EVENT

A Multigroup, Finite Element-Spherical Harmonics Program for the Solution of Steady-State and Time-Dependent Radiation Transport Problems in Arbitrary Geometry

User Notes

by

C.R.E. de Oliveira

Computational Physics and Geophysics Group
T H Huxley School of the Environment, Earth Sciences and Engineering
Imperial College of Science, Technology and Medicine
Prince Consort Road
London SW7 2BP

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1. Introduction

These notes are concerned with the finite element radiation transport program **EVENT**. The program is the practical outcome of the author's investigations on the application of the finite element and spherical harmonics methods to the solution of radiation transport problems. It has been hitherto used mainly as a test-bed for developing and testing new ideas, and also as vehicle for demonstrating the method. It is not, therefore, strictly speaking, a finished product. This, however, should not detract from the program, for careful and systematic coding has been employed in its conception and design, and, as a result, a fairly high degree of optimisation has been achieved throughout . Even in its present stage of development **EVENT** is an extremely competitive and powerful tool for the solution of a wide range of realistic radiation transport problems.

2. Summary of theoretical background and capabilities

EVENT is concerned with the solution of neutral-particle radiation transport problems described by the equation

$$\frac{1}{v}\frac{\partial\psi(\mathbf{r},\mathbf{\Omega},E,t)}{\partial t}+\mathbf{\Omega}.\nabla\psi(\mathbf{r},\mathbf{\Omega},E,t)+\mathbf{H}\,\psi(\mathbf{r},\mathbf{\Omega},E,t)=S(\mathbf{r},\mathbf{\Omega},E,t) \qquad (1)$$

Here $\psi(\mathbf{r},\mathbf{\Omega},E,t)$ is the particle angular flux or intensity, v is the particle speed, $S(\mathbf{r},\mathbf{\Omega},E,t)$ a distributed source, the form of which depends on the type of problem that is being solved (see below), and **H** is the collision operator defined in terms of the total cross section and differential cross section by

$$\mathbf{H}\,\psi(\mathbf{r},\mathbf{\Omega},E,t)\equiv\sigma_t(\mathbf{r},E,t)\psi(\mathbf{r},\mathbf{\Omega},E,t)-\int_{4\pi}d\mathbf{\Omega}'\,\sigma_s(\mathbf{r};\mathbf{\Omega}',E'\rightarrow\mathbf{\Omega}',E,t)\,\psi(\mathbf{r},\mathbf{\Omega}',E',t)$$

The discretisation procedures in **EVENT** are based on the canonical or parity form of eqn (1) which consists of the coupled pair of first-order equations

$$\frac{1}{v}\frac{\partial\psi^{+}}{\partial t}+\mathbf{C}\,\psi^{+}=S^{+}-\mathbf{\Omega}.\nabla\psi^{-}$$

$$\frac{1}{v}\frac{\partial\psi^{-}}{\partial t}+\mathbf{G}\,\psi^{-}=S^{-}-\mathbf{\Omega}.\nabla\psi^{+}$$

where $\psi^{\pm}=[\psi(\mathbf{\Omega})\pm\psi(-\mathbf{\Omega})]/2$, $S^{\pm}=[S(\mathbf{\Omega})\pm S(-\mathbf{\Omega})]/2$, and **C** and **G** are the even- and odd-parity components of the angular flux, distributed source and **H** operator, respectively. Apart from its mathematical usefulness, this resolution into even and odd functions of $\mathbf{\Omega}$ has also physical significance. The neutron scalar flux at **r** is $\int\psi^{+}(\mathbf{r},\mathbf{\Omega},E,t)\,d\mathbf{\Omega}$ and it governs the reaction rate at **r**. The net neutron current in the direction **n** at **r** is $2\int\mathbf{\Omega}.\mathbf{n}\;\phi^{-}(\mathbf{r},\mathbf{\Omega},E,t)\,d\mathbf{\Omega}$.

Problem types

Solutions of eqn (1) are possible by **EVENT** for three types of problems:

(i) <u>time evolution</u>

A time-dependent source or an initial flux distribution is prescribed, and the evolution of the angular flux is followed for a certain period of time. For the case of neutrons, the time-dependent distributed source term takes the general form

$$S(\mathbf{r},\mathbf{\Omega},E,t)=s(\mathbf{r},\mathbf{\Omega},E,t)+\frac{\chi(E)}{4\pi}\int dE'\int_{4\pi}d\mathbf{\Omega}'\,\psi(\mathbf{r},\mathbf{\Omega}',E',t)\,\nu(E')\sigma_f(\mathbf{r},E',t)$$

where s(**r**,**Ω**,E,t) is an extraneous distributed source.

(ii) steady-state fixed-source

The source term is assumed constant in time i.e. S(**r**,**Ω**,E,t) = s(**r**,**Ω**,E) and there is no contribution from fission in the case of neutrons. The flux is explicitly assumed to be time-independent, and the solution obtained corresponds to the long-term (equilibrium) situation.

(iii) steady-state eigenvalue (neutrons)

The neutron flux is assumed to be time-independent and all extraneous sources are assumed zero. The number of neutrons emitted per fission, ν(E), is adjusted so that there is a solution to eqn (1) for

$$S(\mathbf{r},\mathbf{\Omega},E,t) = \frac{\chi(E)}{4\pi K_{eff}} \int dE' \int_{4\pi} d\mathbf{\Omega}' \; \psi(\mathbf{r},\mathbf{\Omega}',E',t)\nu(E')\sigma_f(\mathbf{r},E',t)$$

where K_{eff}, the eigenvalue, provides a measure of whether the system is sub-critical or super-critical and by how much.

Problem geometry

Solution of the above problems is possible in six of the most common geometries of interest :
slab, spherical, infinite cylindrical, x-y, r-z and x-y-z.

Anisotropic scattering

Scattering is assumed independent of the incident angle and the collision operator **H** is explicitly given the form

$$\mathbf{H}\psi(\mathbf{r},\mathbf{\Omega},E,t) \equiv \sum_{l=0}^{L} \frac{(2l+1)}{4\pi} \sigma_l(\mathbf{r};E' \rightarrow E,t) \int dE' \int_{4\pi} d\mathbf{\Omega}' P_l(\mathbf{\Omega}.\mathbf{\Omega}')\psi(\mathbf{r},\mathbf{\Omega}',E',t)$$

where $\sigma_l \equiv \sigma_t - \sigma_{sl}$

Boundary conditions

On external boundaries of the problem domain, one or more of the following boundary conditions may be imposed :

(i) $\psi(\mathbf{r},\mathbf{\Omega},E,t) = 0$ (zero flux- P_1 approximation only)

(ii) $\psi(\mathbf{r},\mathbf{\Omega},E,t) = 0$ for $\mathbf{\Omega}.\mathbf{n} < 0$ (vacuum or bare surface)

(iii) $\psi(\mathbf{r},\mathbf{\Omega},E,t) = T(\mathbf{r},\mathbf{\Omega},t)$ for $\mathbf{\Omega}.\mathbf{n} < 0$ (surface source)

(iv) $$\psi(\mathbf{r},\mathbf{\Omega},E,t) = \alpha(\mathbf{r},E,t) \frac{\int_{\mathbf{\Omega}'.\mathbf{n}>0} d\mathbf{\Omega}'\mathbf{\Omega}'.\mathbf{n}\,\psi(\mathbf{r},\mathbf{\Omega}',E,t)}{\int_{\mathbf{\Omega}'.\mathbf{n}>0} d\mathbf{\Omega}'\mathbf{\Omega}'.\mathbf{n}'}$$ for $\mathbf{\Omega}.\mathbf{n} < 0$ (white albedo)

(iv) $\psi(\mathbf{r},\mathbf{\Omega},E,t) = \psi(\mathbf{r},\mathbf{\Omega}^*,E,t)$ for $\mathbf{\Omega}.\mathbf{n} = -\mathbf{\Omega}^*.\mathbf{n} < 0$ (symmetry)

Boundary conditions (i)-(iv) are possible for any arbitrarily-oriented surface. The symmetry boundary condition is implemented for the following particular cases : planes of symmetry parallel to x-y, x-z and y-z planes; planes of symmetry at angles of 30^0, 45^0 and 60^0 to x-z plane.

Energy discretisation

Energy dependence is discretised via the multigroup approximation. The energy domain is partioned into NG intervals of with ΔE_g, g = 1,2, ..., NG, and eqn (1) integrated over ΔE_g. This results in :

$$\frac{1}{v_g}\frac{\partial \psi_g(\mathbf{r},\mathbf{\Omega},t)}{\partial t} + \mathbf{\Omega}.\nabla\,\psi_g(\mathbf{r},\mathbf{\Omega},t) + \mathbf{H}_g\,\psi_g(\mathbf{r},\mathbf{\Omega},t) = S_g^{eff}(\mathbf{r},\mathbf{\Omega},t) \qquad g=1, ..., NG$$

where, $\psi_g(\mathbf{r},\mathbf{\Omega},t)$, the flux for group g, is no longer a distribution in energy, but the total number of particles in the energy interval., and

$$S_g^{eff}(\mathbf{r},\mathbf{\Omega},t) = S_g(\mathbf{r},\mathbf{\Omega},t) + \sum_{g'=1}^{NG}\sum_{l=0}^{L}\frac{(2l+1)}{4\pi}\,\sigma_{sl}^{g'\to g}(\mathbf{r},t)\int_{4\pi} d\mathbf{\Omega}'\,P_l(\mathbf{\Omega}.\mathbf{\Omega}')\,\psi_{g'}(\mathbf{r},\mathbf{\Omega}',t)$$

is the effective source for group g. Group 1 is the highest energy group. The multigroup equations are solved as a sequence of one-group problems, with the group-to-group scattering contribution providing the coupling between the groups. Problems can involve downscatter only or upscatter as well.

Time discretisation

Integration of the parity equations over time and the use of Padé approximants lead to a number of implicit and explict time-integrating schemes. The schemes implemented in **EVENT** are : Implict (Backward-Euler), Crank-Nicolson, Galerkin, Explicit(Forward-Euler).

Solution procedure

A second-order transport equation for the even-parity flux is written for each energy group :

$$-\mathbf{\Omega}.\nabla\mathbf{G}\mathbf{\Omega}.\nabla\psi^{+} + \mathbf{C}\psi^{+} = S^{+} - \mathbf{\Omega}.\nabla\mathbf{G}S^{-}$$

Solution of this equation is equivalent to finding the function which minimises the functional

$$\mathbf{F}[\phi] = (\mathbf{\Omega}.\nabla\phi, \mathbf{G}\mathbf{\Omega}.\nabla\phi) + (\phi, \mathbf{C}\phi) - 2(\phi, S^{+}) - 2(\mathbf{\Omega}.\nabla\phi, \mathbf{G}S^{-})$$

Approximate solutions to the problem are then obtained via the Ritz procedure. The **EVENT**-parity flux is given the form

$$\psi^{+}(\mathbf{r},\mathbf{\Omega}) = \sum_{i=1}^{M} U(\mathbf{r},\mathbf{\Omega})\psi_i^{+} = \mathbf{U}^{T}\boldsymbol{\psi}^{+}$$

Inserting this expression into (10) we have

$$\mathbf{F}[\boldsymbol{\psi}^{+}] = \boldsymbol{\psi}^{+T}\mathbf{A}\boldsymbol{\psi}^{+} - 2\boldsymbol{\psi}^{+T}\mathbf{B}$$

where

$\mathbf{A} \equiv (\mathbf{\Omega}.\nabla\mathbf{U}^{T}, \mathbf{G}\mathbf{\Omega}.\nabla\mathbf{U}) + (\mathbf{U}^{T}, \mathbf{C}\mathbf{U})$ is a MxM matrix

$\mathbf{B} \equiv (\mathbf{U}^{T}, S^{+}) + (\mathbf{\Omega}.\nabla\mathbf{U}^{T}, \mathbf{G}S^{-})$ is a Mx1 column vector

The requirement that $\delta F[\boldsymbol{\psi}^{+}] = 0$ leads to

$$\mathbf{A}\psi^{+} = \mathbf{B}$$

The solution of this system of linear equations yields the best solution in a least square sense for the given set of trial functions.

Angular discretisation

Spherical harmonics functions are used to approximate the angular dependence of the even-parity flux. This choice has several advantages such as the absence of ray effects in the solution and the facility of their numerical implementation. The numerical implementation is general and there is no restriction on the order of angular approximation.

Spatial discretisation

Isoparametric finite elements are used to represent the spatial dependence of the angular flux. The library of elements available consists of lines, triangles, quadrilaterals, tetrahedra, hexahedra and prisms, with polynomial basis functions up to fith order. All spatial integrations are performed numerically.

Solution algorithms

Several economical sparse-matrix in-core/out-of-core methods for the solution of the linear system are available. Two are based on a direct assembly-cum-reduction gaussian elimination procedure, and the others a preconditioned conjugate gradient procedure.

Mesh generation

The mesh is arbitrary (apart from the use of symmetry boundary conditions). However, full details of the mesh have to be given as data. To assist with this, an user friendly interface, in the form of the program GEM, has been developed to generate the input data.

A brief specification of **EVENT** is presented in Table 1.

3. Using EVENT

3.1 Program Input Information

In this section we describe the input requirements for **EVENT**. This is intended for reference purposes only. Preparing data for **EVENT** is a lengthy and idiosyncratic process except for the very simple cases. For this reason it is strongly recommended that the task of data preparation always be delegated to the pre-processing program **GEM**.

In principle **EVENT** expects data to come from three different files. The main file, associated to channel **STDIN**, provides the basic control parameters for the problem. The other two files, associated to channels **AUXDAT** and **AUXMAT,** provide problem mesh and data details, respectively. While this gives some flexibility to the user, care is necessary when preparing the data, for input mode is, at present, strictly sequential, and the instructions from the various channels are interspersed.

In most of the instructions cards below, the first ten columns may be used for labelling input data since they are skipped before numbers are read. For clarity, the channel from which the instruction is to be read is shown on the right.

The input instruction sequence expected by **EVENT** is as follows :

*From main input file (channel **STDIN**) read :*

(a) Title card [FORMAT(80 A1)] (STDIN)

TITLE	title is copied to box of the output, and also onto any plots.

(b) Input/output card [FORMAT(10X, 7I5)] (STDIN)

AUXDAT	auxiliary input channel for bulk mesh data. If 0 is given AUXDAT is reset to STDIN.
AUXMAT	auxiliary input channel for bulk material data. If 0 is given AUXMAT is reset to STDIN.
LIST	0 suppresses the print of bulk data. 1 gives an echo printout of the bulk data. 2 gives a printout of bulk material data.
PRINT	= 0 only integral results are printed. = 2 nodal scalar fluxes are printed. = 8 nodal even-moments are printed.
LINES	certain nodal and element output is printed with the specified number of lines per page (approximately). 0 is used to obtain the default.
PLOT	0 gives no plot. 1 gives mesh plot before a run (including CASE = 0). 2 gives an unlabelled scalar flux plot after a run. 4 gives an unlabelled moment plot. The values are additive.
DEVICE	selects plotting device. 0 = no plot 1 = X11 2 = A4 PostScript 3 = A4 Colour PostScript 4 = A3 PostScript

(c) Case card [FORMAT(10X, 4I5, 2E15.7)] (STDIN)

CASE	0 = no run, only check data, show mesh and calculate tables. 1 = eigenvalue run. 2 = fixed source run. 3 = time-dependent run.
NGEOM	geometry option. 1 = slab geometry. 2 = spherical geometry. 3 = infinite cylindrical geometry. 4 = x-y geometry. 5 = r-z geometry. 6 = x-y-z geometry.
NADJ	solution mode. 0 = solve for direct (forward) flux. 1 = solve for adjoint flux. 2 = solve for both forward and adjoint fluxes.
SOLTYP	equation solution scheme.

0 = gaussian elimination.
1 = iterative preconditioned conjugate-gradients (PCG)
2 = moment-by-moment (MBM) PCG
3 = MBM DDM PCG
4 = MBM gaussian elimination
5 = parallel MBM DDM PCG
6 = parallel global MBM DDM PCG

RESTRT — starting option.
0 = fresh start
> 0 restart calculation (not operational)

FLXOPT — flux option.
0 = zero initial flux distribution.
1 = read from channel AUXFLX scalar fluxes
2 = read from channel AUXFLX flux moments
3 = read from channel AUXFLX flux moments and interpolate

Obs . For positive values of FLXOPT the flux is read in free format. For negative values the initial flux file is in binary format.

SRCOPT — source option.
0 = piece-wise spatially-constant
1 = spatially-varying

(d) Iteration card [FORMAT(10X, 4I5, 2E15.7)] (STDIN)

MAXCG — maximum number of of pcg iterations. MAXCG = 0 sets MAXCG = 1.

MAXITS — maximum number of power iterations in an eigenvalue calculation. MAXITS = 0 sets MAXITS = 1.

EIGTOL — eigenvalue relative convergence criterio. If zero or negative there is no test on eigenvalue.

VECTOL — eigevector relative convergence. If zero or negative there is no test on the eigenvector.

NEXTRP — Chebyshev extrapolation option.
0 = no extrapolation.
1 = Chebyshev extrapolation with input dominance ratio.
2 = Chebyshev extrapolation with self-estimated dominance ratio.

SIGMAP — Dominance ratio for Chebyshev acceleration of power iterations. No effect if NEXTRP ≠ 1. If SIGMAP = 0.0 and NEXTRP = 1 then NEXTRP is set to 2.

For CASE = 3 include :

(e) Time-zone card [FORMAT(10X, I5, E15.7, 8I5] (STDIN)

NSTEPS — number of time steps in time zone. NSTEPS < 0 triggers automatic time-step size control option.

DELTAT	time-step size or time-zone duration. DELTAT = 0.0 triggers alpha-eigenvalue option (not operational).
TIMSCH	time-integration scheme. 0 = Fully-implicit scheme ($\alpha = 1$). (Default) 1 = Galerkin scheme ($\alpha = 0.66$). 2 = Crank-Nicolson scheme ($\alpha = 0.5$). 3 = Fully-explicit scheme ($\alpha = 0$).
NEWSCT	Read new angular card. = 0 no. > 0 yes.
NEWGRP	Read new energy card. = 0 no. > 0 yes.
NEWMSH	Read new mesh parameters card. = 0 no. > 0 yes.
NEWMIX	Read new mixing instructions. = 0 no. > 0 yes.
NEWDAT	Read new material data. = 0 no. > 0 yes.
NEWSRC	Read new sources. = 0 no. > 0 yes.
PRTOPT	Print options for time-zone. (not yet implemented)

For NEWANG > 0 (always true for CASE ≠ 3) include :

(f) Angular approximation card [FORMAT(10X, 4I5)] **(STDIN)**

MSCTR	order of P_N expansion for the angular flux.. Default is MSCTR = 1 (diffusion approximation).
NSCTR	order of truncated P_L expansion for the scattering kernel. Note that it is possible to have NSCTR > MSCTR. Default is NSCTR = 0 (isotropic scattering).
KSCTR	order of truncated P_K expansion for the scattering kernel. Note that it is possible to have KSCTR > MSCTR. (not implemented) Default is KSCTR = 0 (isotropic source).

For NEWGRP > 0 (always true for CASE ≠ 3) include :

(f) Energy card approximation card [FORMAT(10X, 4I5)] (STDIN)

NGRPS	number of energy groups. Default is NGRPS = 1.
NBGRPS	number of broad energy groups for collapsing. Default is NBGRPS = 0 (no collapsing).
LUMP	lumped-source approximation. 0 = exact (Default). 1 = exact even-parity source contribution. 2 = element-averaged even- and odd-parity source approximation used for evaluating multigroup and time-dependent sources.
NUPSCT	upscattering = 0 no. > 0 yes.

For NEWMSH > 0 (always true for CASE ≠ 3) include :

(g) Mesh data filename [FORMAT(10X, A)] (STDIN)

MSHFIL	file containing mesh data. All characters up to first blank are ignored with filename following. It is recomended that the full pathname be used whenever possible. If name is blank, mesh data is assumed to be read from standard input file.

If the filename is blank then the mesh data is assumed to be read from the main input file assigned to **STDIN**. If the name exists the file is opened and assigned to channel **AUXDAT** = 8. The mesh data consists of the element property list, nodal co-ordinates and constraints (see below).

*For NEWMSH > 0 (always true for CASE ≠ 3) read from channel **AUXDAT** :*

(h) Sizes card [FORMAT(10X, 6I5)] (AUXDAT)

NREG	number of integration regions or surfaces (= 0).
NMAT	number of materials (= 0).
NSOR	number of sources (= 0).
NELM	number of elements (volume + surface) (= 1).
NNOD	number of nodes (= 1).
NCON	number of constraints (= 0).
NALBD	number of albedos (= 0).
OPT	0 = no bandwidth reduction; internal node numbers are the same as user's nos. 1 = attempt to resequence nodes by Durocher-Gasper method; this is the simplest possible method and is suitable only if the number are in random order, or if they are in the worst possible order.
NTRY	number of resequencing attempts with OPT = 1. Normally equal to number of nodes so that sequences can be started from every node. NTRY may be reduced where it is known that fewer attempts will be sufficient (e.g. from a previous run). NTRY = 0 sets NTRY to the number of nodes.

For NEWMAT > 0 (always true for CASE ≠ 3) include :

(i) Material filename card [FORMAT(10X, A)] (STDIN)
(STDIN)

MATFIL	file containing material data. This includes x/s, speeds, sources and fission spectrum. All characters up to first blank are ignored with filename following. It is recomended that the full pathname be used whenever possible. If name is blank, material data is assumed to be read from standard input file.

If the filename is blank then the material data is assumed to be read also from the main input file assigned to **STDIN**. If the name exists the file is opened and assigned to channel **AUXMAT** = 9. The material data comprises of cross-sections, velocities, sources and fission spectrum, in this order.

*For NEWMAT > 0 (always true for CASE ≠ 3) read from channel **AUXMAT** :*

(j) Material data parameters card [FORMAT(10X, 7I5)] (AUXMAT)

MCR	number of materials to be read from cards.
MTPS	number of materials to be read from tape.
NMIX	number of mixing instructions.
IHT	position of total cross-section.
IHS	position of scattering cross-section.
IHM	length of cross section data
DATFMT	material data input format. 0 = **EVENT** format (default) 1 = Los Alamos format. 2 = FIDO format.

For NEWMSH > 0 (always true for CASE ≠ 3) include :

(k) Number of comment cards [FORMAT(10X, I5)] (STDIN)

NCOM	number of following comment cards (= 0)

For NEWMSH > 0 (always true for CASE ≠ 3) and NCOM > 0 read :

(l) Comment cards [FORMAT(A80)] (STDIN)

COMMENT	NCOM cards are copied to the output for run description, or for identifying source of data.

*From mesh file (channel **AUXMAT**) for NEWMAT > 0 (always true for CASE ≠ 3) read :*

(m) Element Cards [FORMAT(A10, 14I5)] (AUXMAT)

There are NELM cards containing

MARGIN	label (ignored)
ITYP	element type number (see Table 1)
IREG	integration region or surface number between 0 and NREG. IREG = 0 denotes that the element is not to be included in the integrations.
IMAT	material number between 1 and NMAT. This is not used for a surface element, but still must be in range.
ISOR	source number between 0 and NSOR; ISOR = 0 denotes zero or no source.
NODES	global node numbers for element nodes. The list of of nodes is terminated by a blank or zero. The number of given non-zero numbers must correspond to the number expected for a given element type. A continuation card with the same input format is expected for certain two- and three-dimensional elements which have more than 10 nodes.

(n) Node card [FORMAT(A10, 2E15.7, I5)] **(AUXDAT)**

For I = 1, NNOD read card containing

MARGIN (10)	label (ignored)
X(I)	x-coordinate of node I.
Y(I)	y-coordinate of node I.
Z(I)	z-coordinate of node I.
NEWNO(I)	internal bandwidth-optimised node number. NEWNO(I) = 0 sets NEWNO(I) = I

Each node should have unique coordinates.

(o) Constraint cards [FORMAT(A10, 2I5)] **(AUXDAT)**

There are NCON cards containing

MARGIN	label (ignored)
NODE	node no. between 1 and NNOD
CONTYP	constraint type (see Table 2)

No cards are read if NCON = 0.
No action is taken if CONNOD = 0 or CONTYP = 0.

*For NEWMIX> 0 (always true for CASE ≠ 3) read from channel **STDIN** :*

(p) Mixture instructions [FORMAT(10X, 2I5, E15.7, A10)] **(STDIN)**

There are NMIX cards containing :

MIXNUM	mixture number.
MIXCOM	mixture composition.
MIXNUM	mixture density.
LABEL	label for mixture intruction.

No cards are read if NMIX = 0.
Note that mixture cards are always required in time-dependent calculations.

I - MATERIAL DATA IN **EVENT** FORMAT (DATFMT=0)

For NEWMAT > 0 (always true for CASE ≠ 3) read :

(q) Material cross-section cards [FORMAT(A10, 4E15.7)] **(AUXMAT)**

Read NGRPS*MCR blocks of cards containing :

First card :

MARGIN	label (ignored)
SIGT (I)	total cross-section σ_t for group I.
SIGA(I)	absorption cross-section σ_a for group I.
NUSIGF(I)	fission production cross-section $\nu\sigma_f$ for group I.
SIGF(I)	fission cross-section σ_f for group I. (only if IHT = 5)

In a fixed-source run, NUSIGF and SIGF are read but not used. In an eigenvalue run at least one material with non-zero NUSIGF must be referenced on an element card.

There follows (NSCTR + 1) block of cards with same format containing :

MARGIN	label (ignored)
SCTRXL(J,I,L)	group-to-group scattering cross sections, L = 0, NSCTR. For downscatter J = I, NGRPS; for upscattter J = 1, NGRPS.

If CASE = 3 and NEWGRP > 0 read :

(r) Particle speed cards [FORMAT(10X, 4E15.7)] (AUXMAT)

NGRPS/4 cards containing :

MARGIN	label (ignored).
VELOC(I)	particle speed for group I

For NEWSRC > 0 (always true for CASE ≠ 3) read :

(s) Source cards [FORMAT(A10, 4E15.7)] (AUXMAT)

NSOR*NGRPS/4 cards containing :

MARGIN	label (ignored).
SORSTR(I,J)	total source strength for a volume- or a surface-source.

When a source is referenced for a volume element

$S^{+}(\mathbf{r}, \mathbf{\Omega}) = (1/4\pi)$ SORSTR

For a surface element

$T(\mathbf{r}, \mathbf{\Omega}) = (1/4\pi)$ SORSTR for $\mathbf{\Omega}.\mathbf{n} < 0$
$=$ undefined for $\mathbf{\Omega}.\mathbf{n} > 0$

In an eigenvalue problem, any sources are read but ignored. In a fixed-source run, at least one element must reference a non-zero source. If NSOR = 0 no source cards are read.

For NEWGRP > 0 (always true for CASE = 1) and CASE ≠ 2 read :

(t) Fission spectrum cards [FORMAT(A10, 4E15.7)] (AUXMAT)

NGRPS/4 cards containing :

MARGIN	label (ignored).
SPCTRM(I)	fission spectrum for group I

II - MATERIAL DATA IN FIDO FORMAT (DATFMT=2)

The order and conditions of input for material data is the same as above and should be obeyed. The FIDO card blocks are expected to start with a * card and terminate with a T. The expected sequence is :

14* T	material x/s (MCR*IHM*NGRPS)
5* T	particle speeds (1, ... NGRPS)
17* T	fixed sources ((1, ... NGRPS), 1, ... NSOR)
1* T	fission spectrum (1, ... NGRPS)

For NEWGRP > 0 (always true for CASE ≠ 3) and NBGRPS > 0 include:-

(u) Broad-group structure [FORMAT(10X, 16I5)] **(STDIN)**

NBGRPS/4 cards containing :

BGRPS(I) no. of fine groups in broad group I.

No cards are read if NBGRPS = 0.

For CASE = 3 repeat procedure starting from card (d) terminating calculation with a NSTEPS = 0 card.

3.2 Program Output

(i) Multiplication factor (eigenvalue run)

The effective multiplication factor K_{eff} is defined as the factor by which the fission cross-sections must be divided to make the system just critical. The estimate for K_{eff} is printed, together with the difference between the last two estimates to indicate the iteration error.

Also in an eigenvalue run, the results are normalised to give unit total fission rate.

The next three items are printed as a block for each energy group

(ii) Neutron Balance

The following items are printed :

(a) Total source input

$$S_T = \int_V d\mathbf{r} \int_{4\pi} d\mathbf{\Omega}\, S^+(\mathbf{r},\mathbf{\Omega})$$

(b) Total capture rate

$$C_T = \int_V dV\,(\sigma_t - \sigma_{\mathbf{s}0}) \int_{4\pi} d\mathbf{\Omega}\, \psi^+(\mathbf{r},\mathbf{\Omega})$$

(c) Total incoming current

$$J_{inT} = \int_{\partial V_B} ds \int_{\mathbf{\Omega}.\mathbf{n}<0} d\mathbf{\Omega} |\mathbf{\Omega}.\mathbf{n}| T(\mathbf{r},\mathbf{\Omega})$$

(d) Total outgoing current

$$J_{outT} = \int_{\partial V_B} ds \int_{\mathbf{\Omega}.\mathbf{n}>0} d\mathbf{\Omega} |\mathbf{\Omega}.\mathbf{n}| \{2\psi^{+}(\mathbf{r},\mathbf{\Omega}) - T(\mathbf{r},\mathbf{\Omega})\}$$

(e) Excess input

$$\Delta = S_T - C_T + J_{inT} - J_{outT}$$

where V is the whole problem region and ∂V_B is the bare surface.

It is easily shown that solutions obtained from the variational principle (using admissible basis functions which can reproduce a constant isotropic flux), can be interpreted as conservative in the sense

$$\Delta = 0$$

The actual value calculated for Δ is therefore a measure of rounding error.

This does not apply to cases where zero flux (constraint type 16) condition is used in place of the proper bare surface conditions (surface elements). Then currents are not calculated, and Δ is an estimate of net leakage.

(iii) Region and surface integrals

If NREG > 0 and appropriate region/surface numbers (between 1 and NREG) are given on the element cards, the following are printed :

regions	surfaces	
(a)	volume or area	surface or length
(b)	mean flux	total incoming current
(c)	total capture rate	total outgoing current
(d)	total source input	net leakage

(iv) Nodal fluxes

If PRINT = 2 the total flux at the nodes is printed. If PRINT = 8 nodal even flux moments are printed.

(v) Time keeping tables

At the end of a run, the processor time in seconds is given for major steps.

(vi) Auxiliary output files

Supplementary output is written to files connected to channels 20 and 21 (in the x20 and x21 subdirectories, respectively).

Output to channel 20 consists of nodal coordinates and scalar fluxes for each group and time-step.

Output to channel 21 consists of a summary of integral results e.g. eigenvalue, time-constant for step, regional production and losses.

Table 1 Brief Specification of **EVENT**

Energy dependence:	conventional multigroup (arbitrary number of groups)
Angular approximation of the flux:	P_N approximation (arbitrary order of expansion)
Anisotropy of scattering:	arbitrary P_L expansion
Spatial approximation:	polynomial basis functions of up to order 5 in various isoparametric element shapes such as line, triangle, quadrilateral, tetrahedron, hexahedron and prism.
Time integration algorithms:	Explicit; Crank-Nicolson; Galerkin; Fully Implicit
Dimensions and geometries:	1-D : slab, sphere, cylinder 2-D : X-Y, R-Z (non-orthogonal) 3-D : X-Y-Z (non-ortogonal)
Solution modes :	direct (i.e. forward) and/or adjoint
Problem types :	steady-state : fixed-source; eigenvalue time-dependent : source driven
Cross section data:	standard ANISN/FIDO interface . Libraries accessed so far: **CASK-23**, **BUGLE-96**, **MATXS87**. Specific few group data can also be input directly.
Boundary conditions:	zero flux; bare; reflection; incoming surface source; white-albedo.
Additional features :	cross section group collapsing; regional reaction rates; user-friendly mesh generator and data preparation module specially written for program; up-scattering; graphical data output for subsequent post-processing.

Table 2 Element Families Implemented in **EVENT**

ITYP	NGEOM = 1, 2, 3	NGEOM = 4, 5	NGEOM = 6
1	2-node line	3-node triangle	4-node tetrahedron
2	1-node surf. elem	2-node line	3-node triangle
3	3-node line	6-node triangle	10-node tetrahedron
4	1-node surf. elem	3-node line	6-node triangle
5	4-node line	10-node triangle	20-node tetrahedron
6	1-node surf. elem	4-node line	10-node triangle
7	5-node line	15-node triangle	4-node tetrahedron
8	1-node surf. elem	5-node line	15-node triangle
9	6-node line	21-node triangle	56-node tetrahedron
10	1-node surf. elem	6-node line	21-node triangle
11	-	4-node quad.	8-node prism
12	-	-	4-node quad.
13	-	9-node quad.	27-node prism
14	-	-	9-node quad.
15	-	16-node quad.	64-node prism.
16	-	-	16-node quad.
17	-	25-node quad.	125-node prism
18	-	-	25-node quad.
19	-	36-node quad.	216-node prism
20	-	-	36-node quad.
21	-	-	6-node skewed wedge

Table 3 Boundary condition types

CONTYP	Boundary Condition
1	symmetry plane parallel to x-z plane
2	symmetry plane at 30 degrees to x-z plane
3	symmetry plane at 45 degrees to x-z plane
4	symmetry plane at 60 degrees to x-z plane
5	symmetry plane parallel to y-z plane
6	symmetry plane parallel to x-y plane
7	intersection of symmetry planes 1-2 or 2-4 or 4-5
8	intersection of planes 1-3 or 3-5
9	intersection of symmetry planes 1-4
10	intersection of symmetry planes 1-5 or 1-6 or 5-6
11	intersection of symmetry planes 2-3 or 3-4 or three symmetry planes
12	intersection of symmetry planes 2-5
13	intersection of symmetry planes 2-6
14	intersection of symmetry planes 3-6
15	intersection of symmetry planes 4-6
16	all moments vanish