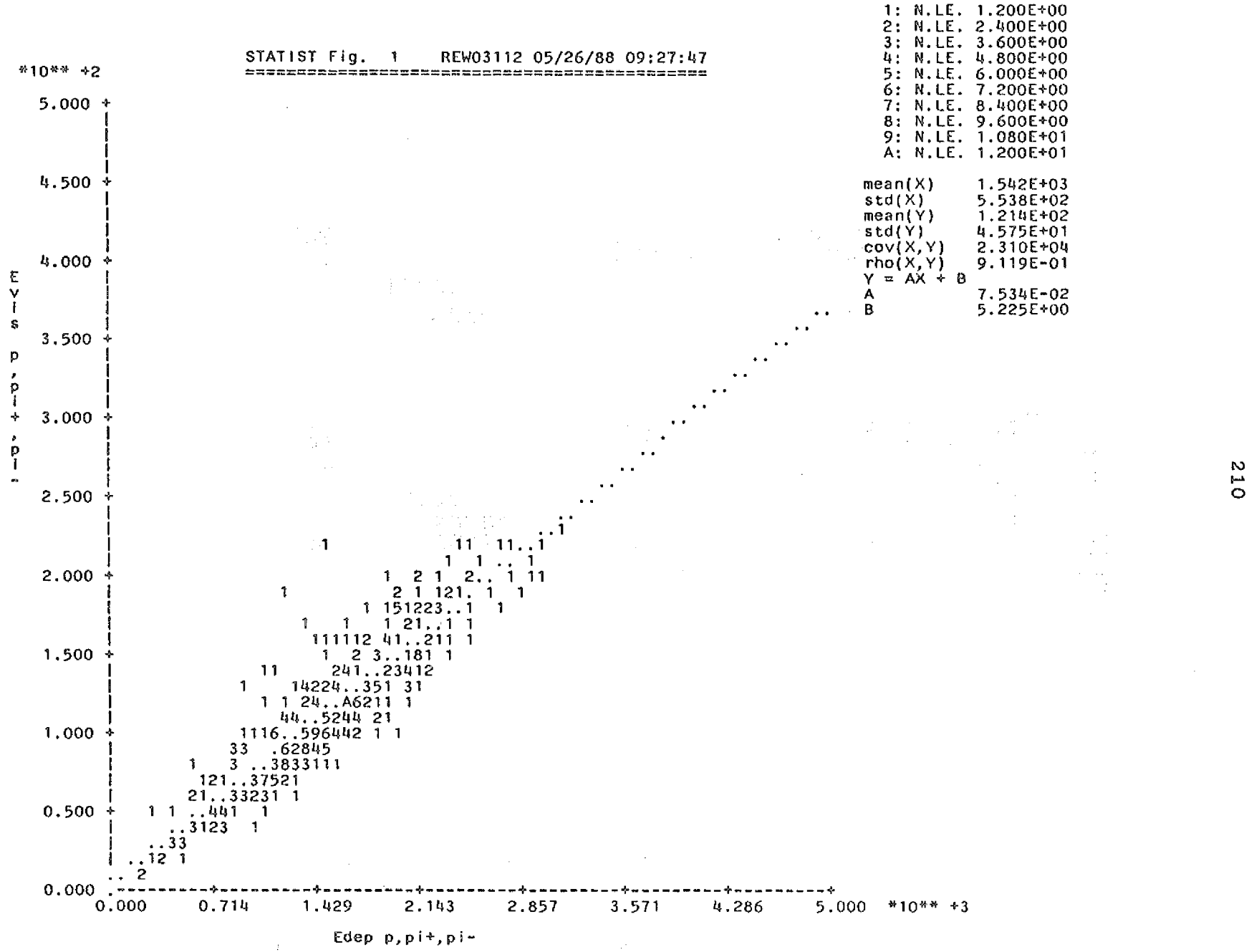
 Esub n                      4.530E+02 1.705E+02 2.764E+03 9.503E-02
 Evis n                      4.384E+01 1.797E+01 9.017E-01 7.834E-01

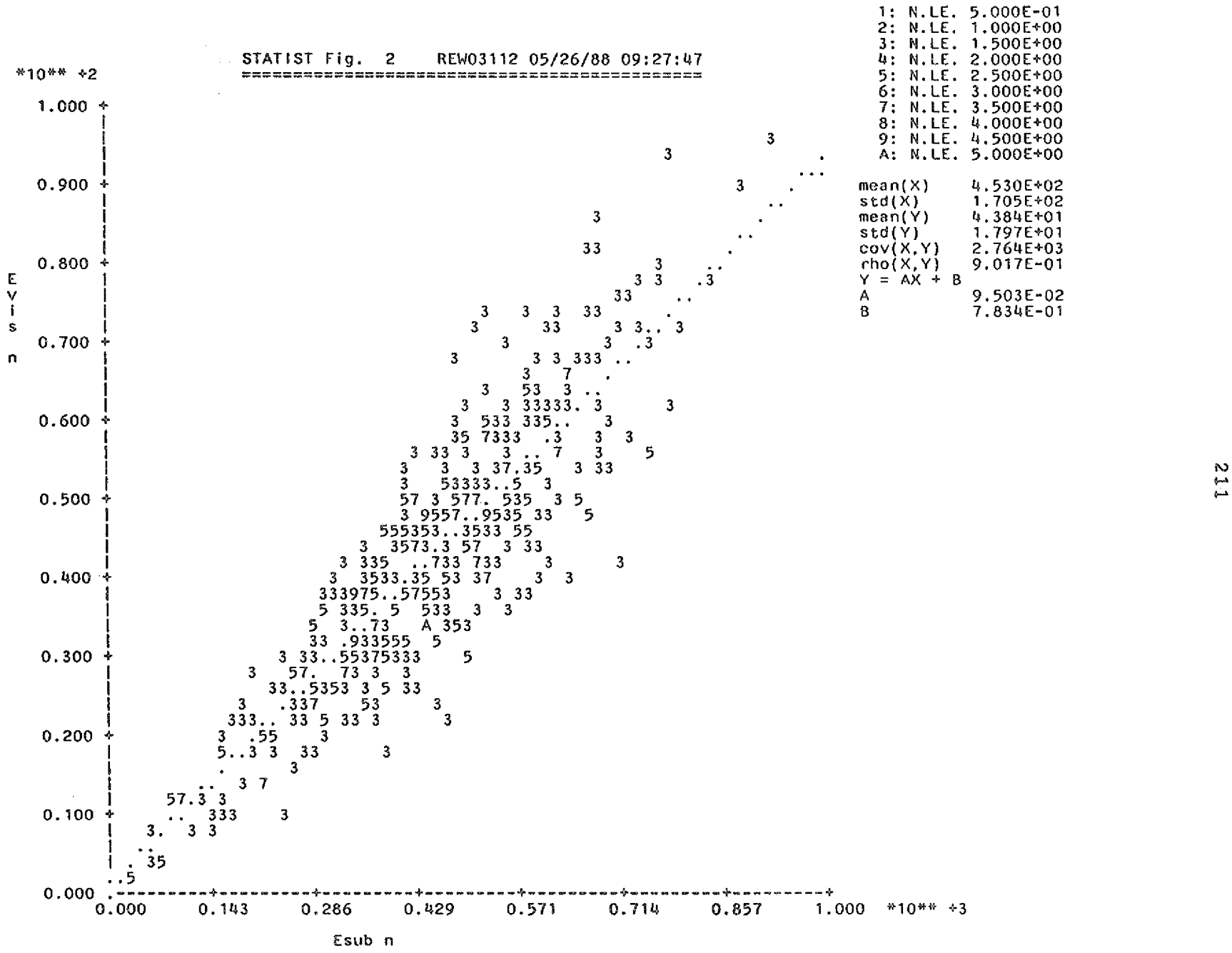
 Esub pi0                    8.984E+02 1.032E+03 5.041E+04 4.730E-02
 Evis pi0                    4.179E+01 5.004E+01 9.759E-01-7.079E-01
UNIVARIATE DATA           STATIST          REW03112 05/26/88 09:27:47
VARIABLE                     N-EVENTS    N-ZERO    N-LOST    MINIMUM    MAXIMUM
 Edep p,pi+,pi-                450.        0.        0. 1.949E+02 3.154E+03
 Esub n                        450.        2.        0. 9.265E+00 9.338E+02
 Esub pi0                      450.      117.        0. 1.394E+02 4.715E+03
 Evis p,pi+,pi-                450.        0.        0. 1.291E+01 2.382E+02
 Evis n                        450.        2.        0. 3.501E-01 9.972E+01
 Evis pi0                      450.      118.        0. 1.809E+00 2.120E+02
 Evis p,pi+,pi-,n,pi0          450.        0.        0. 5.315E+01 3.310E+02
EMPIRICAL MOMENTS         STATIST          REW03112 05/26/88 09:27:47

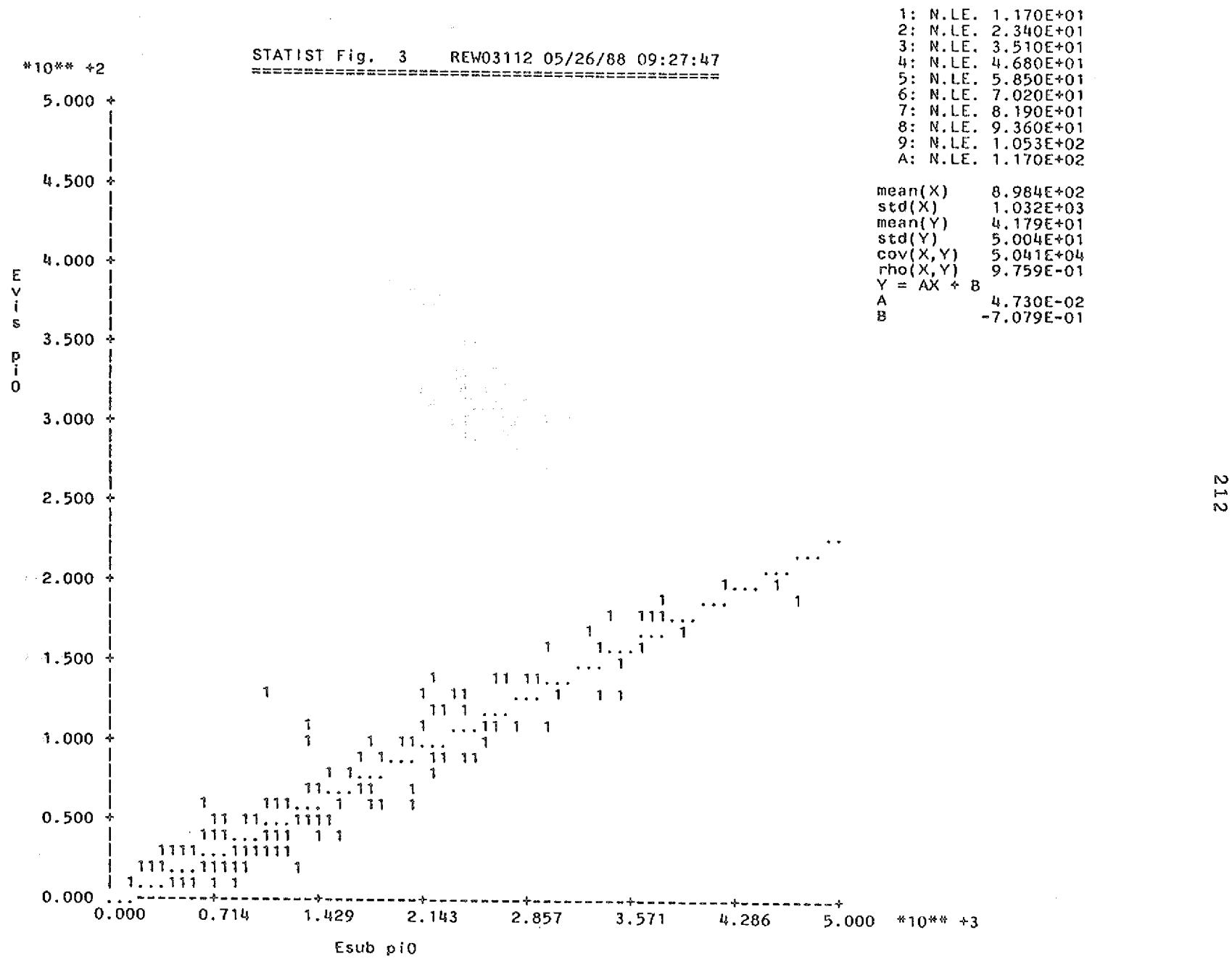
VARIABLE                          MEAN       STD       FSD  SCEWNESS  KURTOSIS
 Edep p,pi+,pi-              1.542E+03 5.538E+02     35.92 1.457E-01-1.846E-01
 Esub n                      4.530E+02 1.686E+02     37.21-2.205E-01 6.329E-02
 Esub pi0                    8.984E+02 1.032E+03    114.90 1.461E+00 1.669E+00
 Evis p,pi+,pi-              1.214E+02 4.575E+01     37.69 2.040E-01-3.898E-01
 Evis n                      4.384E+01 1.785E+01     40.71 5.751E-02 2.595E-02
 Evis pi0                    4.179E+01 5.003E+01    119.72 1.489E+00 1.598E+00
 Evis p,pi+,pi-,n,pi0        2.070E+02 4.252E+01     20.54-3.960E-01 4.850E-01
GROUPED MOMENTS           STATIST          REW03112 05/26/88 09:27:47

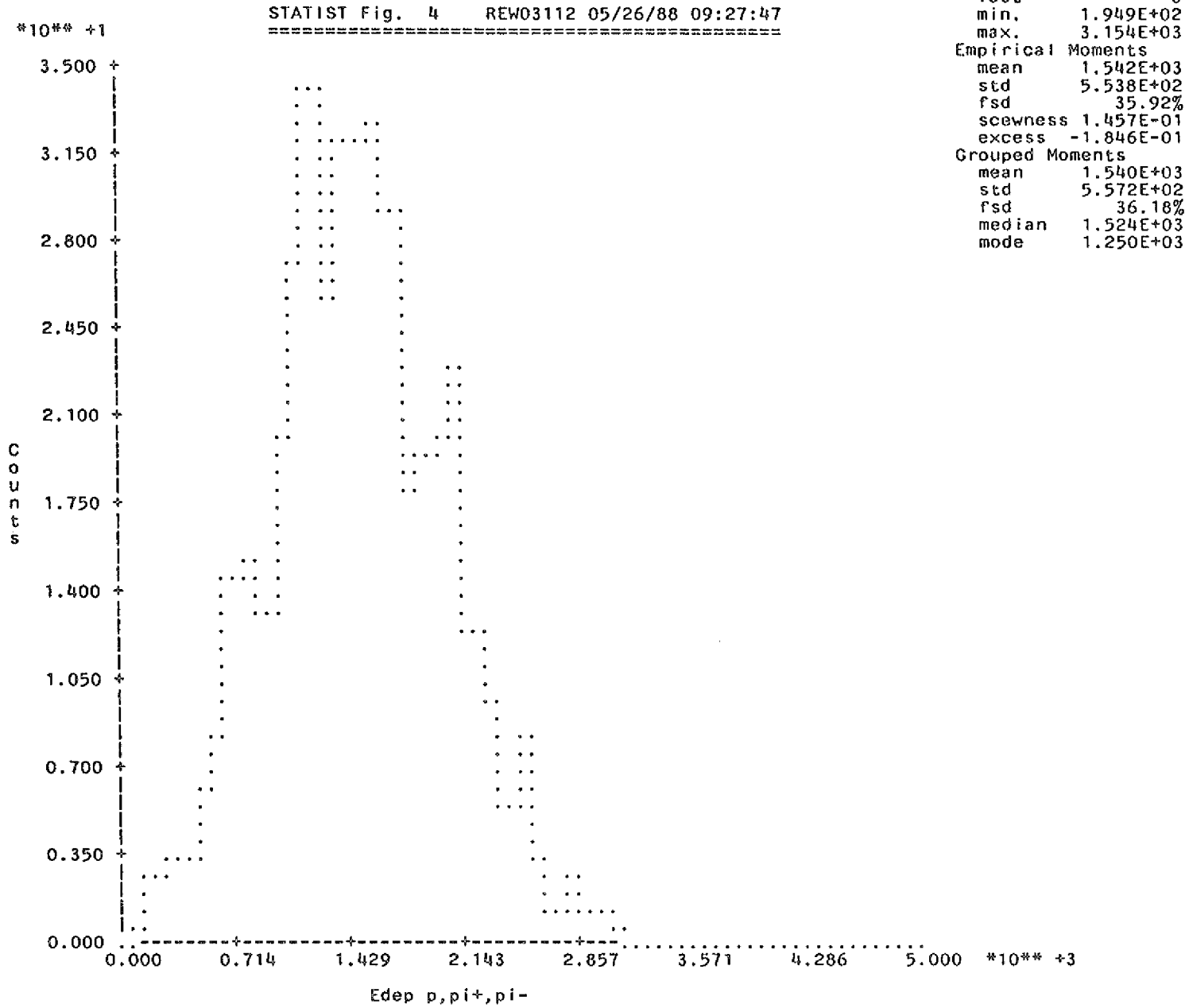
VARIABLE                          MEAN       STD       FSD    MEDIAN      MODE
 Edep p,pi+,pi-              1.540E+03 5.572E+02     36.18 1.524E+03 1.250E+03
 Esub n                      4.548E+02 1.657E+02     36.44 4.608E+02-6.660E+02
 Esub pi0                    1.215E+03 1.032E+03     84.94 8.650E+02 3.500E+02
 Evis p,pi+,pi-              1.214E+02 4.585E+01     37.77 1.186E+02 1.050E+02
 Evis n                      4.402E+01 1.766E+01     40.12 4.390E+01 4.900E+01
 Evis pi0                    5.657E+01 5.076E+01     89.73 3.971E+01 1.500E+01
 Evis p,pi+,pi-,n,pi0        2.070E+02 4.243E+01     20.50 2.091E+02 2.050E+02
FITTED  MOMENTS           STATIST          REW03112 05/26/88 09:27:47

VARIABLE                          FROM         TO     N-FIT       MEAN        FSD
 Edep p,pi+,pi-              0.000E+00 0.000E+00        0. 0.000E+00       0.00
 Esub n                      0.000E+00 0.000E+00        0. 0.000E+00       0.00
 Esub pi0                    0.000E+00 0.000E+00        0. 0.000E+00       0.00
 Evis p,pi+,pi-              0.000E+00 0.000E+00        0. 0.000E+00       0.00
 Evis n                      0.000E+00 0.000E+00        0. 0.000E+00       0.00
 Evis pi0                    0.000E+00 0.000E+00        0. 0.000E+00       0.00
 Evis p,pi+,pi-,n,pi0        1.219E+02 2.920E+02      428. 2.097E+02      17.08
M:STAT3: NUMBER OF EVENTS READ       450
!: EXIT;
```

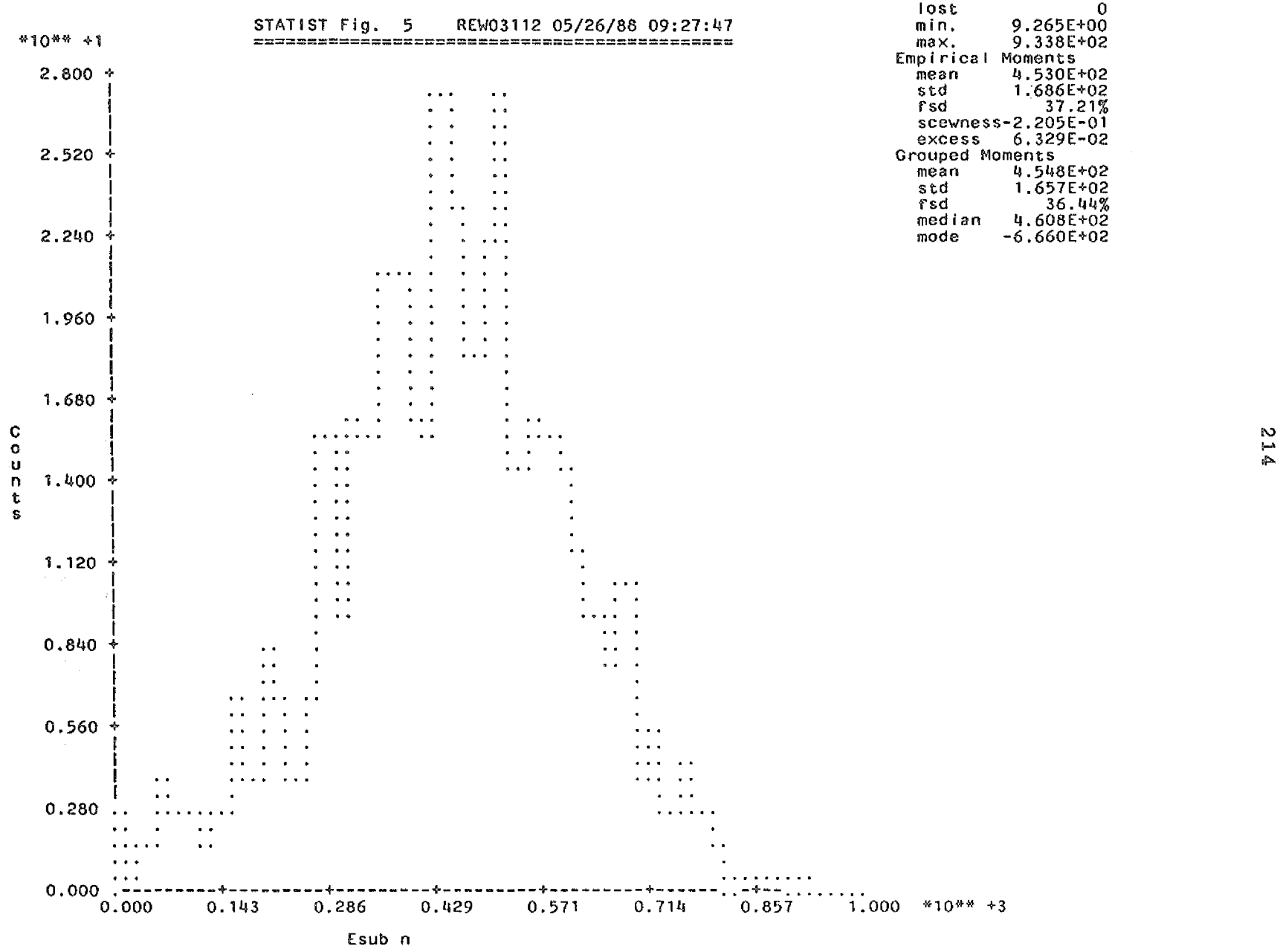

STATIST Fig. 1 REW03112 05/26/88 09:27:47
*10** +2
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Evis p,pi+,pi-
0.000
0.714
1.429
2.143
2.857
3.571
4.286
5.000
*10** +3
Edep p,pi+,pi-
1: N.LE. 1.200E+00
2: N.LE. 2.400E+00
3: N.LE. 3.600E+00
4: N.LE. 4.800E+00
5: N.LE. 6.000E+00
6: N.LE. 7.200E+00
7: N.LE. 8.400E+00
8: N.LE. 9.600E+00
9: N.LE. 1.080E+01
A: N.LE. 1.200E+01
mean(X) 1.542E+03
std(X) 5.538E+02
mean(Y) 1.214E+02
std(Y) 4.575E+01
cov(X,Y) 2.310E+04
rho(X,Y) 9.119E-01
Y = AX + B
A 7.534E-02
B 5.225E+00


STATIST Fig. 2 REW03112 05/26/88 09:27:47
*10** +2
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Evis n
0.000
0.143
0.286
0.429
0.571
0.714
0.857
1.000
*10** +3
Esub n
1: N.LE. 5.000E-01
2: N.LE. 1.000E+00
3: N.LE. 1.500E+00
4: N.LE. 2.000E+00
5: N.LE. 2.500E+00
6: N.LE. 3.000E+00
7: N.LE. 3.500E+00
8: N.LE. 4.000E+00
9: N.LE. 4.500E+00
A: N.LE. 5.000E+00
mean(X) 4.530E+02
std(X) 1.705E+02
mean(Y) 4.384E+01
std(Y) 1.797E+01
cov(X,Y) 2.764E+03
rho(X,Y) 9.017E-01
Y = AX + B
A 9.503E-02
B 7.834E-01

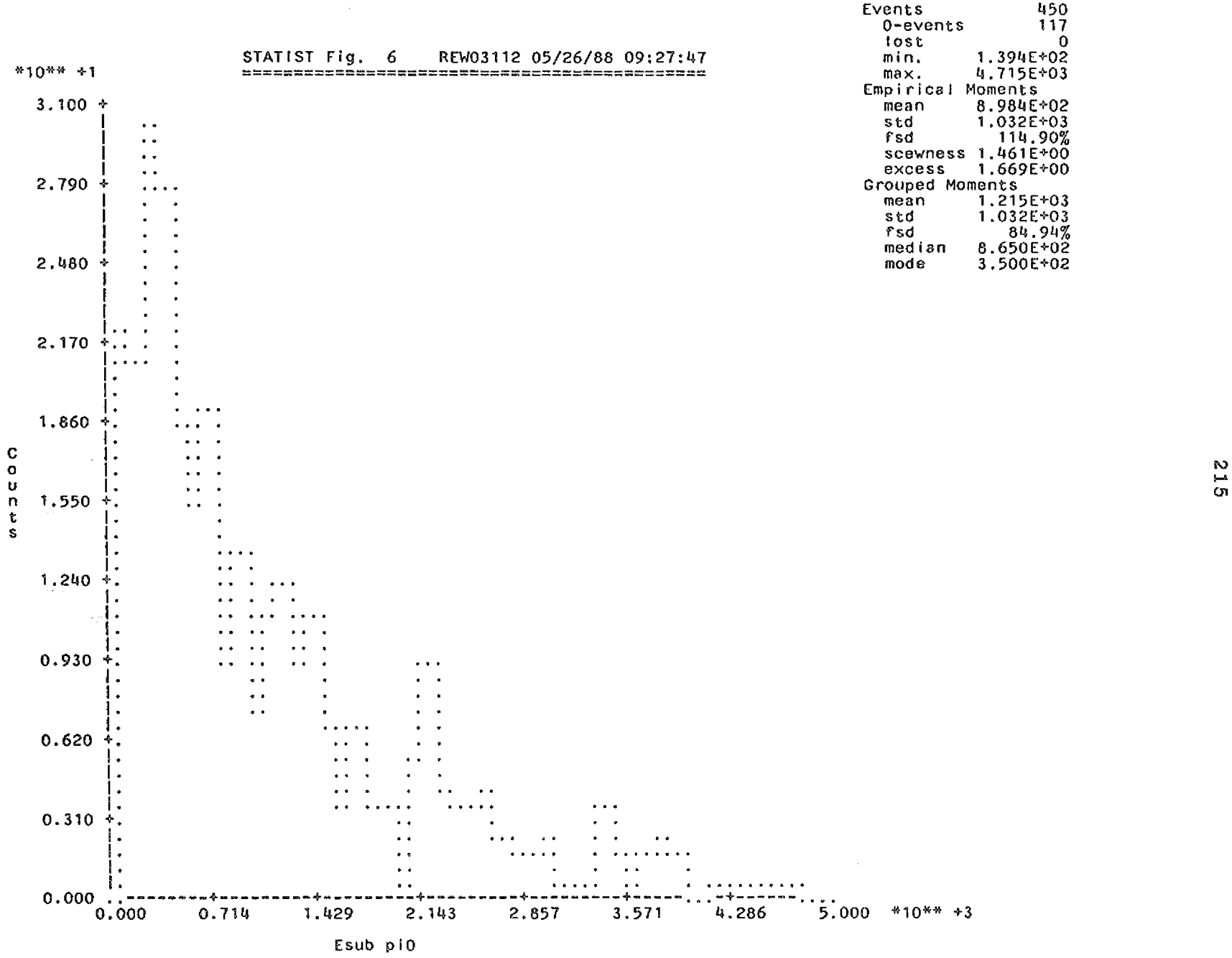

STATIST Fig. 3 REW03112 05/26/88 09:27:47
*10** +2
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
E vis pi0
0.000
0.714
1.429
2.143
2.857
3.571
4.286
5.000
*10** +3
Esub pi0
1: N.LE. 1.170E+01
2: N.LE. 2.340E+01
3: N.LE. 3.510E+01
4: N.LE. 4.680E+01
5: N.LE. 5.850E+01
6: N.LE. 7.020E+01
7: N.LE. 8.190E+01
8: N.LE. 9.360E+01
9: N.LE. 1.053E+02
A: N.LE. 1.170E+02
mean(X) 8.984E+02
std(X) 1.032E+03
mean(Y) 4.179E+01
std(Y) 5.004E+01
cov(X,Y) 5.041E+04
rho(X,Y) 9.759E-01
Y = AX + B
A 4.730E-02
B -7.079E-01



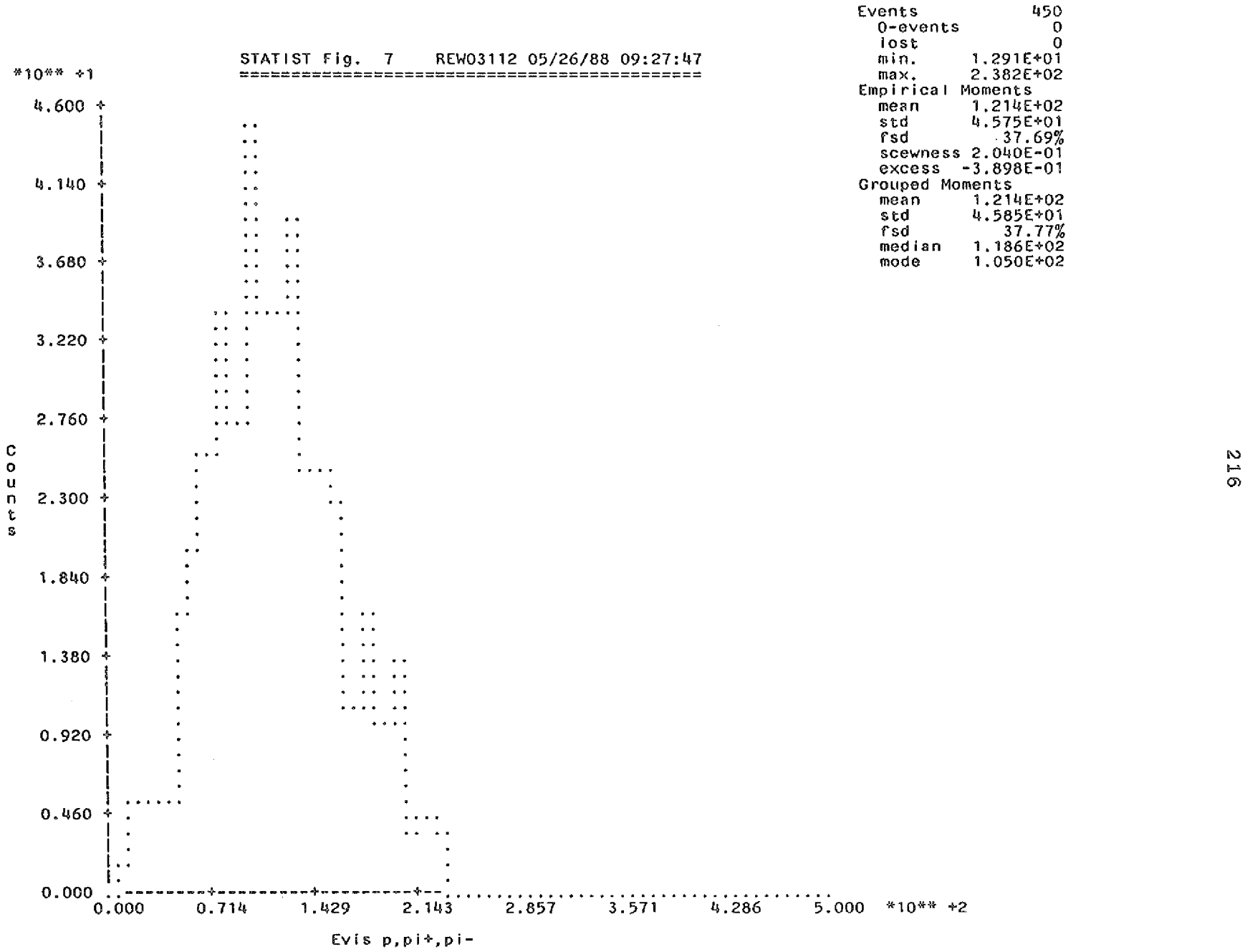
Events	450
0-events	0
lost	0
min.	1.949E+02
max.	3.154E+03
Empirical Moments	
mean	1.542E+03
std	5.538E+02
fsd	35.92%
scewness	1.457E-01
excess	-1.846E-01
Grouped Moments	
mean	1.540E+03
std	5.572E+02
fsd	36.18%
median	1.524E+03
mode	1.250E+03



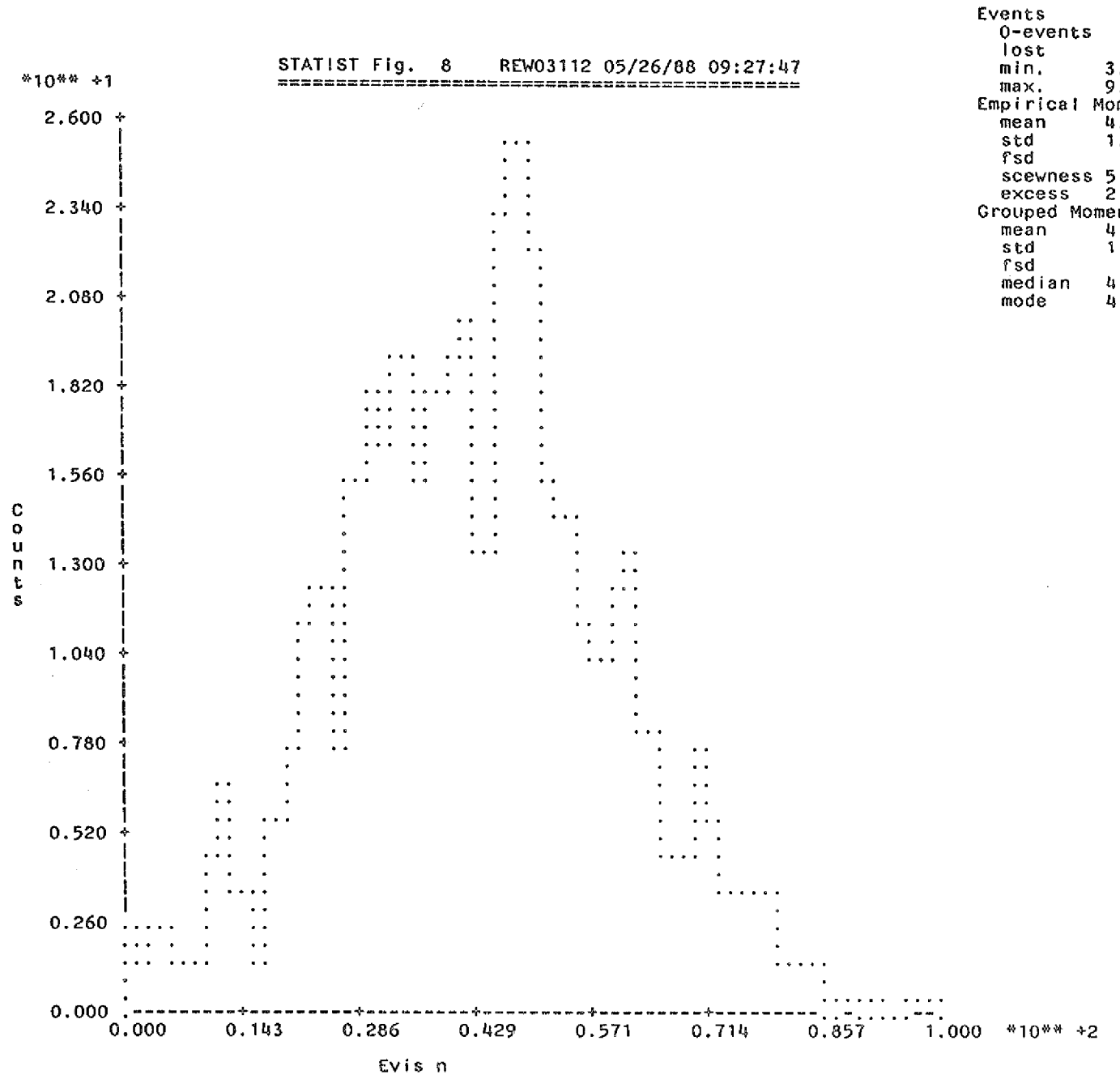
Events	450
0-events	2
lost	0
min.	9.265E+00
max.	9.338E+02
Empirical Moments	
mean	4.530E+02
std	1.686E+02
fsd	37.21%
scewness	-2.205E-01
excess	6.329E-02
Grouped Moments	
mean	4.548E+02
std	1.657E+02
fsd	36.44%
median	4.608E+02
mode	-6.660E+02



Events	450
0-events	117
lost	0
min.	1.394E+02
max.	4.715E+03
Empirical Moments	
mean	8.984E+02
std	1.032E+03
fsd	114.90%
scewness	1.461E+00
excess	1.669E+00
Grouped Moments	
mean	1.215E+03
std	1.032E+03
fsd	84.94%
median	8.650E+02
mode	3.500E+02

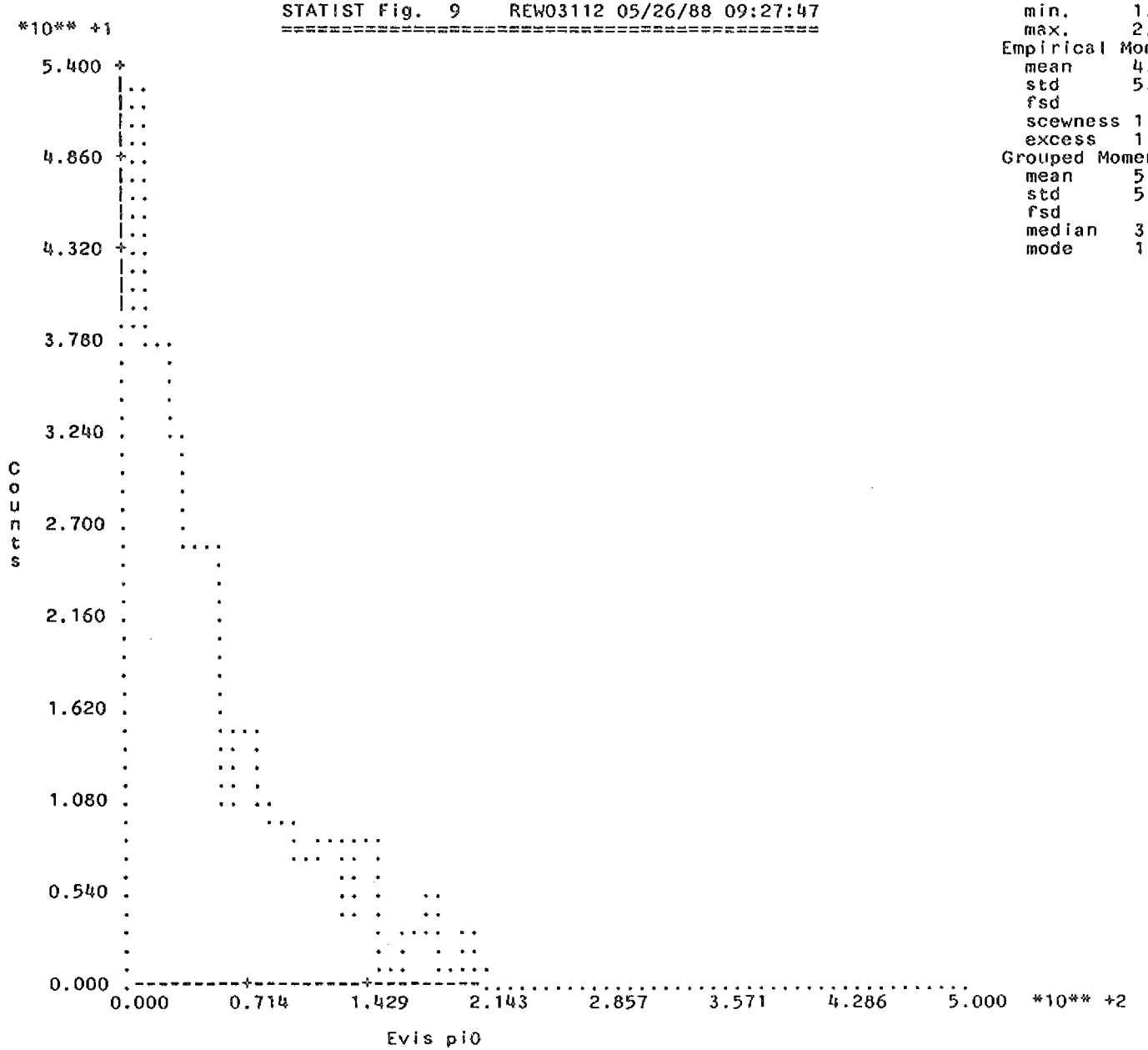


Events	450
0-events	0
lost	0
min.	1.291E+01
max.	2.382E+02
Empirical Moments	
mean	1.214E+02
std	4.575E+01
fsd	37.69%
scewness	2.040E-01
excess	-3.898E-01
Grouped Moments	
mean	1.214E+02
std	4.585E+01
fsd	37.77%
median	1.186E+02
mode	1.050E+02

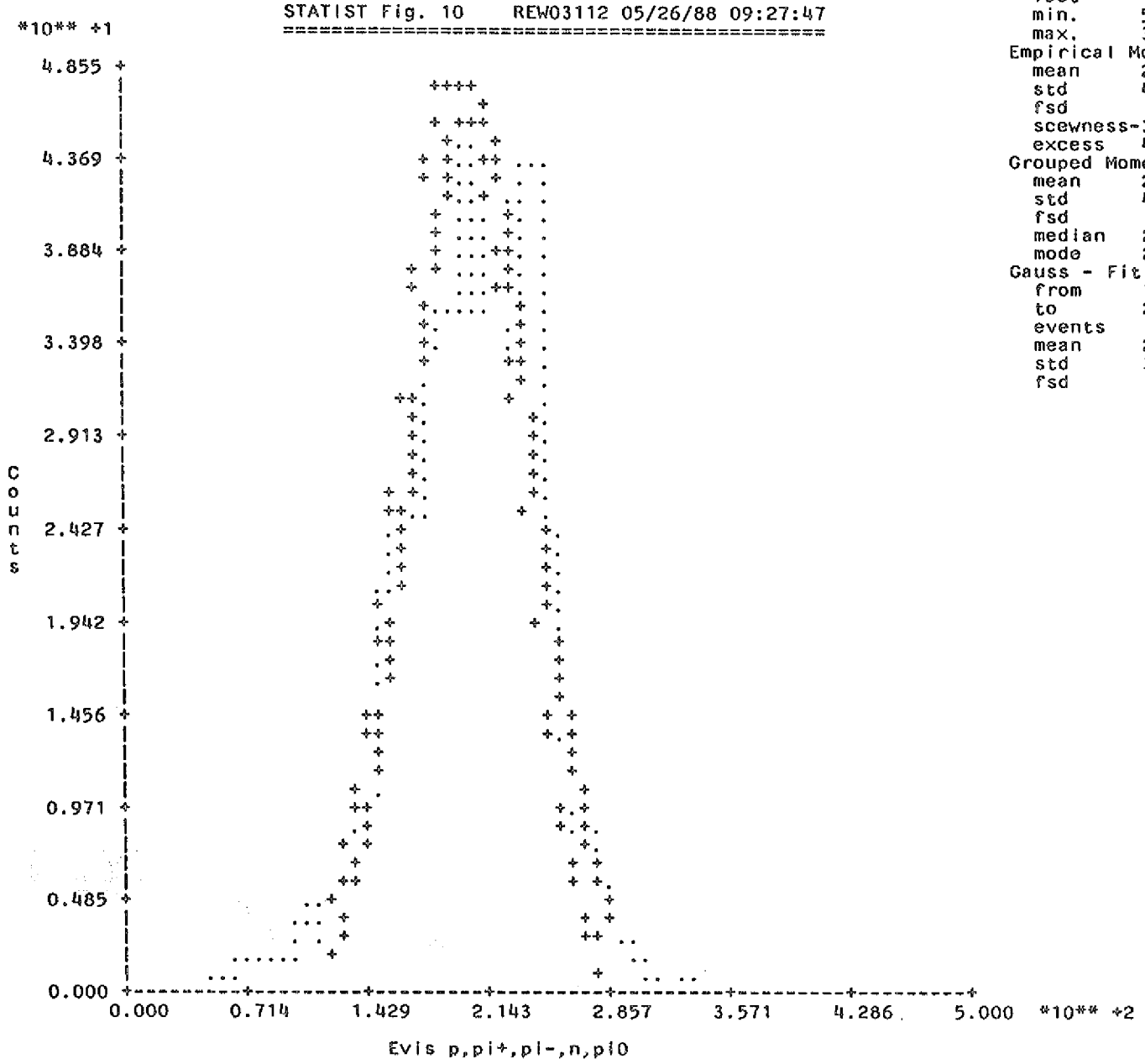


Events	450
0-events	2
lost	0
min.	3.501E-01
max.	9.972E+01
Empirical Moments	
mean	4.384E+01
std	1.785E+01
fsd	40.71%
scewness	5.751E-02
excess	2.595E-02
Grouped Moments	
mean	4.402E+01
std	1.766E+01
fsd	40.12%
median	4.390E+01
mode	4.900E+01

STATIST Fig. 9 REW03112 05/26/88 09:27:47



Events	450
0-events	118
lost	0
min.	1.809E+00
max.	2.120E+02
Empirical Moments	
mean	4.179E+01
std	5.003E+01
fsd	119.72%
scewness	1.489E+00
excess	1.598E+00
Grouped Moments	
mean	5.657E+01
std	5.076E+01
fsd	89.73%
median	3.971E+01
mode	1.500E+01



Events	450
0-events	0
lost	0
min.	5.315E+01
max.	3.310E+02
Empirical Moments	
mean	2.070E+02
std	4.252E+01
fsd	20.54%
scewness	-3.960E-01
excess	4.850E-01
Grouped Moments	
mean	2.070E+02
std	4.243E+01
fsd	20.50%
median	2.091E+02
mode	2.050E+02
Gauss - Fit	
from	1.219E+02
to	2.920E+02
events	428
mean	2.097E+02
std	3.581E+01
fsd	17.08%

E.2 Sample Problem II

Double-Differential Cross-Section Calculation

This is an example using the "thin"-target option of HETC to calculate double-differentail cross-sections. This test case considers an 800 MeV proton beam on lead.

E.2.1 Input Files for Sample Problem II

(1) Input to HETC and SIM

```
//REW101PB JOB ($$ACCOUNT$),THIN,TIME=(60),REGION=3000K,
//    CLASS=K,MSGCLASS=A
/*JOBPARM  L=15
//* PB-208  800.MEV P  ON PB THIN TARGET, PROTON  YIELDS
/*PASSWORD $MVS
/*ROUTE  PRINT CMS
//HET86  EXEC  LGFORTV,COND=(9,LT)
//L.SYSPRINT DD DUMMY
//L.SYSUT1 DD UNIT=TVIO,SPACE=(6400,180)
//L.LOD31  DD DSN=REW031.HERMES,DISP=SHR
//L.SYSIN DD *
   INCLUDE LOD31(THIN)
   INCLUDE LOD31(HETKFA2)
   ENTRY HET
/*
//G.FT20F001 DD DSN=REW071.HET86.BERT,DISP=SHR,LABEL=(,,,IN)      BERTP
//G.FT26F001 DD SYSOUT=*,DCB=(RECFM=UA,BLKSIZE=133)               ECHO
//G.SYSIN DD *
 REAL THE(5);DATA THE=< 0. 15. 45. 90. 180. >
 REAL E(33);DATA E=< 800. A 14 -50. A 3 -25. A 4 -5. A 5 -1. >
 DEFDET CASP,1,0.,$Z,E,THE;
 DEFDET EVAP,2,0.,$Z,E,THE;
 DEFDET YLDP,3,0.,$Z,E,THE;
 DEFDET CP00,1,0.;
 DEFDET CN00,1,1.;
RUN;
 &RUN
     MAXCAS=500,   MAXBCH=20, IRUN=1, ISEED=123456789,
     EMAX=800., ESR=800.,  WSR=1., TIPSR=0.,

     EMIN(1)=1., EMIN(2)=15., EPICUT=2.23, EMUCUT=1.69, ELOP=20.,
     IOSUB=0 , IBERTP=-20, NHSTP=0,
     IELAS=0, ISTRAG=0, IANG=1, IFISS=0,KEYDK=0, IB0=1, B0=8.,

     MXMAT=1,
       NEL(1)=1,  DENH(1)=0.,
      ZZ(1,1)=82.,A(1,1)=208.,DEN(1,1)= 1.000,
 &END
EXIT;
/*
```

E.2.2 Output File Excerpt for Sample Problem II

(1) Output of HETC and SIM

```
/JOB-ID = REW101PB 05/02/88 23:53:05
I: REAL THE(5);DATA THE=< 0. 15. 45. 90. 180. >
I: REAL E(33);DATA E=< 800. A 14 -50. A 3 -25. A 4 -5. A 5 -1. >
I: DEFDET CASP,1,0.,$Z,E,THE;
I: DEFDET EVAP,2,0.,$Z,E,THE;
I: DEFDET YLDP,3,0.,$Z,E,THE;
I: DEFDET CP00,1,0.;
I: DEFDET CN00,1,1.;
I:RUN;
MAXBCH=  20  IBERTP=-20  EMIN(1)= 1.000E+00  ELOP  = 2.000E+01
MAXCAS= 500  IOSUB =  0  EMIN(2)= 1.500E+01  CTOFE = 0.000E+00
IRUN  =   1  NHSTP =  0  EPICUT = 2.230E+00  EMAX  = 8.000E+02
                         EMUCUT = 1.690E+00  BO    = 8.000E+00
NICOL =0  NPIDK =1  NBOGUS =1  NSEUDO=1
NSPRED=0  NWSPRD=0  ISTRAG =0  IANG  =1
IFISS =0  IBO   =1  IGEOM  =0  KEYDK =0
IELAS =0
ISEED =  123456789
LHI   =0  HIA(5)=  0.0  HIZ(5)=  0.0  HIBE(5)= 0.000E+00
/BERTTP(I): I-N-C  DATA READ FORM UNIT 20
/BERTTP(I): EVAP   DATA READ FORM UNIT 20
NON-ISOTROPIC ANGLE OPTION SELECTED
HSIGMX     0.12000E-23    0.64500E-24    0.20000E-24    0.00000E+00    0.67700E-25
THIS IS MEDIUM  1
DENH=0.000000E+00  NEL= 1  SO= 1.000E+00  KB= 0.000E+00
ZZ( 1, 1)=82.0  A( 1, 1)=208.0  DEN( 1, 1)=1.000000E+00
"GEOMETRIC" X-SECTIONS IN (1/CM)

  NUCLIDS:     1          2          3          4          5          6
7          8          9          10
  MEDIA
     1     2.4615E+00
MAXIMUM H-1 X-SECTIONS IN (1/CM)

  MEDIA        PROTONS    NEUTRONS         PI+         PIO         PI-
     1     0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
TRANSPORT X-SECTION = SUM("GEOMETRIC") + MAX. H-1 + MAX. DECAY X-SECTIONS IN (1/CM)

  MEDIA        PROTONS    NEUTRONS         PI+         PIO         PI-         MUE+
MUE-
     1     2.4615E+00  2.4615E+00  2.4686E+00  0.0000E+00  2.4686E+00  8.8943E-05
8.8943E-05
SOURCE DATA:
TYP     =       0.
XYZ     =    0.000     0.000     0.000  GAUSSIAN DISTRIBUTED WITH
XYZ SIG.=    0.000     0.000     0.000  TRUNCATED TO RADIUS
  R     =    0.000                      IF R>0
UVW     =   0.0000    0.0000    1.0000  IF = 0.,0.,0. -> ISOTROPIC
 WT     =    1.000
  E     =  800.000  GAUSSIAN DISTRBUTED WITH
  E SIG.=    0.000
M: YOU ARE USING THIN TARGET SETUP
--> SOR HET   IRUN=    1 ISEED=  123456789
--> SOB HET   IBAT=    1 ISEED=  123456789
/BERTTP(I): I-N-C  DATA READ FORM UNIT 20
/DRES(I): USING 1977 WAPS DATA
--> EOB HET   IBAT=    1 ISEED=  876852125 NHIS=  500 CPU=   45.57SEC.
  MEDIUM   SORS   CASC   SLOW   ESCP   PSEU   ABSO   BRDY   SCAT

      1    500    361      0      0    139      0      0      0      0
   6666      0      0      0      0      0      0      0      0      0
  TOTAL    500    361      0      0    139      0      0      0      0
------------------------------------------------------------------------
```

```
--> SOB HET   IBAT=    2 ISEED=  876852125
--> EOB HET   IBAT=    2 ISEED= 1939235471 NHIS= 1000 CPU=   40.19SEC.
  MEDIUM   SORS   CASC   SLOW   ESCP   PSEU   ABSO   BRDY   SCAT

       1    500    356      0      0    144      0      0      0      0
    6666      0      0      0      0      0      0      0      0      0
   TOTAL    500    356      0      0    144      0      0      0      0
-------------------------------------------------------------------------
            .
            .
            .
--> EOR HET   IRUN=    1 ISEED= 1734564103 NHIS=10000 CPU=  782.97SEC.
  MEDIUM   SORS   CASC   SLOW   ESCP   PSEU   ABSO   BRDY   SCAT

       1  10000   7155      0      0   2845      0      0      0      0
    6666      0      0      0      0      0      0      0      0      0
   TOTAL  10000   7155      0      0   2845      0      0      0      0
             REAL          PSEUDO          REAL          PSEUDO          PSEUDO
REAL          PSEUDO
          NONHYDROG      NONHYDROG       HYDROGEN       HYDROGEN        DECAY
ELASTIC       ELASTIC
         COLLISIONS     COLLISIONS     COLLISIONS     COLLISIONS     COLLISIONS
COLLISIONS     COLLISIONS
MEDIUM  1  0.71550E+04    0.28450E+04    0.00000E+00    0.00000E+00    0.00000E+00
0.00000E+00    0.00000E+00


                                        PSEUDO COLLISIONS WITHIN INTERNAL VOID BY
PARTICLES OF

       TYPE 1         TYPE 2         TYPE 3         TYPE 4         TYPE 5
TYPE 6         TYPE 7

      0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
0.00000E+00    0.00000E+00
--> NEGEX=   0   LOWAZ=   0     NWTC=   0
    MEDIUM     SOURCE-FRACTION      %ERR
         1           1.000E+00      0.00
      VOID           0.000E+00      0.00
    MEDIUM     INELASTIC C./SOURCE  %ERR     ELASTIC C. /SOURCE   %ERR
         1           7.155E-01      0.53           0.000E+00      0.00
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     ABSORPTION  /SOURCE  %ERR     FISSION    /SOURCE   %ERR
         1           0.000E+00      0.00           0.000E+00      0.00
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     P FLUX (CM)          %ERR     N FLUX (CM)          %ERR
         1           0.000E+00      0.00           0.000E+00      0.00
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     PI+  FLUX (CM)       %ERR     PI-  FLUX (CM)       %ERR
         1           0.000E+00      0.00           0.000E+00      0.00
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     MU+  FLUX (CM)       %ERR     MU-  FLUX (CM)       %ERR
         1           0.000E+00      0.00           0.000E+00      0.00
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     P YIELD              %ERR     N YIELD              %ERR
         1           1.685E+00      0.94           9.687E+00      0.72
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     PI+  YIELD           %ERR     PI0  YIELD           %ERR
         1           9.640E-02      1.59           1.097E-01      2.74
      VOID           0.000E+00      0.00           0.000E+00      0.00
    MEDIUM     PI-  YIELD           %ERR
         1           6.220E-02      4.19
```

```
      VOID            0.000E+00       0.00
    MEDIUM     MU+  YIELD              %ERR     MU-  YIELD              %ERR
         1            0.000E+00       0.00          0.000E+00       0.00
      VOID            0.000E+00       0.00          0.000E+00       0.00
    MEDIUM     D    YIELD              %ERR     T    YIELD              %ERR
         1            5.790E-01       1.28          5.444E-01       1.79
      VOID            0.000E+00       0.00          0.000E+00       0.00
    MEDIUM     HE3  YIELD              %ERR     HE4  YIELD              %ERR
         1            2.680E-02       6.84          1.130E+00       1.12
      VOID            0.000E+00       0.00          0.000E+00       0.00
W:RSYS: NO RSYST-TAPE AVAILABLE
YIELD DETECTOR FOR P      FROM INC
DETECTOR NAME =    CASP
THETA1= 0.000E+00 THETA2= 1.500E+01
    E-HIGH     E-LOW INC-YIELD      %ERR
 8.000E+02 7.500E+02 1.930E-02      6.48
 7.500E+02 7.000E+02 1.050E-02     11.38
 7.000E+02 6.500E+02 1.200E-03     18.73
 6.500E+02 6.000E+02 1.200E-03     35.04
 6.000E+02 5.500E+02 2.100E-03     17.58
 5.500E+02 5.000E+02 3.500E-03     19.39
 5.000E+02 4.500E+02 2.800E-03     22.23
 4.500E+02 4.000E+02 5.100E-03     14.36
 4.000E+02 3.500E+02 5.800E-03     13.21
 3.500E+02 3.000E+02 4.900E-03     15.24
 3.000E+02 2.500E+02 5.200E-03     12.60
 2.500E+02 2.000E+02 6.300E-03     13.08
 2.000E+02 1.500E+02 5.300E-03     12.63
 1.500E+02 1.000E+02 6.300E-03     10.87
 1.000E+02 7.500E+01 3.000E-03     19.04
 7.500E+01 5.000E+01 5.100E-03     14.91
 5.000E+01 2.500E+01 7.300E-03      9.38
 2.500E+01 2.000E+01 1.900E-03     24.72
 2.000E+01 1.500E+01 4.200E-03     20.11
 1.500E+01 1.000E+01 3.300E-03     17.18
 1.000E+01 5.000E+00 6.000E-04     42.58
 5.000E+00 4.000E+00 0.000E+00      0.00
 4.000E+00 3.000E+00 0.000E+00      0.00
 3.000E+00 2.000E+00 0.000E+00      0.00
 2.000E+00 1.000E+00 0.000E+00      0.00
 1.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
THETA1= 1.500E+01 THETA2= 4.500E+01
    E-HIGH     E-LOW INC-YIELD      %ERR
 8.000E+02 7.500E+02 9.000E-04     34.10
 7.500E+02 7.000E+02 7.800E-03     13.01
 7.000E+02 6.500E+02 1.340E-02      8.60
 6.500E+02 6.000E+02 8.300E-03     10.08
 6.000E+02 5.500E+02 8.300E-03      8.06
 5.500E+02 5.000E+02 9.500E-03      6.81
 5.000E+02 4.500E+02 1.060E-02     10.16
 4.500E+02 4.000E+02 1.340E-02      7.43
 4.000E+02 3.500E+02 1.570E-02      7.17
 3.500E+02 3.000E+02 1.760E-02      6.57
 3.000E+02 2.500E+02 2.420E-02      7.70
 2.500E+02 2.000E+02 2.590E-02      7.01
 2.000E+02 1.500E+02 3.610E-02      5.17
 1.500E+02 1.000E+02 3.900E-02      4.28
```

```
 1.000E+02 7.500E+01 2.730E-02      5.83
 7.500E+01 5.000E+01 3.190E-02      4.95
 5.000E+01 2.500E+01 4.670E-02      4.95
 2.500E+01 2.000E+01 1.540E-02      7.94
 2.000E+01 1.500E+01 2.640E-02      5.67
 1.500E+01 1.000E+01 2.620E-02      7.30
 1.000E+01 5.000E+00 6.400E-03     12.54
 5.000E+00 4.000E+00 0.000E+00      0.00
 4.000E+00 3.000E+00 0.000E+00      0.00
 3.000E+00 2.000E+00 0.000E+00      0.00
 2.000E+00 1.000E+00 0.000E+00      0.00
 1.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
 0.000E+00 0.000E+00 0.000E+00      0.00
           .
           .
           .
YIELD DETECTOR FOR P      FROM INC
DETECTOR NAME =    CP00
                     INC-YIELD      %ERR
                     1.401E+00      0.92
YIELD DETECTOR FOR N      FROM INC
DETECTOR NAME =    CN00
                     INC-YIELD      %ERR
                     2.800E+00      0.75
-------------------------------------------------------------------------
I:EXIT;
 MESSAGE SUMMARY: MESSAGE NUMBER - COUNT
                          212       9
```

E.3 Sample Problem III

Thick-Target Particle Flux Calculation

This is an example for particle flux calculation performed on a "thick" target formed by an iron cylinder as depicted in Fig. E.3. The fluxes are determined in different regions, energy bins and for different particle types. The target was hit axially by a 1 GeV proton pencil beam.

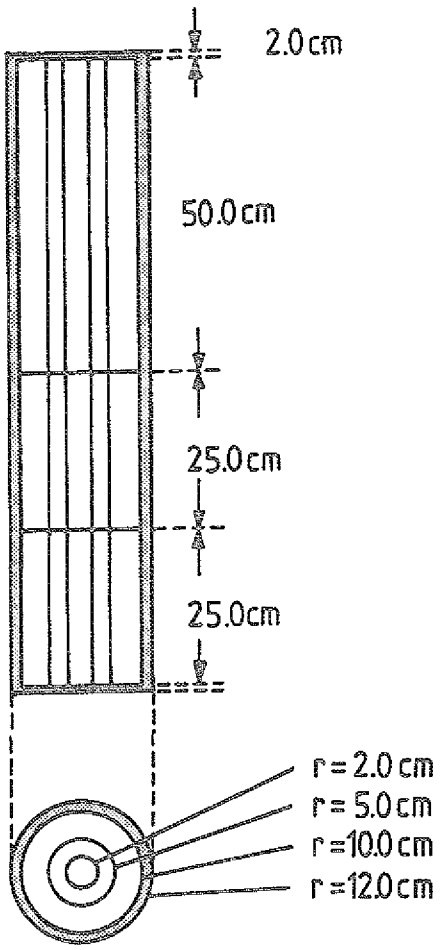


Fig. E.3: Geometrical Setup

E.3.1 Input Files for Sample Problem III

(1) Geometry Description in CMD Language

```
/ Test3 geometry
 GEOCMP 8 13 13 ;
/ Body input
 PZ   1   0.;
 PZ   2  25.;
 PZ   3  50.;
 PZ   4 100.;
 CZ  11  $N  2.;
 CZ  12  $N  5.;
 CZ  13  $N 10.;
 RCC 20  0. 0. -1.    0. 0. 102.    12.;
 END;
/ Zone input
 ZONE    1 11  +11        +1  -2;
 ZONE    1 12  +11        +2  -3;
 ZONE    1 13  +11        +3  -4;
 ZONE    1 21  +12  -11   +1  -2;
 ZONE    1 22  +12  -11   +2  -3;
 ZONE    1 23  +12  -11   +3  -4;
 ZONE    1 31  +13  -12   +1  -2;
 ZONE    1 32  +13  -12   +2  -3;
 ZONE    1 33  +13  -12   +3  -4;
 ZONE 6666 61  +20  +13   -1;
 ZONE 6666 62  +20  +13   +4;
 ZONE 6666 63  +20  -13;
 ZONE   -1 90  -20;
 ENDGEO;
/ Load geometry object file from unit 22;
 GEOIN;
/ Return to terminal input  for test
 UNIT 5;
```

(2) Input to HETC and SIM

```
//REW031H3 JOB ($$ACCOUNT$),'TEST3-HET',TIME=(4),REGION=3000K,
//    CLASS=C,MSGCLASS=A
/*JOBPARM  L=15
/*PASSWORD $MVS
/*ROUTE  PRINT CMS
//HET EXEC GFORTV,NAME=HETKFA2,DS='REW031.HERMES'
//G.FT20F001 DD DSN=REW071.HET86.BERT,DISP=SHR,LABEL=(,,,IN)     BERTP
//G.FT21F001 DD  DSN=REW031.HETSUB.TEST3,DISP=SHR                IOSUB
//G.FT07F001 DD  SYSOUT=P,DCB=(RECFM=F,LRECL=80,BLKSIZE=80),
//  DEST=(CMS,REW031)
//G.FT25F001 DD *                                                INGEO
$INCLUDE TEST3 GEO-0
/*
//G.SYSIN DD *
/ setup detector regions
 INTEGER IR1(9);DATA IR1=<11 12 13 21 22 23 31 32 33>;
/ setup detector energy bins
 REAL EP(12),EN(9);
 DATA EP=< 1000. 750. 500. 250. 100. 50. 25. 20. 15. 10. 5. 1.>;
 DATA EN=< 1000. 750. 500. 250. 100. 50. 25. 20. 15. >;
/ setup detectors
 DEFDET PHIP,8,0.,,EP,,IR1;
 DEFDET PHIN,8,1.,,EN,,IR1;
RUN;   / return to het primary input
 &RUN
    MAXCAS=20,  MAXBCH= 50,
    EMAX=1000., EMIN(1)=1., EMIN(2)=14.9, ELOP=20.,
    IBERTP=-20, IOSUB=21, NHSTP= 0, INGEO=25,
    IELAS=2, IANG=1, IFISS=0,

    MXMAT=1,     DENH=0., NEL=1, ZZ=26., A=56., DEN=.08460,

    TIPSR=0., ESR= 1000. , ZSR=-.5, WSR=1.,
 &END
/ PHI.n(E,z,r) is available on PHIN@EOR
/ PHI.p(E,z,r) is available on PHIP@EOR
/ save detector output for later processing with CMD
/ TEST3 DETECTOR OUTPUT
SAVE PHIN@EOR;
SAVE PHINFSD;
SAVE PHIP@EOR;
SAVE PHIPFSD;
EXIT;
/*
```

(3) Input to MORSE

```
//REW101$$ JOB ($$ACCOUNT$),TEST3,TIME=(128),REGION=6000K,CLASS=C
/*PASSWORD $MVS
/*JOBPARM L=20
/*ROUTE PRINT CMS
//  EXEC  LGFORTV
//L.LOAD DD DSN=REW031.HERMES,DISP=SHR
//L.SYSIN DD *
  INCLUDE LOAD(MORSE)
  INCLUDE LOAD(CGL2)
  ENTRY MORSCG
//G.FT50F001 DD DSN=REW031.HETSUB.TEST3,DISP=SHR,LABEL=(,,,IN)
//G.FT20F001 DD DSN=REW031.EPRLIB,DISP=SHR,LABEL=(,,,IN)
//*.FT21F001 DD DSN=REW101.TEST3.MORDET,DISP=SHR
//G.SYSIN DD *
  HERMES TEST3        9 DETEKTOREN     CARD A
  0  0 32 6                                  /                  CARD A2
 200 2500   50 1 100 21 100 121 0 0 58   1 0/                  CARD B
  1 1 0 0 1.0E+0 1.0E-4 1.0E+4 1.0E-7 .6293E+6 /                    CARD C
   0. 0. 0. 0.  0. 0. 0.                  /                  CARD D
  50                                      /                  CARD D2
  /   ENERGIES (EV)                                          CARD F
 0.149E+08 0.135E+08 0.122E+08 0.111E+08 0.100E+08 0.905E+07 0.819E+07 /
 0.741E+07 0.670E+07 0.607E+07 0.549E+07 0.497E+07 0.449E+07 0.407E+07 /
 0.368E+07 0.333E+07 0.301E+07 0.273E+07 0.247E+07 0.223E+07 0.202E+07 /
 0.183E+07 0.165E+07 0.150E+07 0.135E+07 0.122E+07 0.111E+07 0.100E+07 /
 0.907E+06 0.821E+06 0.743E+06 0.672E+06 0.608E+06 0.550E+06 0.498E+06 /
 0.450E+06 0.408E+06 0.369E+06 0.334E+06 0.302E+06 0.273E+06 0.247E+06 /
 0.224E+06 0.202E+06 0.183E+06 0.166E+06 0.150E+06 0.136E+06 0.123E+06 /
 0.111E+06 0.865E+05 0.674E+05 0.525E+05 0.409E+05 0.318E+05 0.248E+05 /
 0.193E+05 0.150E+05 0.117E+05 0.912E+04 0.710E+04 0.553E+04 0.431E+04 /
 0.335E+04 0.261E+04 0.203E+04 0.158E+04 0.123E+04 0.961E+03 0.749E+03 /
 0.583E+03 0.454E+03 0.354E+03 0.275E+03 0.214E+03 0.167E+03 0.130E+03 /
 0.101E+03 0.789E+02 0.614E+02 0.479E+02 0.373E+02 0.290E+02 0.226E+02 /
 0.176E+02 0.137E+02 0.107E+02 0.832E+01 0.648E+01 0.504E+01 0.393E+01 /
 0.306E+01 0.238E+01 0.186E+01 0.144E+01 0.113E+01 0.876E+00 0.683E+00 /
 0.532E+00 0.414E+00 0.140E+08 0.120E+08 0.100E+08 0.800E+07 0.750E+07 /
 0.700E+07 0.650E+07 0.600E+07 0.550E+07 0.500E+07 0.450E+07 0.400E+07 /
 0.350E+07 0.300E+07 0.250E+07 0.200E+07 0.150E+07 0.100E+07 0.400E+06 /
 0.200E+06 0.100E+06                      ;                E 0 CARD F
000035FA731A                              /                  CARD H
 1 1 0 0 0  1 121 0                       /                  CARD I
   0 0 0 0 0 0 0 1.0E+0 1.00E+0 1.0E+0 0.0E+0 /               CARD J
  -1                                      /                E 0 CARD J
 0 0 0 0                                  /                  CARD L
F 1. ;                        GAMMA PROB.'S GWLO(NMTG,MXREG)   CARD O
MATERIALIEN  EPR WQ P5 VON FT20                               CARD XA
 100 100 21 21 121 124 4  1 1  1 4 2  0/                      CARD XB
 0 0 0 0 0 0 0 20 0 0 0 0  0 0        /                       CARD XC
  19 A 3 1 ; FE
    1   -1  8.4600E-2          FE                              CARD XF
ANALYSIS INPUT                                               CARD AA
    9  100  121    0    0    2    0    0  1 1/                CARD BB
 VQ
F 0. ;                                                       CARD CCX
F 0. ;                                                        CARD CCY
F 0. ;                                                        CARD CCY
11 A 2 1 21 A 2 1 31 A 2 1 ;
F 0 ;                                                        CARD DD

 / NEUTRON FLUX [CM]
  R 100 1. /
   F 0. ;
 / GAMMA FLUX [CM]
```

```
  R 100 0. /
   F 1. ;
                                                              CARD GG
    1 A 120 1 ;                                               CARD HH

 1                          / NUMBR
 14 1. 0.0085 1 4.8295E-2 / NDETEC S KB NEL DENH
 /                          /ID = REGION NUMBERS
1001000 A 6 1000 2001000 A 6 1000;
 F 6. ;         ZZ
 F 12. ;        A
 F 4.8295E-2 ; DEN
//G.FT32F001 DD *
          8         13         13       1000       1000          0          0
          4          0
          0 1.000E+00
  PZ      1      0.000
  PZ      2     25.000
  PZ      3     50.000
  PZ      4    100.000
  CZ     11      0.000      0.000      0.000      2.000
  CZ     12      0.000      0.000      0.000      5.000
  CZ     13      0.000      0.000      0.000     10.000
  RCC    20      0.000      0.000     -1.000      0.000      0.000    102.000
               12.000
  END
    1    11      11       1      -2
    1    12      11       2      -3
    1    13      11       3      -4
    1    21      12     -11       1      -2
    1    22      12     -11       2      -3
    1    23      12     -11       3      -4
    1    31      13     -12       1      -2
    1    32      13     -12       2      -3
    1    33      13     -12       3      -4
 1000    61      20      13      -1
 1000    62      20      13       4
 1000    63      20     -13
   -1    90     -20
  999
/* E O F
```

E.3.2 Output Files Excerpt for Sample Problem III

(1) Geometry Object File

```
        8        13        13      1000      1000         0         0
        4         0
        0 1.000E+00
PZ      1     0.000
PZ      2    25.000
PZ      3    50.000
PZ      4   100.000
CZ     11     0.000     0.000     0.000     2.000
CZ     12     0.000     0.000     0.000     5.000
CZ     13     0.000     0.000     0.000    10.000
RCC    20     0.000     0.000    -1.000     0.000     0.000   102.000
              12.000
END
   1   11     11       1      -2
   1   12     11       2      -3
   1   13     11       3      -4
   1   21     12     -11       1      -2
   1   22     12     -11       2      -3
   1   23     12     -11       3      -4
   1   31     13     -12       1      -2
   1   32     13     -12       2      -3
   1   33     13     -12       3      -4
6666   61     20      13      -1
6666   62     20      13       4
6666   63     20     -13
  -1   90    -20
 999
```

```
/JOB-ID = REW031H3 05/19/88 08:53:44
!:/ setup detector regions
!: INTEGER IR1(9);DATA IR1=<11 12 13 21 22 23 31 32 33>;
!:/ setup detector energy bins
!: REAL EP(12),EN(9);
!: DATA EP=< 1000. 750. 500. 250. 100. 50. 25. 20. 15. 10. 5. 1.>;
!: DATA EN=< 1000. 750. 500. 250. 100. 50. 25. 20. 15. >;
!:/ setup detectors
!: DEFDET PMIP,8,0.,,EP,,IR1;
!: DEFDET PMIN,8,1.,,EN,,IR1;
!:RUN;   / return to het primary input
MAXBCH=  50  IBERTP=-20  EMIN(1)= 1.000E+00  ELOP  = 2.000E+01
MAXCAS=  20  IOSUB = 21  EMIN(2)= 1.490E+01  CTOFE = 0.000E+00
IRUN  =   1  NHSTP =  0  EPICUT = 0.000E+00  EMAX  = 1.000E+03
                         EMUCUT = 0.000E+00  B0    = 8.000E+00
N1COL =0  NPIDK =1  NBOGUS =1  NSEUDO=1
NSPRED=0  NWSPRD=0  ISTRAG =0  IANC  =1
IFISS =0  IB0   =1  IGEOM  =0  KEYDK =0
IELAS =2
ISEED =  123456789
LNI   =0  HIA(5)=  0.0  HIZ(5)=  0.0  HIBE(5)= 0.000E+00
/BERTTP(1): I-N-C  DATA READ FORM UNIT 20
/BERTTP(1): EVAP   DATA READ FORM UNIT 20
NON-ISOTROPIC ANGLE OPTION SELECTED
MS1GMX     0.12000E-23    0.64942E-24    0.20000E-24    0.00000E+00    0.67700E-25
THIS IS MEDIUM  1
DENM=0.000000E+00  NEL= 1  SO= 1.000E+00  KB= 0.000E+00
ZZ( 1, 1)=26.0  A( 1, 1)= 56.0  DEN( 1, 1)=8.459997E-02
"GEOMETRIC" X-SECTIONS IN (1/CM)

  NUCLIDS:      1           2           3           4           5           6           7           8           9           10
  MEDIA
      1     1.1592E-01
MAXIMUM N-1 X-SECTIONS IN (1/CM)

  MEDIA        PROTONS     NEUTRONS          PI+         PIO         PI-
      1     0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
TRANSPORT X-SECTION = SUM("GEOMETRIC") + MAX. N-1 + MAX. DECAY X-SECTIONS IN (1/CM)

  MEDIA        PROTONS     NEUTRONS          PI+         PIO         PI-         MUE+         MUE-
      1     1.1592E-01  1.1592E-01  1.2643E-01  0.0000E+00  1.2643E-01  1.1582E-04  1.1582E-04
SOURCE DATA:
TYP     =        0.
XYZ     =     0.000     0.000    -0.500  GAUSSIAN DISTRIBUTED WITH
XYZ SIG.=     0.000     0.000     0.000  TRUNCATED TO RADIUS
  R     =     0.000                      IF R>0
UVW     =    0.0000    0.0000    1.0000  IF = 0.,0.,0. -> ISOTROPIC
 WT     =     1.000
  E     =  1000.000  GAUSSIAN DISTRBUTED WITH
  E SIG.=     0.000
M:GOMIN INGEO=25 IOGEO= 6
 NUMB. OF BODIES (NUMB)                  6
 NUMB. OF REGIONS (NUMR)                13
 NUMBER OF CODE REGIONS (NCOD)          13
 LENGTH OF FDP ARRAY (LMXX)           1000
 LENGTH OF MA ARRAY (LMYY)            1000
 MODIFIED INPUT (LOUT)                   0
 VOLUME INPUT OPTION (IVOPT)       4 NOT USED
 BOUNDARY OPTION (MEDREG)                0
 DEBUG OPTION (IDBGO)                    0

MACHINE EPS =  0.100000E-07

IPRINT=          0
```

```
                STRETCH= 1.0000000E+00

                NUMBER OF BODIES            8
                LENGTH OF MA -ARRAY        57
                LENGTH OF FPD-ARRAY       100
                NUMBER OF INPUT ZONES      13
                NUMBER OF  CODE ZONES      13
                LENGTH OF INTEGER ARRAY   238
```

```
--> SOR HET    IRUN=     1 ISEED=  123456789
/SUBMIT(I): IOSUB=21
--> SOB HET    IBAT=     1 ISEED=  123456789
/BERTTP(I): I-N-C  DATA READ FORM UNIT 20
/DRES(I): USING 1977 WAPS DATA
--> EOB HET    IBAT=     1 ISEED= 2139219343 NHIS=   20 CPU=   12.16SEC.
  MEDIUM    SORS    CASC    SLOW    ESCP    PSEU    ABSO    BRDY    SCAT

       1       0     109     130       0      61       3     135       0       0
    6666      20       0       0      33       0       0      34       0       0
   TOTAL      20     109     130      33      61       3     169       0       0
/SUBMIT(I): NEUTRONS:    130, PIO:      3, NUCLEI:     57
-------------------------------------------------------------------------------
                .
                .
                .
--> EOR HET    IRUN=     1 ISEED= 1781818119 NHIS= 1000 CPU=  153.94SEC.
  MEDIUM    SORS    CASC    SLOW    ESCP    PSEU    ABSO    BRDY    SCAT

       1       0    6564    7001       0    3198     216    6740       0       0
    6666    1000       0       0    1517      47       0    1523       0       0
   TOTAL    1000    6564    7001    1517    3245     216    8263       0       0
            REAL          PSEUDO          REAL          PSEUDO          PSEUDO          REAL          PSEUDO
           NONHYDROG     NONHYDROG       HYDROGEN       HYDROGEN        DECAY         ELASTIC       ELASTIC
           COLLISIONS    COLLISIONS     COLLISIONS     COLLISIONS     COLLISIONS     COLLISIONS    COLLISIONS
MEDIUM  1  0.35420E+04    0.27370E+04    0.00000E+00    0.00000E+00    0.11000E+02    0.32380E+04   0.45000E+03


                                  PSEUDO COLLISIONS WITHIN INTERNAL VOID BY PARTICLES OF

        TYPE 1         TYPE 2         TYPE 3         TYPE 4         TYPE 5         TYPE 6         TYPE 7

      0.70000E+01    0.38000E+02    0.10000E+01    0.00000E+00    0.00000E+00    0.00000E+00    0.10000E+01
--> NEGEX=    3   LOWAZ=    0     NWTC=    0
/SUBMIT(I): NEUTRONS:  7987, PIO:   184, NUCLEI:  3538
```

MEDIUM	SOURCE-FRACTION	%ERR		
1	0.000E+00	0.00		
VOID	1.000E+00	0.00		
MEDIUM	INELASTIC C./SOURCE	%ERR	ELASTIC C. /SOURCE	%ERR
1	3.326E+00	1.93	3.688E+00	2.52
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	ABSORPTION /SOURCE	%ERR	FISSION /SOURCE	%ERR
1	2.160E-01	6.22	0.000E+00	0.00
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	P FLUX (CM)	%ERR	N FLUX (CM)	%ERR
1	2.358E+01	2.01	2.940E+01	2.60
VOID	7.383E-01	4.64	3.977E+00	2.96
MEDIUM	PI+ FLUX (CM)	%ERR	PI- FLUX (CM)	%ERR
1	7.715E-01	10.77	2.502E-01	15.13
VOID	4.024E-02	27.05	1.456E-02	41.30
MEDIUM	MU+ FLUX (CM)	%ERR	MU- FLUX (CM)	%ERR
1	2.785E-03	15.35	1.021E-03	24.51
VOID	3.844E-04	26.50	7.651E-05	53.63
MEDIUM	P YIELD	%ERR	N YIELD	%ERR
1	8.662E+00	1.69	1.148E+01	1.94
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	PI+ YIELD	%ERR	PIO YIELD	%ERR
1	2.179E-01	7.14	1.839E-01	6.79
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	PI- YIELD	%ERR		
1	1.059E-01	8.70		
VOID	0.000E+00	0.00		
MEDIUM	MU+ YIELD	%ERR	MU- YIELD	%ERR
1	7.825E-04	15.40	3.974E-04	20.98
VOID	3.346E-04	100.00	0.000E+00	0.00
MEDIUM	D YIELD	%ERR	T YIELD	%ERR
1	4.570E-01	5.84	1.110E-01	9.40
VOID	0.000E+00	0.00	0.000E+00	0.00
MEDIUM	HE3 YIELD	%ERR	HE4 YIELD	%ERR
1	1.010E-01	11.00	5.988E-01	3.82
VOID	0.000E+00	0.00	0.000E+00	0.00

W:RSYS: NO RSYST-TAPE AVAILABLE

```
FLUX  DETECTOR FOR P
DETECTOR NAME =     PHIP
  REGION1=         11 REGION2=          0
    E-HIGH      E-LOW         PHI       %ERR
 1.000E+03 7.500E+02 1.135E+01       1.64
 7.500E+02 5.000E+02 1.982E+00       4.36
 5.000E+02 2.500E+02 7.813E-01       7.35
 2.500E+02 1.000E+02 9.172E-01       4.76
 1.000E+02 5.000E+01 4.632E-01       4.88
 5.000E+01 2.500E+01 2.360E-01       4.09
 2.500E+01 2.000E+01 4.486E-02       3.63
 2.000E+01 1.500E+01 4.322E-02       3.44
 1.500E+01 1.000E+01 4.320E-02       3.40
 1.000E+01 5.000E+00 4.284E-02       3.35
 5.000E+00 1.000E+00 2.607E-02       3.05
                .
                .
                .
FLUX  DETECTOR FOR N
DETECTOR NAME =     PHIN
  REGION1=         11 REGION2=          0
    E-HIGH      E-LOW         PHI       %ERR
 1.000E+03 7.500E+02 1.907E-01      18.40
 7.500E+02 5.000E+02 3.181E-01      18.71
 5.000E+02 2.500E+02 9.127E-01       9.32
 2.500E+02 1.000E+02 1.463E+00       5.79
 1.000E+02 5.000E+01 1.148E+00       6.52
 5.000E+01 2.500E+01 1.094E+00       7.04
 2.500E+01 2.000E+01 3.437E-01       9.77
 2.000E+01 1.500E+01 5.862E-01       9.17
  REGION1=         12 REGION2=          0
    E-HIGH      E-LOW         PHI       %ERR
 1.000E+03 7.500E+02 6.895E-04     100.00
                .
                .
                .
-------------------------------------------------------------------------------
I:/ PHI.n(E,z,r) is available on PHIN@EOR
I:/ PHI.p(E,z,r) is available on PHIP@EOR
I:/ save detector output for later processing with CMD
I:/ TEST3 DETECTOR OUTPUT
I:SAVE PHIN@EOR;
I:SAVE PHINFSD;
I:SAVE PHIP@EOR;
I:SAVE PHIPFSD;
I:EXIT;
```

CMD Save File

```
 REAL PHIN@EOR(    8,    1,    9);
 DATA PHIN@EOR=<
  1.907E-01 3.181E-01 9.127E-01 1.463E+00 1.148E+00
  1.094E+00 3.437E-01 5.862E-01
  6.895E-04 1.025E-01 2.712E-01 2.883E-01 2.637E-01
  2.145E-01 5.589E-02 1.173E-01
  0.000E+00 1.889E-02 2.115E-02 3.744E-02 1.482E-02
  5.104E-02 3.063E-03 7.134E-03
  1.075E-01 1.976E-01 6.795E-01 1.656E+00 1.431E+00
  1.441E+00 4.577E-01 7.188E-01
  4.842E-02 8.952E-02 3.477E-01 5.868E-01 5.670E-01
  5.894E-01 1.559E-01 2.181E-01
  0.000E+00 0.000E+00 8.035E-02 1.029E-01 6.867E-02
  8.420E-02 9.328E-03 2.693E-02
  1.419E-02 1.148E-01 5.668E-01 1.633E+00 1.595E+00
  1.628E+00 5.130E-01 8.026E-01
  7.823E-02 1.615E-01 4.979E-01 1.042E+00 7.951E-01
  8.324E-01 2.383E-01 4.193E-01
  1.126E-02 4.414E-02 1.499E-01 3.382E-01 3.578E-01
  2.678E-01 4.400E-02 4.961E-02
>; /
 REAL PHINFSD (    8,    1,    9);
 DATA PHINFSD =<
  1.840E-01 1.871E-01 9.320E-02 5.792E-02 6.519E-02
  7.037E-02 9.769E-02 9.167E-02
  1.000E+00 3.463E-01 1.791E-01 1.394E-01 1.397E-01
  1.589E-01 1.975E-01 1.516E-01
  0.000E+00 1.000E+00 5.884E-01 3.802E-01 4.611E-01
  3.870E-01 8.872E-01 6.789E-01
  2.609E-01 1.876E-01 8.007E-02 6.117E-02 6.737E-02
  5.774E-02 1.004E-01 7.584E-02
  4.733E-01 3.009E-01 1.735E-01 8.848E-02 1.057E-01
  1.177E-01 2.145E-01 1.503E-01
  0.000E+00 0.000E+00 3.781E-01 2.614E-01 3.242E-01
  3.128E-01 8.476E-01 4.033E-01
  6.368E-01 2.554E-01 1.091E-01 7.556E-02 7.051E-02
  6.410E-02 1.006E-01 8.117E-02
  4.193E-01 2.317E-01 1.278E-01 1.006E-01 9.272E-02
  1.147E-01 1.807E-01 1.377E-01
  1.000E+00 4.840E-01 3.245E-01 2.143E-01 1.818E-01
  2.043E-01 3.972E-01 3.087E-01
>; /
 REAL PHIP@EOR(   11,    1,    9);
 DATA PHIP@EOR=<
  1.135E+01 1.982E+00 7.813E-01 9.172E-01 4.632E-01
  2.360E-01 4.486E-02 4.322E-02 4.320E-02 4.284E-02
  2.607E-02
  0.000E+00 1.853E+00 1.141E+00 1.876E-01 1.008E-01
  4.493E-02 8.279E-03 7.753E-03 7.390E-03 7.263E-03
  4.394E-03
  0.000E+00 0.000E+00 4.312E-02 2.223E-01 3.568E-02
  1.058E-02 1.668E-03 1.472E-03 1.257E-03 1.066E-03
  6.094E-04
  3.556E-02 3.389E-01 4.187E-01 5.820E-01 2.235E-01
  8.970E-02 1.455E-02 1.325E-02 1.185E-02 1.053E-02
  6.164E-03
  0.000E+00 1.454E-01 3.607E-01 2.168E-01 6.879E-02
  2.887E-02 5.040E-03 4.631E-03 4.171E-03 3.773E-03
  2.272E-03
  0.000E+00 0.000E+00 6.810E-03 5.375E-02 1.332E-02
  4.721E-03 7.377E-04 6.342E-04 5.368E-04 4.041E-04
  2.472E-04
  0.000E+00 7.748E-02 2.164E-01 2.076E-01 1.093E-01
```

```
  4.920E-02 8.594E-03 7.891E-03 7.045E-03 6.537E-03
  3.942E-03
  0.000E+00 3.665E-02 2.063E-01 1.823E-01 7.429E-02
  3.240E-02 5.486E-03 5.010E-03 4.636E-03 4.180E-03
  2.604E-03
  0.000E+00 0.000E+00 1.008E-02 2.425E-02 1.500E-02
  6.728E-03 1.132E-03 1.026E-03 1.069E-03 1.008E-03
  6.267E-04
>; /
 REAL PHIPFSD (   11,    1,    9);
 DATA PHIPFSD =<
  1.638E-02 4.360E-02 7.345E-02 4.760E-02 4.876E-02
  4.093E-02 3.628E-02 3.442E-02 3.400E-02 3.347E-02
  3.050E-02
  0.000E+00 6.682E-02 9.951E-02 1.011E-01 8.182E-02
  8.936E-02 8.766E-02 8.599E-02 8.955E-02 9.200E-02
  9.091E-02
  0.000E+00 0.000E+00 1.642E-01 1.727E-01 1.862E-01
  1.971E-01 1.817E-01 1.760E-01 1.716E-01 1.804E-01
  1.841E-01
  3.735E-01 1.538E-01 1.063E-01 7.755E-02 5.434E-02
  5.564E-02 5.276E-02 5.195E-02 4.936E-02 4.954E-02
  4.692E-02
  0.000E+00 2.196E-01 1.565E-01 1.123E-01 9.868E-02
  9.654E-02 8.567E-02 7.889E-02 7.782E-02 7.752E-02
  7.246E-02
  0.000E+00 0.000E+00 4.821E-01 2.958E-01 2.892E-01
  2.618E-01 2.479E-01 2.470E-01 2.305E-01 2.126E-01
  2.461E-01
  0.000E+00 2.575E-01 1.329E-01 1.381E-01 9.393E-02
  8.276E-02 7.787E-02 7.473E-02 6.978E-02 5.945E-02
  5.997E-02
  0.000E+00 3.864E-01 2.206E-01 1.355E-01 1.323E-01
  1.177E-01 1.051E-01 1.052E-01 1.106E-01 1.008E-01
  9.259E-02
  0.000E+00 0.000E+00 1.000E+00 3.223E-01 2.225E-01
  2.142E-01 2.087E-01 2.042E-01 1.891E-01 1.897E-01
  1.878E-01
>; /
```

(3) Output of MORSE

```
   HERMES TEST3        9 DETEKTOREN     CARD A

    NSTRT    NMOST     NITS    NQUIT   NGPQTN  NGPQTG     NMGP     NMTG  NCOLTP    IADJM  MAXTIM    MEDIA  MEDALB
      200     2500       50        1      100      21      100      121       0        0   58.00         1       0

    ISOUR   NGPFS  ISBIAS             WTSTRT       EBOTN       EBOTG        TCUT       VELTH
        1       1       0         1.0000E+00  1.0000E-04  1.0000E+04  1.0000E-07  6.2930E+05

              XSTRT       YSTRT       ZSTRT      AGSTRT        UINP        VINP        WINP
          0.000E+00   0.000E+00   0.000E+00   0.000E+00    0.000000    0.000000    0.000000
***UNIT-NUMBER OF HERMES SUBMISSION  :     50

GROUP PARAMETERS, GROUP NUMBERS GREATER THAN  100 CORRESPOND TO SECONDARY PARTICLES
   GROUP      UPPER EDGE         VELOCITY
                 (EV)           (CM/SEC)
      1      1.4900E+07       5.2115E+09
      2      1.3500E+07       4.9576E+09
                .
                .
                .
    120      2.0000E+05       2.9979E+10
    121      1.0000E+05       2.9979E+10

INITIAL RANDOM NUMBER =      35FA731A

NSPLT= 1      NKILL= 1      NPAST= 0      NOLEAK= 0      IEBIAS= 0      MXREG=  1      MAXGP=121

WEIGHT STANDARDS FOR SPLITTING AND RUSSIAN ROULETTE AND PATHLENGTH STRETCHING PARAMETERS

 NGP1  NDG NGP2  NRG1 NDRG NRG2     WTHIH1       WTLOW1       WTAVE1         XNU
    0     0     0     0    0     0  1.0000E+00  1.0000E+00  1.0000E+00  0.0000E+00

NSOUR= 0      MFISTP=  0      NKCALC= 0      NORMF= 0

GWLOW(IG,NREG)

 GROUP        REGION 1
    1       1.0000E+00
    2       1.0000E+00
              .
              .
              .
   99       1.0000E+00
  100       1.0000E+00

 NUMB. OF BODIES (NUMB)                    8
 NUMB. OF REGIONS (NUMR)                  13
 NUMBER OF CODE REGIONS (NCOD)            13
 LENGTH OF FDP ARRAY (LNXX)             1000
 LENGTH OF MA ARRAY (LNYY)              1000
 MODIFIED INPUT (LOUT)                     0
 VOLUME INPUT OPTION (IVOPT)         4 NOT USED
 BOUNDARY OPTION (MEDREG)                  0
 DEBUG OPTION (IDBGO)                      0

MACHINE EPS =  0.100000E-07


IPRINT=         0
STRETCH= 1.0000000E+00

NUMBER OF BODIES            8
LENGTH OF MA -ARRAY        57
LENGTH OF FPD-ARRAY       100
NUMBER OF INPUT ZONES      13
NUMBER OF  CODE ZONES      13
```

```
MATERIALIEN  EPR WQ P5 VON FT20                                  CARD XA

NUMBER OF PRIMARY GROUPS (NGP)          100
NUMBER OF PRIMARY DOWNSCATTERS (NDS)    100
NUMBER OF SECONDARY GROUPS (NGG)         21
NUMBER OF SECONDARY DOWNSCATTERS (NDSG)  21
NUMBER OF PRIM+SEC GROUPS (INGP)        121
TABLE LENGTH (ITBL)                     124
LOC OF WITHIN GROUP (SIG GG) (ISGG)       4
NUMBER OF MEDIA (NMED)                    1
NUMBER OF INPUT ELEMENTS (NELEM)          1
NUMBER OF MIXING ENTRIES (NMIX)           1
NUMBER OF COEFFICIENTS (NCOEF)            4
NUMBER OF ANGLES (NSCT)                   2
RESTORE COEFF (ISTAT)                     0
ADJOINT SWITCH (FROM MORSE)               0

INPUT/OUTPUT OPTIONS
     IRDSG (AS READ)          0
     ISTR (AS STORE)          0
     IFMU (MUS)               0
     IMOM (MOMENTS)           0
     IPRIN (ANGLES,PROB)      0
     IPUN (IMPOSSIBLE COEF)   0
     CARD FORMAT (IDTF)       0
     INPUT TAPE (IXTAPE)     20
     MORSEC TAPE (JXTAPE)     0
     O6R TAPE (IO6RT)         0
     ICQPT (LAST GRP. O6R)    0
     CROSS-TAPE AUS RSYST     0
     ICRO CROSS. FOR MEDIA
     N TO G TRANSFER          0
     PRINT OF BADMOMENTS      0

     ELEMENTS FROM LIBRARY TAPE
IDENTIFIERS   19   20   21   22
ELEMENT        1        19        121   124     0    19FE 1192 100N-21G GPS P8 800K INF DIL          07/25/84

STORAGE ALLOCATIONS
CROSS SECTIONS START AT      5186
LAST LOCATION USED (PERM)   18995
TEMP LOCATIONS USED        928664 TO  950000
EXCESS STORAGE (TEMP)      909669
ELEMENT        1        19        121   124     0    19FE 1192 100N-21G GPS P8 800K INF DIL          07/25/84
ELEMENT        1        20        121   124     0    20FE 1192 100N-21G GPS P8 800K INF DIL          07/25/84
ELEMENT        1        21        121   124     0    21FE 1192 100N-21G GPS P8 800K INF DIL          07/25/84
ELEMENT        1        22        121   124     0    22FE 1192 100N-21G GPS P8 800K INF DIL          07/25/84
          MIXING TABLE

 MEDIA    1 CONTAINS ELEMENT    1  WITH DENSITY   8.4600E-02
BANKS START AT       18996
LAST LOCATION USED   56495
ANALYSIS INPUT                                        CARD AA
ND=  9, NNE=100, NE=121, NT=  0, NA=  0, NRESP=  2, NEX=  0, NEXND=  0
IORESP=1 IOFLUX=1
DET      X              Y              Z            MED1            MED2

TO IS SET TO 0.0 IN ALL CASES


  1                                          11      0.0000E+00      0.0000E+00
  2                                          12      0.0000E+00      0.0000E+00
  3                                          13      0.0000E+00      0.0000E+00
  4                                          21      0.0000E+00      0.0000E+00
  5                                          22      0.0000E+00      0.0000E+00
  6                                          23      0.0000E+00      0.0000E+00
```

```
  7                                                          31      0.0000E+00      0.0000E+00
  8                                                          32      0.0000E+00      0.0000E+00
  9                                                          33      0.0000E+00      0.0000E+00
 GROUP          RESP( 1)          RESP( 2)
     1       1.0000E+00        0.0000E+00
     2       1.0000E+00        0.0000E+00
                 .
                 .
                 .
   120       0.0000E+00        1.0000E+00
   121       0.0000E+00        1.0000E+00

          NUMBER OF PRIMARY ENERGY BINS    100
          TOTAL NUMBER OF ENERGY BINS      121
             LOWER     LOWER
 BIN NO.     LIMIT     ENERGY         DELTA
             GROUP     LIMIT            E

                     1.490E+07
     1           1   1.350E+07     1.400E+06
     2           2   1.220E+07     1.300E+06
                 .
                 .
                 .
   120         120   1.000E+05     1.000E+05
   121         121   1.000E+04     9.000E+04

       NUMBER OF TIME BINS   0

        NUMBER OF ANGLE BINS   0
 UPPER LIMITS OF COSINE BINS

 4295 CELLS USED BY ANALYSIS,889210 CELLS REMAIN UNUSED.
```

```
TIME REQUIRED FOR INPUT WAS   4 SECONDS .
YOU ARE USING THE DEFAULT VERSION OF STRUN WHICH DOES NOTHING.

***START BATCH    1                          RANDOM=    35FA731A

SOURCE DATA

MET-IDENTIFIKATION:      REWO    31H3    05/1    9/80    08:5    3:44


YOU ARE USING THE DEFAULT VERSION OF SOURCE WHICH SETS WATE TO DDF AND PROVIDES AN ENERGY IG.
  WTAVE       IAVE    UAVE    VAVE    WAVE       XAVE       YAVE       ZAVE       AGEAVE
 1.300E+02    16.54  -0.0529 -0.0522  0.0723   2.100E-01  1.443E-02  1.129E+01   0.000E+00

NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)    FISHN   GAMGEN REALCOLL   ALBEDO    BDRYX   ESCAPE    E-CUT TIMEKILL R R KILL R R SURV  GAMLOST  FISGEN
      130      67        0      176     1429        0      631      165        0         6      205     1231        0        0

TIME REQUIRED FOR THE PRECEDING BATCH WAS   1 SECOND .

***START BATCH    2                          RANDOM=    788D386A

SOURCE DATA

  WTAVE       IAVE    UAVE    VAVE    WAVE       XAVE       YAVE       ZAVE       AGEAVE
 2.100E+02    17.93   0.0531  0.0334  0.0817   6.616E-01 -7.574E-02  1.764E+01   0.000E+00

NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)    FISHN   GAMGEN REALCOLL   ALBEDO    BDRYX   ESCAPE    E-CUT TIMEKILL R R KILL R R SURV  GAMLOST  FISGEN
      210     114        0      311     2532        0     1059      268        0         6      363     2173        0        0

TIME REQUIRED FOR THE PRECEDING BATCH WAS   2 SECONDS .
                .
                .
                .
***START BATCH   49                          RANDOM=    2F2E804E

SOURCE DATA

  WTAVE       IAVE    UAVE    VAVE    WAVE       XAVE       YAVE       ZAVE       AGEAVE
 1.740E+02    19.09  -0.0003  0.0174  0.0584  -2.648E-01 -2.026E-01  1.019E+01   0.000E+00

NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)    FISHN   GAMGEN REALCOLL   ALBEDO    BDRYX   ESCAPE    E-CUT TIMEKILL R R KILL R R SURV  GAMLOST  FISGEN
      174      96        0      246     2145        0      906      228        0         8      282     1872        0        0

TIME REQUIRED FOR THE PRECEDING BATCH WAS   2 SECONDS .

***START BATCH   50                          RANDOM=    33AAFE8A

SOURCE DATA

  WTAVE       IAVE    UAVE    VAVE    WAVE       XAVE       YAVE       ZAVE       AGEAVE
 1.510E+02    18.46   0.0260 -0.0326  0.1471   1.675E-01  7.725E-03  1.521E+01   0.000E+00
NUMBER OF COLLISIONS OF TYPE NCOLL
  SOURCE SPLIT(D)    FISHN   GAMGEN REALCOLL   ALBEDO    BDRYX   ESCAPE    E-CUT TIMEKILL R R KILL R R SURV  GAMLOST  FISGEN
      151      80        0      205     1824        0      786      199        0         5      233     1593        0        0

TIME REQUIRED FOR THE PRECEDING BATCH WAS   1 SECOND .
```

/ NEUTRON FLUX [CM]

CARD DD

RESPONSES(DETECTOR)

DETECTOR	UNCOLL RESPONSE	FSD UNCOLL	TOTAL RESPONSE	FSD TOTAL
1	0.0000E+00	0.00000	1.7990E+01	0.02723
2	0.0000E+00	0.00000	4.6661E+00	0.07635
3	0.0000E+00	0.00000	5.1120E-01	0.18050
4	0.0000E+00	0.00000	4.0528E+01	0.02972
5	0.0000E+00	0.00000	1.3825E+01	0.04608
6	0.0000E+00	0.00000	1.7700E+00	0.13744
7	0.0000E+00	0.00000	5.7800E+01	0.03056
8	0.0000E+00	0.00000	2.3853E+01	0.04504
9	0.0000E+00	0.00000	3.8090E+00	0.10494

/ GAMMA FLUX [CM]

CARD DD

RESPONSES(DETECTOR)

DETECTOR	UNCOLL RESPONSE	FSD UNCOLL	TOTAL RESPONSE	FSD TOTAL
1	0.0000E+00	0.00000	6.9535E+00	0.04039
2	0.0000E+00	0.00000	1.7514E+00	0.08446
3	0.0000E+00	0.00000	1.6529E-01	0.24773
4	0.0000E+00	0.00000	1.8049E+01	0.03801
5	0.0000E+00	0.00000	5.0836E+00	0.06550
6	0.0000E+00	0.00000	5.4571E-01	0.13158
7	0.0000E+00	0.00000	2.1992E+01	0.04181
8	0.0000E+00	0.00000	7.2519E+00	0.05949
9	0.0000E+00	0.00000	1.2392E+00	0.13384

FLUENCE(ENERGY,DETECTOR) CARD GG

DETECTOR NO. ENERGIES	1	2	3	4	5	6	7	8	9
1.490E+07	1.676E-07	2.924E-08	0.000E+00	1.674E-07	4.382E-08	0.000E+00	1.608E-07	4.791E-08	3.260E-08
	0.161	0.341	0.000	0.152	0.349	0.000	0.151	0.351	0.425
1.350E+07	1.965E-07	4.248E-08	1.294E-09	2.544E-07	5.971E-08	1.129E-09	2.733E-07	9.444E-08	3.221E-09
	0.110	0.332	1.000	0.116	0.222	1.000	0.144	0.229	0.616
1.220E+07	1.642E-07	1.928E-08	1.216E-09	2.143E-07	5.141E-08	5.498E-09	2.425E-07	8.117E-08	9.896E-09
	0.133	0.278	1.000	0.151	0.320	0.987	0.161	0.204	0.579

.
.
.

FLUENCE(ENERGY,DETECTOR) CARD GG

DETECTOR NO. ENERGIES	1	2	3	4	5	6	7	8	9
2.000E+05	7.954E-06	2.334E-06	2.676E-07	2.436E-05	7.016E-06	6.356E-07	2.892E-05	1.026E-05	1.497E-06
	0.049	0.119	0.328	0.046	0.072	0.178	0.049	0.073	0.140
1.000E+05	2.826E-08	7.255E-09	6.607E-10	8.358E-08	2.239E-08	2.931E-09	9.773E-08	3.293E-08	3.607E-09
	0.097	0.210	0.565	0.059	0.100	0.329	0.050	0.129	0.210
1.000E+04									

TIME REQUIRED FOR THE PRECEDING 50 BATCHES WAS 1 MINUTE 17 SECONDS .