COMMISSION OF THE EUROPEAN COMMUNITIES

CONDOR 3

A TWO-DIMENSIONAL REACTOR LIFETIME PROGRAM WITH LOCAL AND SPECTRUM DEPENDENT DEPLETION

by

E. SALINA (A.R.S.)

1970

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By means of the spatial modal expansion the program determines the eigenvalue of the reactor, which can be in turn the K_{eff} (multiplication factor), the $(^H)$ (dilution factor of a diluted poison), the Σ_p or the boundary of a prefixed control region.

By means of the finite difference method, the program improves the calculation of the K_{eff} and the group flux spatial distribution.

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ABSTRACT

CONDOR 3, as the preceding nuclear codes of the CONDOR series is a few-group bidimensional lifetime program written in Fortran IV for the IBM 360/65. It couples the method of the spatial modal expansion with the 5 point finite difference method.

By means of the spatial modal expansion the program determines the eigenvalue of the reactor, which can be in turn the K_{eff} (multiplication factor), the (^{H}) (dilution factor of a diluted poison), the Σ_p or the boundary of a prefixed control region.

By means of the finite difference method, the program improves the calculation of the K_{eff} and the group flux spatial distribution.

KEYWORDS

INTRODUCTION AND SUMMARY *)

CONDOR-3, as the preceding nuclear codes of the CONDOR series (5,14), is a few-group bidimensional lifetime program written in Fortran IV for the IBM 360/65. It couples the method of the spatial modal expansion (3,9,11) with the 5 point finite differenêe method.

By means of the spatial modal expansion the program determines the eigenvalue of the reactor, which can be in turn the K_{eff} (multiplication factor), the Θ (dilution factor of a diluted poison), the Σ_p or the boundary of a prefixed control region.

By means of the finite difference method, the program improves the calculation of the K_{eff} and the group flux spatial distribution.

The coupling between the two methods has been suggested by the realization that the spatial modal expansion is able to determine the eigenvalue of the reactor with an acceptable precision, even in reactors where the point fluxes, especially the thermal ones, disagree to a large extent with the point fluxes determined by means of the finite difference (4).

The main advantages attainable in using the CONDOR programs are:

1) The criticality searches are very speedy, for they are performed by the modal expansion only.
2) The modal expansion fluxes can be used as initial guess for the finite difference calculations.
   Due to advantages 1), 2) and referring to a many point calculation ($> \sim$ 4000 points), one can state that the computational time required for a diluted poison search (with final finite difference calculation) is nearly the same as that required for a straight K-effective calculation with a flat guess for the finite difference fluxes.
3) A problem can be restarted from any time-step already carried out, using basically a tape and cards only for those data which are to be changed.

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*) Manuscript received on 21 July 1970

The main features of CONDOR-3 which are not present in CONDOR-2, are:

1) The depletion equations are solved at each mesh element (i.d. the rectangular cell bounded by two successive horizontal and vertical mesh lines) and so the fuel burn-up calculation is as refined as possible, while in CONDOR-2 it was carried out only regionwise, a region being a collection of mesh-rectangles.

2) More than one cross-section library can be specified by cards and therefore the microscopic cross-sections may have different values in different regions.

3) As an alternative to the straight specification by cards (as explained above), the microscopic cross-sections can be calculated at each time-step by the program itself, taking into account the local values of some basic parameters such as the moderating ratio, the Pu-concentration, the fuel and moderator temperatures etc.

Details about the actual computational procedure which obviously must be set up bearing in mind the reactor type (6), can be found in Appendix E.

A brief account of the main physical features of the program is summarized.

Depletion Equations

The chains of burnable isotopes can be defined by the code's user without unjustified restrictions. Nevertheless those which are not interested in special isotopic chains, can find a standard set of isotopic chains built-in in the code (See par. IV).

The depletion equations are solved by mesh element, that is, at each time-step the program evaluates a new set of macroscopic cross-sections at each mesh rectangle. In addition to the above said time-dependent or burnable isotopes, which are rigidly numbered from 1 to n_b, time-independent isotopes can be present in the reactor and arbitrarily numbered up to a maximum.

Number of groups

The program performs optionally from 1 to 4 group calculations.

Types of poisons:

There are 4 types of poisons:

a) The burnable poisons. They are treated in the depletion equations.

b) A uniform poison smeared over the entire reactor; because it simulates a chemical poison, it will be called diluted poison from now forth.
Its absorption cross-section in group 1 is the product of a Σ_{dp}, a group fraction t_d^1 and a dilution factor. θ. This last factor can be varied to maintain the criticality.

c) A number of poisoned regions, called rodded regions, because they simulate banks or rings of homogenized control rods, each characterized by a Σ_{rp} (different from one region to another). The rodded regions can be defined independently and superposed on the reactor regions, about which we shall talk later on (see Region and Composition). The criticality can be maintained managing the rodded regions, either varying the boundary or the value of Σ_{rp} (see Diffusion calculations).

d) The so-called non-diffusion regions (rod regions) where the fluxes of one or more groups are not calculated but satisfy, on the boundary, to a logarithmic derivative condition of the form

$$D \frac{1}{\varphi^1} \frac{\partial \varphi^1}{\partial n} = - C^1 \varphi^1$$

1 = group index

$\frac{\partial}{\partial n}$ = derivative normal to region

boundary and C^1 is a given positive constant.

Diffusion Calculations

At each time step the program may perform optionally 4 types of diffusion calculations:

i) straight K-effective calculation;

ii) criticality calculation, varying the dilution factor θ(cfr. Types of poisons. point b)) until a given K_{eff} is reached. This option simulates the control by means of a chemical poison.

iii) criticality calculation, varying the top boundary of a spe-
cified rodded region or group of rodded regions. If the top
or bottom limit of the moving boundary is achieved without
reaching the criticality, the program goes to the next rodded
region or group of rodded regions, specified by a list (cfr.
Control Programming);

iv) same as iii) but the varying parameter is the Σ_{rp} instead of
the boundary.

Control Programming

A list of "rodded regions" can be specified at the beginning of
life. The criticality then will be maintained during the burn-up
of the reactor by managing the Σ_{rp} or the boundary in one region
at the time (or in one group of regions), following the specifi-
cation list. Once the poison of a "rodded region" is totally re-
moved (or removed up to some prefixed value) the program auto-
matically goes on to adjust the poison in the next region or group
of regions specified in the list.

Cross-section Library

Each cross-section library is divided into 3 main blocks:

block A: library of microscopic cross-sections σ_{tr} (transport),
σ_a (absorption), σ_r (removal to next group) for any iso-
tope;

block B: library of microscopic cross-sections σ_f (fission), $\nu\sigma_f$
(nu-fission), e (energy per fission) for any fissionable
isotope;

block C: fission yields for any fissionable isotope.

At any time step the program can read in any or all of the blocks
A, B, C. A block may be read only partially for a restricted num-
ber of elements.

The possibility of reading the library at any time step permits
to take into account changes of the spectrum during the lifetime.
Moreover, as mentioned above, the microscopic cross-sections can
be supplied by the program itself.

Self-Shielding Factors

The isotopes can be assigned either constant self-shielding factors or self-shielding factors which are concentration-dependent with a polynomial law:

$$\xi^{i,j,p} = \sum_{h=0}^{g} a_h^{i,j,l} (N^{j,p})^h$$

p = mesh element index

i = group index

j = isotope index

l = index of the region of which element p is a part

$\xi^{i,j,p}$ = self-shielding factor

$N^{j,p}$ = number density in mesh element p

The self-shielding factors and (or) the polynomial coefficients may be read in at any time-step.

Time-step Data

First, we shall define what is meant exactly as a "time-step".
A time-step begins with the calculation of the new number densities (burn-up calculation) and ends with the calculation and the normalization of the group fluxes (diffusion calculation). Exception is made for the time-step 0, where the burn-up calculation is replaced by the mere specification of the input number densities.

The duration and the reactor power at each time-step can be arbitrarily prefixed. Moreover, each time-step can be divided at will into a number of smaller substeps of the same length.
At each time-step the program carries out only one diffusion calculation while at each substep it recalculates the concentration-dependent self-shielding factors and the time-dependent number densities with no flux renormalization taking place.

A few input data, namely the bucklings, the control data, the microscopic data, the self-shielding data, the shuffling data, can be read at each time-step after the relevant burn-up calculation and before the diffusion calculation. Moreover, fig.1 shows the "restart points" where a problem interrupted in a previous run,

owing to machine error, time overflow, etc., can be restarted.
If the interruption is programmed to occur in a restart point,
as it is possible to the user, there is no loss of computer
time.
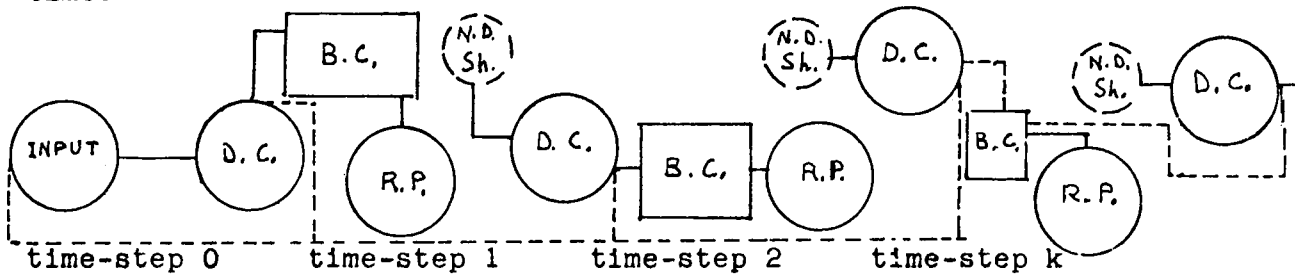
B.C. = burn-up calculation
N.D. = new input data
Sh. = shuffling   fig. 1
D.C. = diffusion calculation
R.P. = restart point

Region and Composition

It is easy to realize that, after the first time-step has elap-
sed, each mesh rectangle (or mesh element) has a different com-
position, owing to the spatial distribution of the fluxes. Never-
theless more mesh elements may be arranged into the same region.
A region is defined as a collection of one or more mesh elements,
even disjoint, which have the same buckling, the same diluted
poison cross-section, the same library and self-shielding data
and the same initial composition. The idea of region is introdu-
ced especially for input purposes in order to make the specifica-
tion of the input data easier, but it may be even physically
meaningful, with reference to the initial status of the reactor,
since the program calculates and prints integrated quantities
and flux weighted macroscopic cross-sections, showing up in this
way the total effect of the burn-up at each region.

Strictly speaking in this report, a composition is a mixture of
isotopes which, at the beginning of the lifetime, can be shared
by different regions with nuclear properties undergoing a diffe-
rent evolution during the reactor lifetime, and which, later on,
can be fed into the reactor by a shuffling procedure. The concept
of composition is auxiliary in respect of the concept of region
and it is introduced only to simplify the specification of the

input atomic densities.

Shuffling

At any prefixed time-step the program may take the (time-dependent) number densities of a rectangular block of mesh elements and, after clockwise or counter-clockwise rotation, transfer them in another rectangular block element by element. For instance, a possible pattern is sketched in fig. 2.

Also fresh fuel (that is a uniform mixture made up of the isotopes present at the beginning of life) can be fed into any rectangular block of mesh elements. Moreover, a new region index can be assigned to the mesh elements.

The above operations can be repeated for as many rectangular blocks as desired and can be used to simulate the transfer and the substitution of fuel elements or the replacement of a control rod by its follower.

| 1st block | rotation (90° clockwise) | translation | 2nd block |
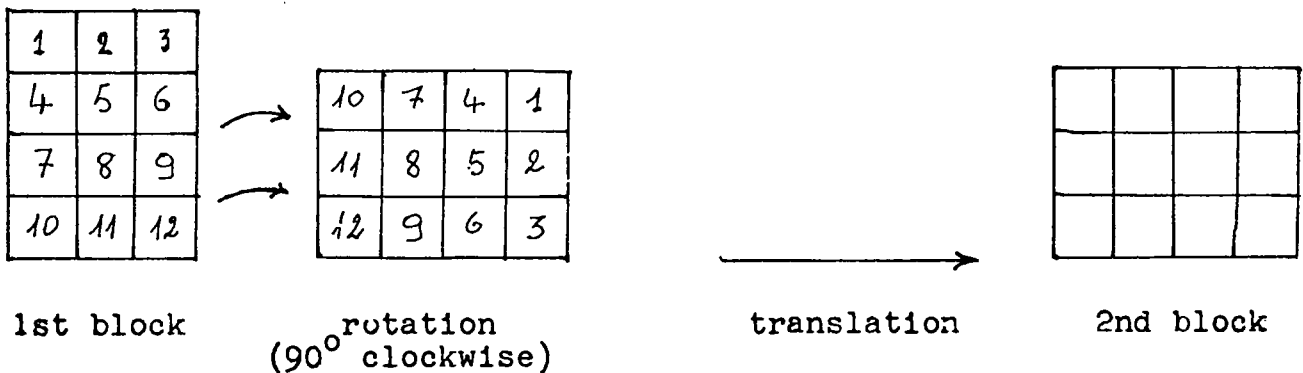
fig. 2

I - THE DIFFUSION EQUATIONS

I.1 - Statement of the Problem

At any time-step, the stationary group diffusion equations are (the time-step index having been dropped):

$$- \text{div} \left[D^1(x,y) \, \text{grad} \, \varphi^1(x,y) \right] + \left[\Sigma_T(x,y) + \Sigma_p(x,y) \right] \varphi^1(x,y) = \psi^1(x,y)$$

$$\psi^1(x,y) = \frac{\chi^1}{\lambda} \sum_{j=1}^{ng} \nu\Sigma_f^j(x,y)\varphi^j(x,y) + \Sigma_R^{1-1}(x,y)\varphi^{1-1}(x,y)$$

$$(1-1)$$

$$i = 1, 2, \ldots ng$$

The physical interpretations of these symbols are:

i = group index;

ng = number of groups $(ng \leqslant 4)$;

$$\Sigma_R^0 = 0$$

$$\Sigma_T^i = \Sigma_a^i + \Sigma_R^i + D^i B_i^2$$

$$\Sigma_p^i = \Theta t_d^i \ \Sigma_{dp} + t_r^i \ \Sigma_{rp}$$

Σ_a^i = the macroscopic absorption cross-section

Σ_R^i = the macroscopic removal cross-section

B_i^2 = the transverse buckling

D^i = the diffusion coefficient

Σ_{dp} = the macroscopic absorption cross-section of a diluted poison (dp)

t_d^i = fraction of Σ_{dp} in the group i

Θ = dilution fraction. It may be either an eigenvalue of the problem, or an input data

Σ_{rp} = the macroscopic cross-section of a rodded poison (rp)
Also Σ_{rp} may be either a problem eigenvalue or a given data

t_r^i = fraction of Σ_{rp} in the group i

$\nu\Sigma_f^i$ = the macroscopic cross-section of neutron production

φ^i = the neutron flux

χ^i = the fission spectrum integral over group i

λ = eigenvalue of the problem when a straight diffusion calculation is performed. Otherwise λ is a given parameter, and the eigenvalue of the problem is either Θ or Σ_{rp}, or the boundary (this last does not appear algebraically in eqs. (1-1), but it is contained in the functional form of $\Sigma_{rp}(x,y)$).

Any equation of system (1-1) must be solved at each point internal to the domain R, delimited by the external contour Γ of the reactor.

The functions $\varphi^1(x,y)$ and $\psi^1(x,y)$ on Γ fulfill the boundary conditions of the type:

$$\left[\begin{array}{l} \varphi^1(x,y) = \psi^1(x,y) = 0 \\[2mm] \dfrac{\partial \varphi^1(x,y)}{\partial n} = \dfrac{\partial \psi^1(x,y)}{\partial n} = 0 \\[2mm] (x,y) \ni \Gamma \end{array}\right. \qquad (1\text{-}2)$$

The domain R is also delimited internally by one or more internal contours γ_h^1, on which the flux $\varphi^1(x,y)$ fulfills the condition of assigned logarithmic derivative of the type:

$$D^1(x,y)\ \frac{\partial \varphi^1}{\partial n} + C^1(x,y)\varphi^1 = 0$$

$$(x,y) \ni \gamma_h^1 \qquad (1\text{-}3)$$

where C^1 is a positive function.

The internal contours γ_h^1 are the contours of the non-diffusion regions, where the flux φ^1 of one or more groups, but not necessarily of all, is not defined in the points inside.

Moreover, the functions $\varphi^1(x,y)$ and $D^1(x,y)$. grad $\varphi^1(x,y)$ are to be continuous in any point of the domain R.

I.2 - Solution of the Problem by Means of the Spatial Modal Expansion and Variational Technique

If the functions $\psi^1(x,y)$ are supposed known, then the functions $\varphi^1(x,y)$ that satisfy eqs. (1-1), conditions (1-2), (1-3), and the continuity conditions, make stationary the following functional (3):

$$F^1[\,\varphi^1(x,y)\,] = \int_R \left\{ \frac{1}{2}\, D^1(x,y)\ \text{grad}\ \varphi^1 \cdot \text{grad}\ \varphi^1 + \frac{1}{2}[\Sigma_T^1(x,y) + \right.$$

$$+ \Sigma_p^1(x,y)] \cdot [\,\varphi^1(x,y)\,]^2 - \psi^1(x,y)\ \varphi^1(x,y) \left.\right\} \rho(x)\ dx\ dy +$$

$$+ \sum_{h=1}^{n_{1r}} \oint_{\Upsilon_h^1} \frac{1}{2}\, C^1(x,y)\,[\,\varphi^1(x,y)\,]^2\ d\sigma \tag{1-4}$$

where the symbol . represents the scalar product, n_{1r} is the number of logarithmic regions, and:

$$\rho(x) \begin{cases} = 2\,\pi x & \text{in cylindrical geometry} \\ = 1_t & \text{in plane cartesian geometry} \end{cases}$$

The symbol $\displaystyle\oint_{\Upsilon_h^1}$ represents an integral over an internal contour, and it is a curvilinear integral in cartesian geometry and a surface integral in cylindrical geometry.

The flux $\varphi^1(x,y)$ is expanded in a series of eigenfunctions: [*]

$$\varphi^1(x,y) = \sum_{h=1}^{n_x} \sum_{k=1}^{n_y} \alpha_{hk}^1\ X_h(x)\ Y_k(y) \tag{1-5}$$

where n_x and n_y are the number of eigenfunctions taken in directions x and y respectively.

$n_h = n_x \cdot n_y$ is the total number of two-dimensional harmonics

$W_{hk}(x,y) = X_h(x)\ Y_k(y)$.

The eigenfunctions $X_h(x)$ and $Y_k(y)$ are chosen such that they themselves satisfy the conditions (1-2) on the external boundary. The program CONDOR employs the following eigenfunctions:

[*] Such expansion will take the name of "spatial modal expansion" throughout the text.

$$X_h(x) \begin{cases} \cos(2h-1)\dfrac{\pi x}{L_x} & \text{both in cylindrical and cartesian geometry, with a symmetry condition at } x = 0 \\[2em] \sin h \dfrac{\pi x}{L_x} & \text{in cartesian geometry with the condition } \varphi^i(x,y)\Big|_{x=0} = 0 \end{cases}$$

(1-6)

$$Y_k(y) \begin{cases} \cos(2k-1)\dfrac{\pi y}{L_y} & \text{cartesian geometry with symmetry condition at } y = 0 \\[2em] \sin k \dfrac{\pi y}{L_y} & \text{cartesian geometry with the condition } \varphi^i(x,y)\Big|_{y=0} = 0 \end{cases}$$

(1-7)

L_x and L_y are the two sides of the rectangular domain R.

The program CONDOR does not solve cell problems: the fluxes are always supposed to vanish on the right and bottom contours of the reactors.

The domain R is represented in fig. 3.
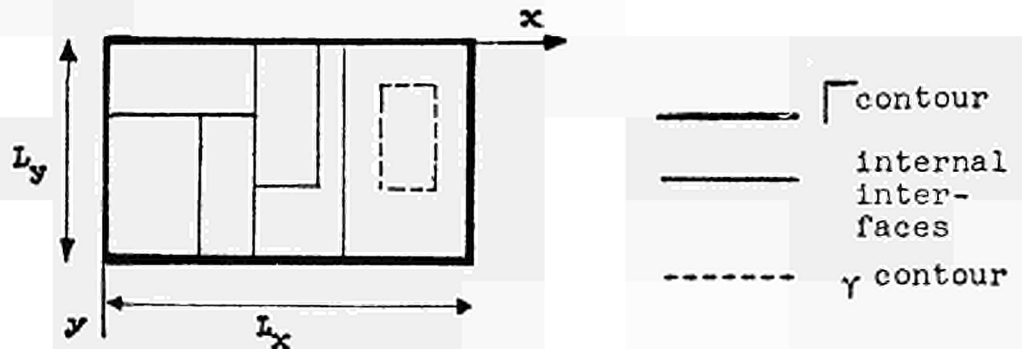
fig. 3

I.3 - Matricial Form of the Diffusion Equations

By substituting the series expansions (1-5) into the functionals (1-4), the coefficients of the fluxes α_{rs}^i are determined by equations (1-9):

$$\frac{\partial F^i(\varphi^i)}{\partial \alpha_{rs}^i} = 0 \quad (r = 1, 2, \dots n_x; \ s = 1, 2, \dots n_y; \ i = 1, \dots n_g)$$

(1-9)

Defining:

$$A^1_{hkrs} = \int_R D^1(x,y)[\dot{X}_h(x)Y_k(y)\dot{X}_r(x)Y_s(y) + X_h(x)\dot{Y}_k(y)X_r(x)\dot{Y}_s(y)].$$

$$(1\text{-}10)$$

$$\rho(x)dxdy + \int_R [\Sigma^1_t(x,y)+\Sigma^1_p(x,y)]X_h(x)Y_k(y)X_r(x)Y_s(y)\rho(x)\ dx\ dy$$

$$(1\text{-}11)$$

$$S^1_{hkrs} = \int_R \nu\Sigma^1_f(x,y)X_n(x)Y_k(y)X_r(x)Y_s(y)\rho(x)\ dx\ dy \qquad (1\text{-}11)$$

$$R^1_{hkrs} = \int_R \Sigma^1_R(x,y)X_h(x)Y_k(y)X_r(x)Y_s(y)\rho(x)\ dx\ dy \qquad (1\text{-}12)$$

Equations (1-9) are reduced to the following system of n_h linear equations in the n_h unknowns α^1_{rs}:

$$\sum_{h=1}^{n_x}\sum_{k=1}^{n_y} A^1_{hkrs}\ \alpha^1_{hk} = \frac{\chi^1}{\lambda}\ \psi_{rs} + \sum_{h,k} R^{1-1}_{hkrs}\ \alpha^{1-1}_{hk}$$

$$\psi_{rs} = \sum_{j=1}^{n_g}\sum_{h,k} S^j_{hkrs}\ \alpha^j_{hk} \qquad (1\text{-}13)$$

$$R^0_{hkrs} = 0$$

Reducing the four-index matrices to two-index matrices, following the schemes described in (3), equations (1-13) can be written in a compact matricial form:

$$A^1\ \alpha^1 = \frac{\chi^1}{\lambda}\psi + R^{1-1}\ \alpha^{1-1}$$

$$\psi = \sum_{j=1}^{n_g} S^j\ \alpha^j \qquad (1\text{-}14)$$

$$R^0 = 0 \qquad 1 = 1,2,\ \ldots\ n_g$$

To calculate the multiplication constant K_{eff}, which, from the

statical standpoint (18) coincides with the eigenvalue largest in modulus of eqs. (1-14), use is made of the straight power method, whose convergence is guaranteed by the fact that system (1-14) can be reduced easily to the classical form:

$$M \psi = \lambda \psi \qquad \qquad (1-15)$$

The criticality searches are performed by varying the control parameter and solving system (1-14) each time, until the convergence is reached.
More details about the matrix equations (1-14) and its solution can be found in (3,14).

I.4 - Restrictions of the Modal Expansion Method

The maximum number of harmonics n_h^{max} permissible in the program CONDOR has been determined in such a way that the matrices A^1, S^1, R^1 of eqs. (1-14), taking into account their symmetry, could be simultaneously stored in the fast memory of the available computer, avoiding the time-expensive use of peripheral storage units in the iterative cycles of the power method.

Even with a high number of harmonics (up to 100), the matrices A^1 can be inverted with rapidity and precision by means of a direct method.

Should n_h^{max} be greater than ~100, not only the intervention of peripheral units would be necessary at each iteration, but also the substitution of the matrix inversion iterative methods to the direct ones.

II. - GENERAL FEATURES OF THE PROGRAM

II.1 - Types of Reactor Regions

The domain R representing the reactor, is made up of regions which can be of three types:
1) Diffusion Regions, where all group fluxes are defined and fulfill eqs. (1-1) with $D^1(x,y) > 0$.
   All points belonging to a same diffusion region have a uni-

form initial composition, the same buckling, the same diluted poison cross-section, the same microscopic cross-sections and self-shielding data. On the contrary, after the time-step 0, the macroscopic cross-sections D^1, Σ_a^1, Σ_r^1, $\nu\Sigma_f^1$ in a fuel region have different values at each mesh rectangle owing to the spatial distribution of the fluxes and the consequent non-uniform burn-up of the fuel. Also the absorption cross-section Σ_{rp} due to a rodded poison can take different values in points of a same diffusion region (cfr. Rodded Regions), due to the fact that the rodded regions can be superimposed at will over the diffusion regions.

ii) **Non-Diffusion or Logarithmic Regions**

The flux of one or more groups is not defined in the points internal to such a region, but fulfill a condition of assigned logarithmic derivative on the contour γ_1

$$\frac{D^1(x,y)}{\varphi^1(x,y)} \frac{\partial\varphi^1(x,y)}{\partial n} = -C^1$$

$$(x,y) \ni \gamma_1 \tag{2-1}$$

where n is the inwardly oriented normal to γ_1. For all other groups, the region is a regular diffusion region. We shall call it preferably a logarithmic region, instead of rod region, as PDQ (1) does, to avoid confusion with the rodded regions described below.

The regions considered in i) and ii) are not necessarily rectangular but may have a boundary of whatever shape, provided it is composed of horizontal and vertical segments of mesh lines. Moreover, a region (e.g. a non-burnable region or a logarithmic region) can be constituted by two or more disjoint sets of mesh points.

iii) **Rodded Regions**

These regions are rectangularly shaped and can be superimposed at will over the diffusion regions. Their effect is that of adding a rodded poison absorption cross-section

$t_r^1 \, \Sigma_{rp}$ to the pre-existing group - 1 absorption cross-section at every point covered by a rodded region.

They are called <u>rodded regions</u> because they simulate the poison of control rods, properly homogenized and smeared out over portions of the reactor which generally have not the same contours of the diffusion regions.

II.2 - Mesh Points

In order to solve the finite difference equations, derived from eqs. (1-1), the domain R is discretized in a grid of mesh points. The horizontal and vertical lines, called respectively rows and columns of the grid, are separated by intervals of arbitrary width, but they must be assigned in such a way that the external boundary of domain R and the contours of all the regions, of whatever type, coincide exactly with these lines.

The columns are numbered from left to right and the rows from top to bottom, beginning with 1.

The coordinate axes x and y lie respectively on the top and left contours of the domain R. The y axis is oriented downwardly. Fig. 4 will show an example of grid.

The rectangular symmetry axes, if any, lie on the coordinate axes. Moreover, there may be a diagonal symmetry axis through the origin (1,1) and oriented to 45° with respect to the coordinate axes.

fig. 4
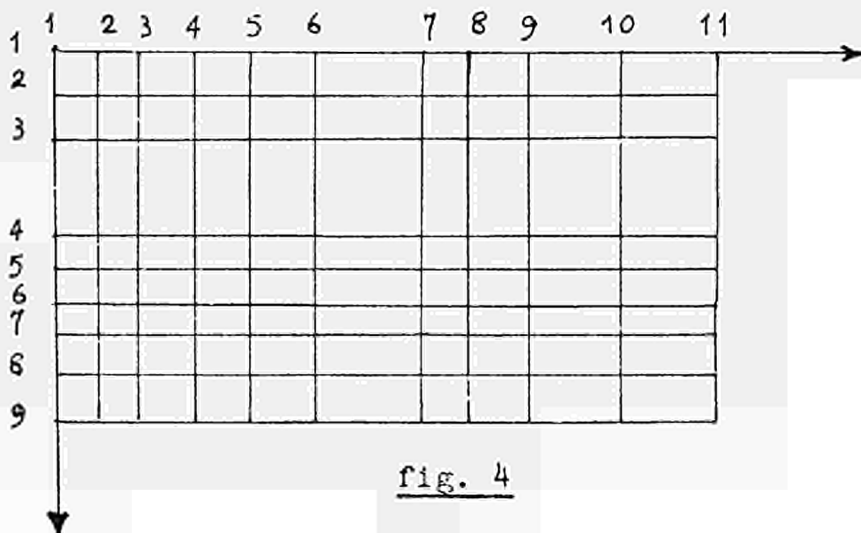
II.3 - Diffusion Calculation and Criticality Searches

The diffusion equations (1-1) can be solved in three different ways, depending on what parameter is considered as the eigenvalue of the system (1-1).

1) Straight K_{eff} Calculation. This coincides with the λ greatest in modulus of eqs. (1-14).

2) Diluted Poison Search. At any time-step the program determines the critical dilution factor Θ (crit) for a wanted eigenvalue λ_c with the following procedure:

   a) The program calculates the eigenvalue λ ($=K_{eff}$) for $\Theta = \Theta^{(max)}$ where $\Theta^{(max)}$ is the maximum allowable dilution factor given in input. If $\lambda(\Theta^{(max)}) > \lambda_c$, meaning that the reactor is supercritical even with the maximum poison concentration, the program stops.

   If $\lambda(\Theta^{(max)}) < \lambda_c$, the program calculates λ for $\Theta = \Theta^{(1)}$ where $\Theta^{(1)}$ is a guess, supplied by the input for the beginning diffusion calculation and by the last value $\Theta^{(crit)}$ obtained in the preceeding time-step, for the other time-steps.

   b) If $\lambda(\Theta^{(1)}) > \lambda_c$, a new value $\Theta^{(2)}$ is obtained by linear interpolation between $\Theta^{(max)}$ and $\Theta^{(1)}$.

   c) If $\lambda(\Theta^{(1)}) < \lambda_c$, the program evaluates λ for $\Theta = \Theta^{(min)}$, where $\Theta^{(min)}$ is the minimum allowable value of Θ, given in input.
   If $\lambda(\Theta^{(min)}) < \lambda_c$, meaning that the reactor is subcritical even with the minimum poison concentration, the program stops.

   d) If $\lambda(\Theta^{(min)}) > \lambda_c$, a new value $\Theta^{(2)}$ is obtained by linear interpolation between $\Theta^{(1)}$ and $\Theta^{(min)}$.

   e) All other values of Θ : $\Theta^{(3)}$, $\Theta^{(4)}$ ... are obtained by linear interpolation between the two last values calculated:

$$\Theta^{(t)} = \Theta^{(t-1)} + \frac{\lambda_c - \lambda^{(t-1)}}{\lambda^{(t-1)} - \lambda^{(t-2)}} [\Theta^{(t-1)} - \Theta^{(t-2)}] \qquad (2-2)$$

until a $\Theta^{(crit)}$ is obtained, satisfying the condition

$$\left| \lambda_\oplus^{(crit)}) - \lambda_c \right| < \eta$$

3) <u>Rodded Poison Search</u>. As already said, the rodded poison is present as an absorption Σ_{rp} in rectangular regions called <u>rodded regions</u>. The program determines either the critical cross-section $\Sigma_{rp}^{(crit)}$ or the critical top [*] boundary $y^{(crit)}$ of a rodded region for a wanted eigenvalue λ_c.

In both cases, naming V the parameter to determine, the iterative process is based on the following concepts:

a) For each rodded region are specified in input:
   - a value of the parameter V
   - a value $V^{(max)}$, corresponding to a maximum poisoning
   - a value $V^{(min)}$, corresponding to a minimum poisoning.

   If the parameter V means the boundary, $V^{(min)}$ and $V^{(max)}$ are respectively the lower and upper ordinate of the rodded region.

b) The control rods are inserted from bottom to top [*], that is the moving boundary advances in the negative sense of the y axis.

c) A Control List is given in input, that is the sequence of the rodded regions followed by the program in the criticality searches of this type. A region cannot be repeated in the list. Two or more regions listed consecutively in the control list can be grouped in the same "control bank" provided that they have the same input values of $V^{(min)}$ and $V^{(max)}$. The program does adjust the parameter V simultaneously in all regions belonging to the same control bank. The first objective of the search is to identify the rodded bank where the criticality can be reached, that is the bank in which the parameter V can take a value such that the K_{eff} is λ_c.

[*] This corresponds to a physical insertion from top to bottom, because the y axis is downwards oriented.

d) At time-step 0, the program evaluates the K_{eff} putting $V = V_{max}$ in all rodded regions of the Control List. If K_{eff} is $> \lambda_c$, the program stops; if $K_{eff} < \lambda_c$, the parameter V takes its actual value, specified in input, in all of the rodded regions, and the program initiates the search in the first bank of the Control List as explained in f).

e) At the successive time-steps, the program starts the criticality search beginning with the critical bank of the preceding time-step.

f) When the program acts on the parameter V of a bank given in the Control List, primarily calculates the K_{eff} for $V = V^{(max)}$. If $\lambda (V^{(max)}) > \lambda_c$, the program leaves this bank with a status of poison specified in g) and goes to the next bank.

If $\lambda (V^{(max)}) < \lambda_c$, the program calculates $\lambda (V^{(min)})$; if this is $< \lambda_c$, the program leaves and goes to the next bank. If $\lambda (V^{(min)}) > \lambda_c$, this means that in this bank the criticality can be attained varying V between $V^{(min)}$ and $V^{(max)}$, and this is accomplished by successive linear interpolations, as described in h).

g) When the program jumps from one bank to the next as indicated by the Control List, there are two alternatives about the value taken by the parameter V in the regions of the just abandoned bank:

1. Parameter V takes its actual input value,
2. Parameter V maintains its last assumed value, that is $V^{(max)}$ if the $K_{eff}(V^{(max)})$ was $> \lambda_c$ or $V^{(min)}$ if $K_{eff}(V^{(min)}) < \lambda_c$.

It will be referred to these two alternatives as to the alternatives A and B respectively.

h) When the critical rodded bank is identified ($K_{eff}(V^{(max)}) < \lambda_c$ and $K_{eff}(V^{(min)}) > \lambda_c$ contemporaneously), the program searches for the $V^{(crit)}$ interpolating between the two last values of V; the first guess $V^{(1)}$ is obtained interpolating between $V^{(min)}$ and $V^{(max)}$, the second guess $V^{(2)}$ between

$V^{(1)}$ and $V^{(min)}$, and successively:

$$V^t = V^{(t-1)} + \frac{\lambda_c - K_{eff}^{(t-1)}}{K_{eff}^{(t-1)} - K_{eff}^{(t-2)}} \left(V^{(t-1)} - V^{(t-2)} \right)$$

until a $V^{(crit)}$ is found such that:

$$\left| K_{eff} \left(V^{(crit)} \right) - \lambda_c \right| < \eta \qquad (2\text{-}3)$$

1) If the search is performed following the alternative B, the program stops when all banks of the Control List are exhausted.

On the contrary, when the Control List is exhausted in searches following the alternative A, the program goes back to the first bank of the List and restarts the control search with the alternative B.

All of the three different diffusion calculations described above (Straight K_{eff}, Dilute poison search, Rodded poison search) are performed by CONDOR by means of the modal expansion method.

Successively, the program evaluates the K_{eff} and the pointwise group fluxes by means of the finite differences. In the criticality searches (Dilute Poison search, Rodded Poison search), the critical parameter $V^{(crit)}$ found by the harmonics is not revaluated by the finite differences.

The flux guess for the finite differences is supplied by the flux expansion (2-4):

$$\varphi^1 (x,y) = \sum_{h=1}^{n_x} \sum_{k=1}^{n_y} \alpha_{hk}^1 X_h (x) Y_k (y) \qquad (2\text{-}4)$$

$$(l = 1, 2, \ldots ng)$$
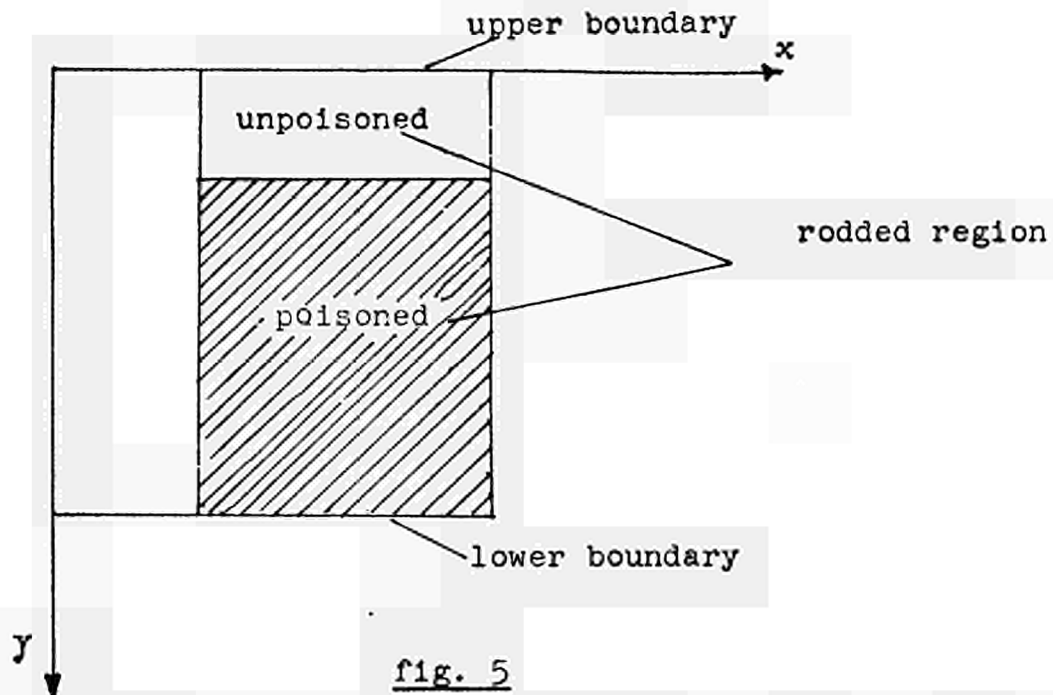
fig. 5

III. - <u>SELF-SHIELDING FACTORS AND MACROSCOPIC CROSS-SECTIONS</u>

As already stated, the self-shielding factors $\xi^{i,j,p}$ may be time-independent during the reactor lifetime or may vary with a polynomial law of the form:

$$\xi^{i,j,p} = \sum_{h=0}^{g_p} a_h^{i,j,l} \, (N^{j,p})^h$$

i = group index

j = isotope index   (3-1)

p = mesh element index

l = region index of p

$N^{j,p}$ = number density

The time-independent self-shielding factors or the polynomial coefficients $a_h^{i,j,l}$ may be specified for each group, isotope and region. It is to be noted that the concentration-dependent self-shielding factors are evaluated at each mesh element while the time-independent self-shielding factors may vary only from region to region.

The macroscopic cross-sections are calculated at each mesh element by the usual formulae:

$$D^{i,p} = [\ 3 \sum_{j=1}^{n_{is}} N^{j,p}\ \sigma_{tr}^{i,j,1}]^{-1} \qquad (3\text{-}2)$$

$$\Sigma_a^{i,p} = \sum_{j=1}^{n_{is}} N^{j,p}\ \xi^{i,j,p}\ \sigma_a^{i,j,1} \qquad (3\text{-}3)$$

$$\Sigma_R^{i,p} = \sum_{j=1}^{n_{is}} N^{j,p}\ \sigma_r^{i,j,1} \qquad (3\text{-}4)$$

$$\Sigma_f^{i,p} = \sum_{j=1}^{n_f} N^{j,p}\ \xi^{i,j,p}\ \sigma_f^{i,j,1} \qquad (3\text{-}5)$$

$$\nu\,\Sigma_f^{i,p} = \sum_{j=1}^{n_f} N^{j,p}\ \xi^{i,j,p}\ \nu\,\sigma_f^{i,j,1} \qquad (3\text{-}6)$$

$$E_f^{i,p} = \sum_{j=1}^{n_f} N^{j,p}\ \xi^{i,j,p}\ e^{i,j,1}\ \sigma_f^{i,j,1} \qquad (3\text{-}7)$$

where:

n_{is} = highest index of the isotopes

n_f = highest index of the "fuel"-isotopes

$N^{j,p}$ = number density of isotope j in mesh element p

$\sigma_{tr}^{i,j,1}$ = microscopic transport cross-section

$\sigma_a^{i,j,1}$ = microscopic absorption cross-section

$\sigma_r^{i,j,1}$ = microscopic removal cross-section

$\sigma_f^{i,j,1}$ = microscopic fission cross-section

$\nu\,\sigma_f^{i,j,1}$ = microscopic fission cross-section times the average number of neutrons per fission

$e^{i,j,1}$ = energy release (joule) per fission

For a non-diffusion (or logarithmic) region, the program sets:

$$\Sigma_a^{i,p} = c^{i,1}$$

setting to zero all other cross-sections, where $c^{1,1}$ is a positive constant, representing the logarithmic derivative on the contour of region 1, group 1.

We remind that a same microscopic cross-section can take different values in different regions (whence the superscript 1 applied to the microscopic cross-sections). These values can be supplied by the input data or can be calculated by the program itself.

IV. - DEPLETION EQUATIONS

CONDOR-3 is not bounded to a fixed chain of burnable isotopes, but can treat any isotopic chain specified in input (within the restrictions listed below).

However, in order to simplify the input work of the users who are not interested in special chains, a standard chain is incorporated in the program (cfr. Table 2).

The statement of the "burnable" isotopes (that is the isotopes, numbered from 1 to NUCL, whose number densities are time-dependent) is governed by the following rules:

a) An isotope i cannot have more than 2 parents by radiative capture and 1 parent by beta decay.
b) The isotopic transformation is downwards only, that is the isotope of index i can only produce, by radiative capture, decay, fission yields, isotopes of index $\geqslant$ i.
c) The fuel isotopes are neatly separated from the fission product isotopes: there is an integer NIF such that all isotopes with index i $\leqslant$ NIF are considered "fuels", and all isotopes with index i $>$ NIF are considered "fission products" or burnable poisons.

The equation governing the time behaviour of the generic fuel isotope f is:

$$\frac{dN_f}{dt} = - N^f (\lambda^f + \sum_{i=1}^{NG} \sigma_a^{i,f} \xi^{1,f} \varphi^1) + \lambda^{p3} N^{p3} + N^{p1} \sum_{i=1}^{NG} \sigma_c^{i,p1} \xi^{1,p1} \varphi^1 +$$

$$+ N^{p2} \sum_{i=1}^{NG} \sigma_c^{i,p2} \xi^{i,p2} \varphi^i \qquad (4\text{-}1)$$

$$(f = 1,2, \ldots NIF)$$

with: NG = number of groups

$\xi_i^{i,j}$ = self-shielding factor of isotope j, group i

φ^i = group i flux, averaged over the considered mesh element

λ^j = decay constant of isotope j

$\sigma_c^{i,j} = \sigma_a^{i,j} - \sigma_f^{i,j}$ = microscopic capture cross-section of isotope j

$p1,p2,p3$ = indexes of the capture parents 1 and 2, and decay parent respectively

The equation governing the generic fission product FP is:

$$\frac{dN^{FP}}{dt} = - N^{FP} \left(\lambda^{FP} + (1-\zeta) \sum_{i=1}^{NG} \sigma_c^{i,FP} \xi^{i,FP} \varphi^i \right) + \lambda^{p3} N^{p3} +$$

$$+ N^{p1} \sum_{i=1}^{NG} \sigma_c^{i,p1} \xi^{i,p1} \varphi^i + N^{p2} \sum_{i=1}^{NG} \sigma_c^{i,p2} \xi^{i,p2} \varphi^i +$$

$$+ \sum_{j=1}^{NIF} \gamma^{j \rightarrow FP} N^j \sum_{i=1}^{NG} \sigma_f^{i,j} \xi^{i,j} \varphi^i \qquad (4\text{-}2)$$

$$(FP = NIF + 1, NIF + 2, \ldots NIF + NIP)$$

where $\gamma^{i \rightarrow FP}$ is the yield of the fission product FP produced by fission of isotope i and ζ is a "lumping factor" ($0 < \zeta \leqslant 1$ for a lumped fission product or fission product aggregate).

The remaining isotopes, if any are included between NIF + NIP + 1 and NUCL, are considered neither fuels nor fission products; they satisfy equations of type (4-1), but are not fissionable.

According to the aforementioned rules, and equations (4-1) and (4-2), isotopic chains of practical use can be defined.

Two such sets, very simple, but commonly used in diffusion-depletion codes (10-13) are given in Tables 1 and 2.

The standard set, incorporated in CONDOR-3 is the one shown in Table 1.

TABLE 1

No.	Name	1st capture par.	2nd capture par.	Decay parent	Fission-able	Fission Product
1	U-235	-	-	-	yes	no
2	U-236	1	-	-	yes	no
3	U-238	-	-	-	yes	no
4	Pu-239	3	-	-	yes	no
5	Pu-240	4	-	-	yes	no
6	Pu-241	5	-	-	yes	no
7	Pr-149	-	-	-	no	yes
8	Sm-149	-	-	7	no	yes
9	I-135	-	-	-	no	yes
10	Xe-135	-	-	9	no	yes
11	Lumped Fission Products					
12	Boron	-	-	-	no	no
13	Burnable Poison	-	-	-	no	no

The isotopes of the Table 1 (standard option) excepted, the secular equations (4-1) and (4-2) are solved analytically. All numerical calculations are performed in double precision in order to minimize intermediate roundoff errors.

These roundoff errors could produce numerical criticalities in evaluating very small number densities (e.g. an initially zero number density after too short a time-step). A discussion of the method and its numerical drawbacks can be found in Appendix C.

Anyway, this method of solution does not set any upper limit
to the length of the time-steps.

TABLE 2

No.	Name	1st Capture par.	2nd Capture par.	Decay parent	Fissionable	Fission Product
1	Th-232	-	-	-	yes	no
2	Pa-233	1	-	-	yes	no
3	U-233	-	-	2	yes	no
4	U-234	2	3	-	yes	no
5	U-235	4	-	-	yes	no
6	U-236	5	-	-	yes	no
7	U-238	-	-	-	yes	no
8	Np-239	7	-	-	yes	no
9	Pu-239	-	-	8	yes	no
10	Pu-240	8	9	-	yes	no
11	Pu-241	10	-	-	yes	no
12	Pu-242	11	-	-	yes	no
13	Pr-149	-	-	-	no	yes
14	Sm-149	-	-	13	no	yes
15	I-135	-	-	-	no	yes
16	Xe-135	-	-	15	no	yes
17	1st group of fission products	-	-	-	no	yes
18	2nd group	--	-	-	no	yes
19	3rd group of fission products	-	-	-	no	yes
20	Boron-10	-	-	-	no	no
21	burnable poison	-	-	-	no	no

The depletion equations of the Table 1 are solved by approximate
methods which are much less time-consuming than the analytical
method yet giving results of comparable accuracy. These methods
do not set any lower limit to the length of the time-steps as
does the analytical method, but obviously it sets an upper limit
which is dependent on the power level and on the desired accuracy.

In any case any time-step can be further subdivided into an
arbitrary number of smaller substeps of equal length, in each
of which the time-dependent number densities, as well as the
concentration-dependent self-shielding factors, are recalcula-
ted but no flux renormalization takes place.

The details about the equations governing the standard chains
of Table 1 and their approximate solutions can be found in
ref. 15.

V. - PROGRAM OUTPUT

The program prints out all input data as soon as they are read
at any time-step (e.g. control data, library and self-shielding
data etc.)

Moreover, the following data are printed at each time-step:
- The region and composition average number densities,
- The weights (grams) of the burnable isotopes and the fuel en-
  richments in each composition,
- The number densities per mesh element in a tabular form, iso-
  tope by isotope (optional),
- If a shuffling is to be carried out, the preceding items are
  repeated for the new fuel arrangement,
- The macroscopic cross-sections per mesh element, namely the
  cross-sections of neutron and energy production, the diffusion
  coefficient, the absorption and removal cross-sections (optional),
- The successive approximations of λ_{max} (by the modal expansion
  method), for any level of poisoning in the criticality searches,
- The eigenvectors α^1 corresponding to the last criticality search
  iteration after satisfying the eigenvector convergence criterium,
- The more significant results of the $\lambda_{max} = K_{eff}$ calculation by
  the finite difference method,
- The volume, power, average power density, fission neutron pro-
  duction and average density of each region,
- The flux weighted macroscopic cross-sections for each region
  and group,
- The integrated and average flux and some reaction rates for each
  region and group,

- The last two items are repeated for the rodded poison regions, if any,
- Some quantities relating to the power on the mesh stripes (channels) parallel to the x or y axis, that is to the stripes of the reactor rectangular domain bounded by two successive rows or columns,
- The average power density per mesh element in a tabular form (optional),
- The volumes per mesh element in the same tabular form (optional),
- The ratio between the average power density at each mesh element and the <u>core</u> average power density ("peak-to-average values of the power density) in a tabular form,
- The point fluxes for each group, and the peak-to-average values of the thermal flux (optional),
- The average fluxes per mesh element for each group (optional), These latter values, normalized to the actual reactor power, are used in the calculation of new time-dependent number densities at each mesh element.

The numerical integrations of a function defined at each mesh point (e.g. the group fluxes) are carried out by approximate formulae which can be found in Ref. 14, with many other details concerning the program output.

VI. - <u>PROGRAMMED STOPS</u>

The program stops and prints an appropriate message when one of the following circumstances happens:

- Inconsistency in the input data,
- If both the diffusion coefficient and the logarithmic derivative are zero for a same group and mesh element,
- If some macroscopic cross-section is negative,
- If the maximum number of iterations by the modal expansion method is exceeded,
- If the criticality cannot be maintained,
- If the maximum number of outer iterations (finite difference method) is exceeded,
- If the K_{eff}, recalculated by the finite difference method, dif-

fers from the wanted eigenvalue λ_c by more than an input va-
lue (e.g. 1%), after a criticality search has been carried
out. In this case the problem can be restarted using the lo-
gical unit 10 (See Chap. XIV).

VII. - UNIT SYSTEM

- The microscopic cross-sections are to be specified in barn,
- The number densities in Szilard = 10^{24} nuclei/cm^3,
- The macroscopic cross-sections are in cm^{-1},
- The time in hours,
- The energy in joule,
- The power in watt,
- The flux in neutrons/cm^2/sec,
- The weight in gram,
- The length in cm,
- The power density in watt/cm^3.

VIII. - PROGRAM ORGANIZATION

CONDOR-3 is an "overlay" program constituted by the following
links (the decks constituting the link, system library routines
excluded, are shown in parentheses).

- LINK0 (MAIN, SSVAL, MAFLC3, GRIFØ3, EXPRI, EXPAND)
- LINK1 (AINSUB)
- LINK2 (BINSUB, DELTAX)
- LINK3 (CINSUB, MAPC3)
- LINK4 (DINSUB).
  The function of these four links is to read, check, reorder and
    print the input data. Moreover, the program prints out three
    reactor pictures, one for the regions, one for the initial
    compositions and one for the rodded regions, and writes on
    the pertinent unit the data for the RESTART.
- LINK5 (EINSUB)
- The number densities of the time-dependent isotopes are prin-
    ted and the fuel shuffling is carried out.
- LINK6 (SETCAL)
  The self-shielding factors and the macroscopic cross-sections
    are calculated at each mesh-element (only if the library data
    are available from the input)

- LINK7:
  The object of this link is alternative to the previous one
  and is to calculate the macroscopic cross-sections when the
  library data are to be supplied (calculated) by the program
  itself. The decks are not indicated, for this link can be
  shaped at will of the code's user within rather wide limits.

- LINK8 (HARCAL):
  The macroscopic cross-sections per mesh-element are printed
  (optional) and the modal expansion calculation is set up.

- LINK9 (CRØCØ3, FLØRA, IØLE, IRIS, LØTØ, CLIVIA, INCHA):
  The criticality search by the modal expansion method is car-
  ried out.

- LINK10 (EXHARM, IPPØ):
  The point fluxes are calculated by the modal expansion method
  and saved as a first approximation to the finite difference
  calculation. Moreover, if a boundary search is dealt with,
  the moving boundary is settled on the nearest mesh-line.

- LINK11 (RØDØN):
  The coefficients for the finite difference method are calcu-
  lated.

- LINK12 (NEWCAL, CINDER):
  The K_{eff} and the point fluxes are calculatee by the finite dif-
  ference method (the control parameters, such as the cross-sec-
  tion or the boundary of a poison, remain as calculated by the
  modal expansion method).

- LINK13 (ELPRI):
  The program calculates the normalization factor, the integrated
  fluxes per mesh-element, and the power, the average power den-
  sity, the neutron production per region (these last results
  are also printed).

- LINK14 (WESEC):
  The flux weighted macroscopic cross-sections, the flux integrals
  and several neutron reaction rates are calculated and printed.

- LINK15 (ELFI):
  The program calculates and prints out some quantities relating

to the power on the strips (channels) parallel to the coordinate axes, the average and the peak-to-average values of the power density at each mesh-element. Moreover, it prints out the point fluxes for each group, the peak-to-average values of the thermal flux and the average fluxes for mesh-element (optional). These latter are used in the depletion calculation.

- LINK16 (REDENS, SINBUR, DBURN, SUBDEP, BBB, SPLIT):

  The depletion calculation, that is the calculation of the new values of the time-dependent number densities which are burnt or built up, is carried out at each mesh element, recalculating the self-shielding factors at each substep.

IX. - INPUT DATA PREPARATION

Some remarks of general character must be premised:

A) The maximum number of bytes available to the programmers on the IBM 360/65 is not yet definitely settled and is likely to undergo changes in a near future. Therefore, in view of possible future restrictions of the machine available storage, the limitations of CONDOR-3 (e.g. the maximum number of groups, of regions, of mesh points and so on) cannot be specified on this report, so they are indicated parametrically.

The numerical values of these parameters, for the present versions of CONDOR-3 now running at Ispra, are given in Appendix C, so that future changes of the program restrictions will only imply the uptodating of Appendix C.

B) The correspondence between the logical peripheral storage units used by CONDOR-3 and the physical units of the IBM 360/65 system (tapes, disks or drums) is not strictly determined but is left widely to the user's choice (see Appendix B).

The input data have been divided into 66 card sets (one set may contain one or more cards):

1 - TITLE

One card (18A4):
Col 1-56   - Title of the problem (any alphameric characters)
Col 57-72 - Leave blank these columns: they are used only in

RESTART problems

-2 - GENERAL PARAMETERS

One card (24I3):

Col 1- 3   NG (≤KGD) = number of groups

Col 4- 6   NR (≤KREG) = number of regions

Col 7- 9   NCMP (≤KCD) = number of compositions

Col 10-12   NPX (≤KXD) = number of columns (the columns are rumbered rightwardly from 1 to NPX)

Col 13-15   NPY (≤KYD) = number of rows (the rows are numbered downwardly from 1 to NPY)

    N.B. - It must be NPX·NPY ≤ KPD except for diagonally symmetric cases (IDIAG = 1 on card no. 3, columns 16-18) which have to fulfill only the broader condition:

$$(NPX + 1) \cdot NPX/2 \leqslant KPD$$

Col 16-18   NIS (≤KIS) = last isotope number

Col 19-21   NUCL (≤KIV) = number of time-dependent isotopes. The time-dependent isotopes are numbered from 1 to NUCL.

Col 22-24   NIF (≤KIF) = number of fuel isotopes. The fuel isotopes are numbered from 1 to NIF (≤NUCL)

Col 25-27   NIP (≤KIP) = number of fission products. The fission products are numbered from NIF + 1 to NIF + NIP (it must be NIF + NIP ≤ NUCL)

If the field 19-21 (NUCL, is zero or left blank, the program automatically assumes the standard nuclide chains of Table 1, with NUCL = 13, NIF = 6, NIP = 5 and 2 burnable poisons.

3 - OPTIONS

One card (24I3):

Col 1- 3   NGRINT (≤KRINT) = last time-step. The time steps are numbered starting from 0.
    One time-step encompasses both a depletion and a diffusion calculation. At the time-step No. 0, the depletion calculation is replaced by the mere specification of the initial number densities and therefore the diffusion calculation is carried out at the

beginning   life conditions.

Col 4- 6   NRUN = last time-step to be completed (depletion + diffusion calculation) in the present run (NRUN ≤ NGRINT). If NRUN = NGRINT, the program ends just after the diffusion calculation of time-step NRUN.

If NRUN < NGRINT, the program ends just after the calculation of the time-step (NRUN + 1) number densities and the RESTART data saving and before the reading of new data (bucklings, control data, library data, self-shielding factors), the fuel shuffling (if any) and the diffusion calculation.

Col 7- 9   JGX geometry indicator for the left side of the reactor (coincident with the y axis). See fig. 6.

JGX = 1   x-y geometry, symmetry (zero derivative) condition at x = 0

= 2   x-y geometry, zero flux condition at x = 0

= 3   cylindrical geometry (x = r, y = z). The cylinder axis is at x = 0.

Col 10-12   JGY geometry indicator for the top side of the reactor (coincident with the x axis). See fig. 6.

JGY = 1   symmetry condition at y = C

= 2   zero flux condition at y = 0

Col 13-15 IPCF = 0   the flux first approximation, at time step 0, is supplied by the program (i.e. is calculated by the modal expansion method),

= 1   the flux first approximation is supplied by a data set (e.g. a magnetic tape). See Chap. XIII,

= 2   both the flux first approximation and the overrelaxation factors are supplied by the same data set. This option, however, should be checked only if the flux unit has been prepared during the execution of the same diffusion calculation (see Chap. XI). In the opposite case, let the overrelaxations factors be calculated by the program itself.

Col 16 - 18 IDIAG = 1 The reactor is symmetric about the
main diagonal (oriented from the top
left corner towards the bottom right
one)

= 0 is not symmetric
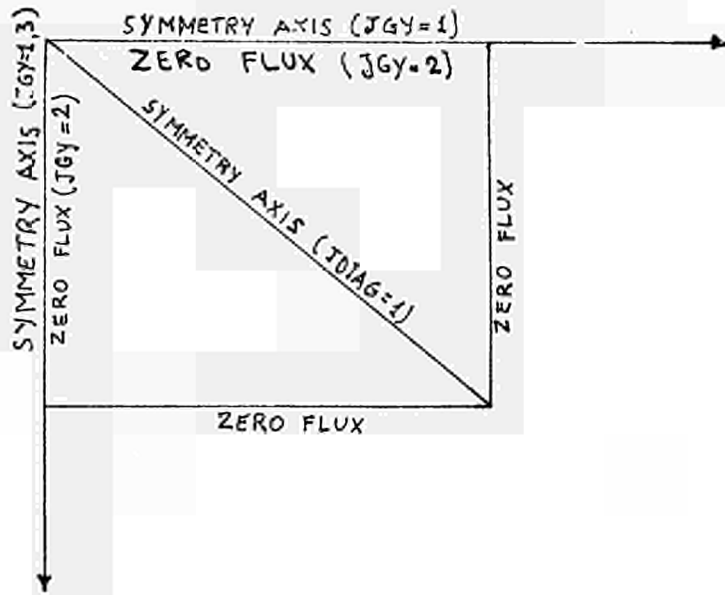
Fig. 6

Col 19-21 IBK = 0 group-independent buckling

= 1 group-dependent buckling

Generally speaking, the transverse buckling is as-
sumed to be region-dependent.

Col 22-24 LIBCAL = 0 the library data (microscopic cross-sec-
tions, fission yields) and the self-shield-
ing data must be supplied by cards

= 1 the aforementioned data are supplied (i.e.
calculated at each time-step) by the pro-
gram

Col 25-27 NAX ($\leqslant$KAX) = number of harmonics (wave equation ei-
genfunctions) along the x axis. See (1-6).
If a criticality search is not dealt with, the value
NAX = 1 is advised. On the contrary, if this field
is blank or zero, the program sets NAX = 7.

Col 28-30 NAY ($\leqslant$KAY) = number of harmonics along the y axis.
See (1-7). As above, the value NAY = 1 is advised

for a straight K_{eff} calculation (no criticality search) and NAY = 7 is the standard value if a blank or a zero value is punched.

4 - MISCELLANEOUS

One card (7E10.5):

Col 1-10 DEL = δ = pointwise convergence criterion for the finite difference calculation of the K_{eff} and fluxes:

$$\frac{\bar{\lambda} - \lambda}{2} \leqslant \delta$$

(The same value is used as an eigenvector convergence criterion in the modal expansion calculation)

Col 11-20 HERR = ε_H = allowed error in the modal expansion calculation:

$$\left| \lambda_H - \lambda_D \right| \leqslant \varepsilon_H$$

where λ_H and λ_D are the eigenvalues (K_{eff}) calculated respectively by the modal expansion and by the finite differences. If this field is left blank, the program sets HERR = 0.01.

If, at any time-step, a criticality search does not meet the above condition, the program will give a warning message and will stop at the end of the same time-step. If required, the problem could be continued with a RESTART procedure (see Chap. XIV), eventually after modifying the value of HERR (see Chap. X).

5 - LIST OF TIME-STEPS WITH NEW SPECIFICATIONS FOR POINTWISE EDIT

One or more cards (24I3), present only if NGRINT > 0, for the specification of the vector NEDIT(K), K = 1, NGRINT, where:

NEDIT(I) = 1 the program reads new details as for the pointwise edit, after the calculation of the time-step I number densities,

= 0 the aforementioned data are not read but they
remain the same as in the previous time-step.

6 - LIST OF TIME-STEPS WITH NEW BUCKLINGS

One or more cards (24I3) present only if NGRINT > 0, for
the specification of the vector NBK(L), L = 1, NGRINT,
where:

NBK(I) = 1 the program reads new bucklings (by region and,
eventually, by group) after the depletion cal-
culation of the time-step I,

= 0 new bucklings are not to be read at time-step I.

7 - LIST OF TIME-STEPS WITH NEW CONTROL DATA

One or more cards (24I3), present only if NGRINT > 0, for
the specification of the vector NCT(K), K = 1, NGRINT,
where:

NCT(I) = 1 the program reads new control data after the de-
pletion calculation of the time-step I,

= 0 new control data are not read.

8 - LIST OF TIME-STEPS WITH A NEW LIBRARY

One or more cards (24I3), present only if NGRINT > 0, for the
specification of the vector NTL(K),K = 1, NGRINT, where:

NTL(I) = 1 the program reads new library data after the de-
pletion calculation of the time-step I,

= 0 no library data are read. All library data keep the
last specified values in the previous time-steps.

9 - LIST OF TIME-STEPS WITH NEW SELF-SHIELDING DATA

One or more cards (24I3), present only if NGRINT > 0, for the
specification of the vector NTS(K), K = 1, NGRINT, where:

NTS(I) = 1 the program reads new self-shielding data after the
depletion calculation of the time-step I,

= 0 no self-shielding data are read.

N.B. 1) The card sets 8 and 9 should be missing if:
the option LIBCAL = 1 on col 22-24 of card no. 3 (cal-
culation of the microscopic data by the program itself)
is checked;

2) <u>All data</u>, for which the card sets 5,6,7,8,9 allow new values to be read during the reactor lifetime, <u>are automatically required by the program at the time-step 0</u>, that is at the beginning of the problem.

10 - LIST OF TIME-STEPS WITH SHUFFLING

One or more cards (24I3), present only if NGRINT > 0, for the specification of the vector NFU(K), K = 1, NGRINT.

NFU(I) = 1 the program carries out a fuel shuffling before the time-step I diffusion calculation. The details of each shuffling will be given by the card set no. 65,66,

       = 0 no shuffling at time-step I.

11 - SUBSTEP DIVISION

This set of one or more cards (24I3), present only if NGRINT > 0, specifies the subdivision of each time-step I into NSA(I) substeps of equal length. The first card contains:

col 1-3 NSA(1) = number of substeps into which the time-step 1 is divided,

col 4-6 NSA(2) = ...

and so on, up to NSA(NGRINT)

12 - TIME-STEP LENGTHS

This set, present only if NGRINT > 0, is made up of one or more cards (7E10.5). On the first card:

col 1-10 DELTAT(1) = length (in hour) of the time-step 1,
col 11-20 DELTAT(2) = same for time-step 2.

.....

and so on, up to DELTAT(NGRINT), using as many cards as necessary.

13 - TIME-STEP POWERS

This set contains one or more cards (7E10.5). The first card is:

col 1-10 W(1) = power (watt) for time-step 1,

col 11-20 W(2) = power (watt) for time step 2, and so forth, up to W(NGRINT)

If a straight diffusion-calculation (NGRINT=0) is dealt with, only one card (7E10.5) should be supplied.

col 1-10 W = power (or any arbitrary normalization factor) for the flux normalization.

It is understood that, for an x-y plane reactor, only the power per unit transverse height (watt/cm) is to be given.
Moreover, if the reactor is symmetric about one or both coordinate axes (cylinder revolution axis excluded), only 1/2 or, respectively, 1/4 of the actual reactor power must be supplied.

Finally, we remind that, at any time step K, the fluxes are normalized in such a way that:

$$\sum_{i=1}^{G} \int_{0}^{L_x} \int_{0}^{L_y} E_f^i \, \varphi^i(x,y) \, \rho(x) \, dx \, dy = W(K)$$

where L_x and L_y are the lengths of the sides of the rectangular domain under investigation, E_f^i is given by (3-7) and:

$$\rho(x) \begin{cases} = 1 \text{ for a plane reactor} \\ = 2_\pi x \text{ for a cylindrical reactor} \end{cases}$$

14 - χ^i SPECIFICATION

One card (7E10.5) containing the fission spectrum integrals χ^i (i = 1,2,...NG) for all groups.
It must be $\chi^i \geqslant 0$ and $\sum_{i=1}^{NG} \chi^i > 0$.

15 - Δx - MESH SPECIFICATION (along the x-axis)

Each card is divided into 6 parts [6(E9.3,I3)] of 12 columns each. Each part is constituted by a floating point field (E9.3) allotted to a value of Δx(= distance in cm between two successive columns of mesh points) and by a fixed point field (I3) for the column number ("termination point") up to which the previous value of Δx is extended. All these integer numbers must be specified in an increasing order and the last one must be NPX.

This input pattern will be given the name of "F sequential expansion form", and, later on, will be used for the specification

of other floating variables.

16 - Δy-MESH SPECIFICATION (along the y-axis)

The same input pattern as before is applied. The last termination point must be coincident with NPY.

N.B. - This set of cards must be omitted in diagonal symmetry problems (IDIAG = 1 on card No. 3)

17 - COMPOSITION - REGION CORRESPONDENCE

Each card is divided into 8 parts [8(2I3,3X)] of 9 columns each. Each part is constituted by a fixed point field (I3) rented to a composition number, another fixed point field (I3) for a "termination point", that is, in this card set, the region number up to which the previous composition is extended and, finally, a 3 column blank field (3X).

The integer numbers representing termination points must be given in an increasing order and the last one must coincide with NR. This input pattern will be namend "I sequential expansion form" and will be used for the specification of other integer variables. The compositions are numbered according to the order in which the correspondent number densities are specified (see set No. 23;-NUMBER DENSITIES PER COMPOSITION).

18 - REGION DESCRIPTION

The geometric specification of the regions is made through an input pattern which commonly is given the name of "overlay expansion method".
The lay-out of the regions is input by a sequential specification of rectangular blocks of a given region index.
Any of such blocks can cover totally or partially the preceding ones. Each rectangle of the mesh grid ("mesh element") takes the region index of the last occurring block which includes this rectangle. The specification of the rectangular blocks is carried out by inputing as many sets of 6 integers:

col   1- 3 i_r = region index of the block
col   4- 6 C_1 = left column bounding the block

col 7- 9 C_2 = right column bounding the block ($1 \leqslant C_1 < C_2 \leqslant NPX$)

col 10-12 r_1 = upper row bounding the block

col 13-15 r_2 = lower row bounding the block ($1 \leqslant r_1 < r_2 \leqslant NPY$)

col 16-18 these columns are ignored by the program

The specification is continued in columns 19-33, 37-51 and 55-69, using as many cards as necessary.

19 - BLANK CARD

A blank card marks the end of the region lay-out

20 - SPECIFICATION OF THE ISOTOPIC CHAINS

This card set, present only if the field 19-21 (NUCL) of card No.2 is not blank or zero, is constituted by NUCL cards (2A4,3I4,3E10.5), one per each time dependent nuclide, following the order of the isotope index from 1 to NUCL.

col 1- 8 Isotope name (any alphameric characters)

It is suggested that the name start at column 1

col 9-12 N_{C_1} = index of the first capture parent

col 13-16 N_{C_2} = index of the second capture parent

col 17-20 N_β = index of the decay parent

col 21-30 λ = decay constant (sec^{-1})

col 31-40 Atomic weight (g/mole)

col 41-50 ζ = "lumping factor" ($0 \leqslant \zeta \leqslant 1$)

If a fissionable nuclide or an individual fission product is being described, this field should be left blank. On the contrary, for a lumped fission product, it could be ζ = 1.0 or at least, $\zeta > 0$.

We recall that the integers N_{C_1}, N_{C_2}, N_β must be less than the index of the isotope to which they are associated.

21 - COMPOSITION DATA PARAMETERS

One card (24I3) containing the following data items:

col 1- 3 NEC = number of isotopes whose number densities are specified per composition ($0 \leqslant NEC \leqslant NIS$)

col 4- 6 NEMIR = Number of isotopes whose number densities are given per region ($0 \leqslant NEMIR \leqslant NUCL + 1$)

col 7- 9 NSTEP = 0 no reading of atomic densities from the

RESTART unit.

> 0 the atomic densities of the burnable isotopes per mesh element are supplied by the RESTART unit (see Chap. XIII).More precisely, NSTEP is the time-step number of a previous calculation at which the number densities to be read were recorded on the RESTART unit (see Chap.XII). In this case, the number of rows and columns (and hence of mesh elements) and the number of isotopes must be the same in both the present and the previous calculation.

col 10-12 NRC = number of compositions for which logarithmic derivatives are specified. (0≤NRC≤NCMP)

col 13-15 IPUN=1 the region averaged atomic densities (calculated by the program) of the first NUCL+1 isotopes are punched on cards (1P7E10.4) at each time-step, before the shuffling.
These punched cards can be used to input number densities per region in other problems.

IPUN=0 no punched cards.

The number densities of the time-independent isotopes, except the first (of index NUCL+1), can be specified only by composition. Instead the number densities of the first NUCL+1 isotopes (that is the time-dependent isotopes plus the immediately next one), can be specified either by composition or by region or both. Also, except for the isotope NUCL+1, they can be specified by mesh element through the RESTART unit. If this last option is checked, it is yet possible to specify number densities per composition but, as for the burnable isotopes, they can be fed into the reactor "as fresh fuel" only by a shuffling procedure (see card set No.65). Moreover, only the number densities of the isotope NUCL+1 can be specified by region. Finally, we warn that, after the reading of the relevant number densities, all information on the RESTART unit will be lost.

22 - LIST OF ISOTOPES WITH NUMBER DENSITIES GIVEN PER COMPOSITION

One or more cards (24I3), present only if NEC>0, specifying the NEC isotopes with number densities given per composition.

23 - NUMBER DENSITIES PER COMPOSITION

This set is present only if NEC>0.

For each of the NEC isotopes specified in 22, one or more cards (7E10.5) containing NCMP number densities, one for each composition.

Start a new card for a new isotope.

24 - LIST OF ISOTOPES WITH NUMBER DENSITIES GIVEN PER REGION

One or more cards (24I3), present only if NEMIR>0, specifying the NEMIR isotopes with number densities given per region.

25 - NUMBER DENSITIES PER REGION

This set is present only if NEMIR>0.

For each of the NEMIR isotopes specified in 24, one or more cards (7E10.5) containing NR (= number of regions. See col 4-6 of card No.2) number densities, one for each region.

Start a new card for a new isotope.

If overlapping occurs, the specification per region overrides that per composition (contained in card sets 22, 23).

26 - LIST OF COMPOSITIONS WITH LOGARITHMIC DERIVATIVES

One or more cards (24I3), present only if NRC>0, specifying the NRC compositions which have logarithmic derivatives.

27 - LOGARITHMIC DERIVATIVES

NRC cards (7E10.5), one for each of the NRC compositions specified in 26, containing the logarithmic derivatives c^i for all groups (i= 1,2,...NG). If $c^i > 0$, the composition is a "rod material" with respect to the group i; in this case the flux φ^i is not evaluated at the mesh-points inside the composition but satisfies, on the boundary points, the condition:

$$D^i \frac{\partial \varphi^i}{\partial n} = - c^i \varphi^i$$

If $c^i = 0$, the composition is a normal diffusion material with respect to group i.

28 - FUEL TEMPERATURE

Only if the microscopic data are to be calculated by the program (LIBCAL=1 in col 22-24 of card No. 3), supply the fuel temperature per region in F sequential expansion form (see 15) with each termination point being a region number. The final termination point must be equal to NR (= number of regions).

29 - MODERATOR TEMPERATURE

Only if LIBCAL=1, supply the moderator temperature per region as stated in 28.

30 - BUCKLING

The transverse square bucklings are required by the program at the beginning of a problem (time-step No. 0) and at any time-step I such as NBK(I)=1 (see 6 - LIST OF TIME STEPS WITH NEW BUCKLINGS).
Supply the transverse square buckling per region in F sequential expansion form with each termination point being a region number.
If a group dependent buckling is required (IBK=1 in col 19-21 of card No.3), the previous expansion specification must be repeated NG times, starting a new card for a new group.

In cylindrical geometry, although not compulsory, the best policy is to put IBK=0 and supply one blank card as card set 30.

CONTROL DATA

The data, included in the card sets No. 31, 32, 33, 34, 35, 36 are read by the program at the beginning of a problem (time-step No.0) and at any time-step I such as NCT(I)=1.
(See 7 - LIST OF TIME STEPS WITH NEW CONTROL DATA).

31 - CONTROL OPTIONS

One card (24I3)

col 1- 3 IC = 1 straight K_{eff} calculation

= 2 criticality search by means of the dilution factor ⊚

= 3 criticality search by means of a region-wise

programmed poison variation

col 4- 6 NCØN = total number of rodded regions (NCØN ≤ KCØN)

col 7- 9 NC = maximum number of criticality iterations (IC= 2,3). Leave blank or zero if IC=1

col 10-12 JZX≠0, the control parameter of the regionwise programmed search (IC=3) is the poison cross section Σ_{rp}

         =0, the control parameter of the same search (IC=3) is the boundary

col 13-15 IRR=1, the rodded poison search is carried out following the alternative A

         =2, the rodded poison search is carried out following the alternative B (see Rodded poison search in II-3)

If IC=1,2, the columns 10-12 and 13-15 are left blank or zero.

32 - CONTROL PARAMETERS

One card (7E10.5)

col 1-10 AUT = K_c = wanted K_{eff}, in the criticality searches (IC=2=3)

          = minimum attainable K_{eff}, in the straight burn-up calculations (IC=1).

          If, at some time-step, the K_{eff} becomes < AUT, the program stops.

If AUT is zero or left blank, the program automatically sets AUT=1.

col 11-20 ETA = η = convergence criterion for the criticality searches. The problem is converged when:

$$\left| K_{eff} - K_c \right| < \eta$$

Generally it is: $\eta = 10^{-3}$

Leave blank ETA if IC=1

col 21-30 TV = ϑ = actual value of the dilution factor if IC = 1,3

          = first guess of the dilution factor (ϑ^0) if IC=2

The following two parameters are given only if IC=2

col 31-40 TMAX = Θ^{max} = upper limit of the dilution factor ϑ

col 41-50 TMIN = Θ^{min} = lower limit ($\Theta^{min} < \Theta < \Theta^{max}$)

33 - GROUP FRACTIONS OF DILUTED POISON

One card (7E10.5)

col 1-10 TD(1) = t_d^1 = fraction of diluted poison in group 1

col 11-20 TD(2) = t_d^2 = fraction of diluted poison in group 2

. . . .

34 - DILUTED POISON CROSS SECTIONS

Each card 6 (E9.3,I3) of this set can contain up to 6 couples (Σ_{dp},Nr), where Σ_{dp} is the macroscopic absorption cross section of the diluted poison, applied to all regions up to Nr.

The values of Nr must be in increasing order, and the last one must coincide with NR (F sequential expansion form).

If only one blank card is present in this set, Σ_{dp} is zero in all regions.

35 - DESCRIPTION OF THE RODDED REGIONS

This set is present only if NCØN >0.

The rodded regions are rectangular, and must not overlap each other.

When a rodded poison criticality search is performed (IC=3 on card 31) the rodded regions can be grouped in banks and the control parameter (Σ_{rp} or the boundary) is regulated simultaneously in all regions belonging to a same bank.

The specification of the rodded regions is made through NCØN cards (5I3,3E10.5,2A4). Each contains:

col 1- 3 p_{x1} = column constituting the left side of the region

col 4- 6 p_{x2} = " " " right " " " "

col 7- 9 p_{y1} = row " " top " " " "

col 10-12 p_{y2} = " " " bottom " " " "

col 13-15 p_{yv} = blank, if IC$\neq$3 or JZX$\neq$0.

= the row delimiting the poison, in the rodded poison search. It means that, when the region under consideration is not involved in the search, only the part of the region comprised between p_{y2} and p_{yv} is actually occupied by the poison (Cf. also Chap. II-3).

It must be $p_{y1} \leqslant p_{yv} \leqslant p_{y2}$

The content of the next three fields of the card depends on the type of the search:

1) <u>In a search of Σ_{rp}</u> (IC=3. JZX$\neq$0)

col 16-25 Σ_{rp}^{max} = maximum permissible value of Σ_{rp}

col 26-35 Σ_{rp} = actual value of Σ_{rp} (its role is analogous to that of p_{yv}, when the region is not involved in the search)

col 36-45 Σ_{rp}^{min} = minimum permissible value of Σ_{rp}

11) <u>In any other cases</u>

col 16-25 Σ_{rp} = actual value of Σ_{rp}

col 26-35 blank

col 36-45 blank

The content of the next two alphameric fields (2A4) is considered by the program <u>only in a rodded poison search</u>. In this case it is:

col 46-53   If this field is not blank (e.g. contain the words BANK 1), the region under consideration is the first of a control bank.

If the field is blank, the region belongs to the same bank of the preceding one.

In this last case, the values of p_{y2}, p_{y1} or Σ_{rp}^{min} Σ_{rp}^{max} in the boundary and in the Σ_{rp} search respectively, should be the same for all the regions belonging to the same bank.

Should this identity be not verified, the bank takes these values from the first region of the bank.

36 - GROUP FRACTIONS OF RODDED POISON

One card (710.5), present only if NC$\emptyset$N > 0:

col 1-10 TR(1) = t_r^1 = fraction of the rodded poison in group 1

col 11-20 TR(2) = t_r^2 = fraction of the rodded poison in group 2

. . . .

SPECIFICATIONS FOR THE POINTWISE EDIT

The data included in the card sets No. 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, are read by the program at the beginning of a problem (time-step Q) and at any time-step I such as NEDIT(I) = 1.

At the time-step 0, all these data are initialized to zero, whereas at the successive time-steps they are initialized to the values of the previous time-steps.

Thus each new reading of these data provides a modification, partial or total, of the details for pointwise edit with respect to the previous time-step.

37 - EDIT PARAMETERS

One card (24I3):

col 1- 3   If this field is not zero or blank, the card set 38 must be present

col 4- 6   If not zero or blank, the card set 39 must be present

col 7- 9   The same for the card 40

col 10-12 The same for the card 41

. . . .

and so on, each consecutive 3 column field until 24-27 being associated to each consecutive card set until 46.

38 - NUMBER DENSITIES BY MESH ELEMENT (BEFORE SHUFFLING)

One or more cards (24I3), present only if the field 1-3 of the previous card is not zero, for the specification of the vector NDEN1(J), J=1, NUCL, where:

NDEN1(J)   = 1 the elementwise number densities of the burnable isotope J, before the fuel shuffling, are printed in a tabular form;

= 0 they are not.

39 - NUMBER DENSITIES BY MESH ELEMENT (AFTER SHUFFLING)

One or more cards (24I3), present only if the field 4-6 of card No.37 is not zero, for the specification of the vector NDEN2(J), J=1, NUCL, where:

NDEN2(J)   = 1 the elementwise number densities of the burnable isotope J, after the shuffling, are printed in a tabular form;

= 0 they are not.

40 - DIFFUSION COEFFICIENTS

One card (24I3), present only if the field 7-9 of card No.37 is

not zero, for the vector NDIF(I), I=1, NG, where:

NDIF(I) = 1 the diffusion coefficients of the group I are
printed in tabular form (by mesh element);

= 0 no diffusion coefficient is printed for group I.

41 - ABSORPTION CROSS-SECTIONS

This card (24I3) is present only if the field 10-12 of card 37
is not zero. Follow the same procedure as in 40, to have the
macroscopic absorption cross-sections printed.

42 - REMOVAL CROSS-SECTIONS

The same as in 40 for the printing of the macroscopic removal
cross-sections of each group.

43 - NEUTRON PRODUCTION CROSS-SECTIONS

The same as in 40 for the neutron production cross-sections ($\nu\Sigma_f$)
group by group.

44 - ENERGY PRODUCTION CROSS-SECTIONS

The same as in 40 for the energy production cross-sections.

45 - POINT FLUXES

The same as in 40 for the printing of the point fluxes group by
group. Moreover, if 1 is punched on the field (NG+1), the program
prints the peak-to-average at values of the thermal flux (i.d.
the ratio between the thermal flux at each point and the average
thermal flux in the diffusion region).

46 - AVERAGE FLUXES BY MESH-ELEMENT

The same as in 40 for the printing of the average fluxes by mesh-
element (always arranged in a tabular form). Moreover, if 1 is
punched on the fields (NG+1) and (NG+2), the program prints
respectively the average power densities and the volumes by mesh-
element.

The peak-to-average values (i.d. the ratios between the average
power density at each mesh-element and the core average power den-
sity) are always printed.

LIBRARY DATA

The library data, included in the card sets no. 47, 48, 49, 50, 51, 52, 53, 54, 55, are read by the program at the beginning of a problem (time-step No. 0) and at any time-step K such as NTL(K) = 1.

At the time-step 0, all the library data are initialized to zero, whereas at the successive time-steps they are initialized to the values of the previous time-step.

Thus the reading of new library data provides a modification, partial or total, of the library data of the preceding time-step.

47 - NUMBER OF LIBRARY SETS

One card (24I3), containing:

col 1- 3 NLIB = number of library sets. More than one library set can be specified. The library sets are numbered in the same order as they are specified and a library set number must be assigned to each reactor region (see card set 55). NLIB cannot be zero at the beginning of the problem (time-step 0). At a next time-step, NLIB=0 means that the library data remain exactly the same as in the previous time-step.

The succession of the card sets 48, 49, 50, 51, 52, 53, 54 must be repeated NLIB times (it is missing if NLIB=0).

We warn that, except for the time-step 0, NLIB, if not zero, must equal the last specified value of the same parameter, that is the value of NLIB cannot be changed throughout the calculation, and that, if NLIB > 0, each library set must be represented at least by one blank card (namely the card No. 48).

It must be: NLIB.NG.NIS ≤ KIBDA

NLIB.NG.NIF ≤ KSIGF

NLIB.NIF.NIP ≤ KYLDE

48 - LIBRARY PARAMETERS (24I3)

col 1- 3 NLL = number of isotopes for which the cross-sections σ_{tr}, σ_a, σ_r are given.

col 4- 6 NFL = number of isotopes for which the cross-sections
σ_f, $\nu\sigma_f$, e are given.

col 7- 9 NYL = number of isotopes for which the fission yields
are given.

49 - LIST OF ISOTOPES WITH σ_{tr}, σ_a, σ_R

This set, present only if NLL > 0, is made of one or more cards
(24I3) containing the indexes of the NLL isotopes for which σ_{tr},
σ_a, σ_r must be specified.

50 - VALUES OF σ_{tr}, σ_a, σ_r

For each isotope declared in the list 49, there must be the fol-
lowing three cards:

a) card for the transport cross-sections σ_{tr}

    col 1- 8 Isotope name (it is suggested to start from column 1).
               This name is used for the print-out of the non-burn-
               able isotopes.

    col 9-10 Are ignored by the program

    col 11-20 σ_{tr}^1 = group 1 microscopic transport cross-section

    col 21-30 σ_{tr}^2 = group 2 microscopic transport cross-section

    . . . .

b) card for the absorption cross sections σ_a

    col 1-10 Any alphameric characters

    col 11-20 σ_a^1 = group 1 microscopic absorption cross-section

    col 21-30 σ_a^2 = group 2 microscopic absorption cross-section

    . . . .

c) card for the removal cross sections σ_r

    col 1-10 Any alphameric characters

    col 11-20 σ_r^1 = group 1 microscopic removal cross-section

    col 21-30 σ_r^2 = group 2 microscopic removal cross-section

    . . . .

    This card is missing if NG=1 (one group calculation)

51 - LIST OF ISOTOPES WITH σ_f, $\nu\sigma_f$, e

This set, present only if NFL > 0, is made of one or more cards
(24I3) containing the indexes of the NFL isotopes for which σ_f,
$\nu\sigma_f$, e must be specified.

52 - <u>VALUES OF $\sigma_f, \nu\sigma_f, e$</u>

For each isotope declared in the list 51, there must be the following three cards:

a) <u>card for the fission cross section σ_f</u>

   col 1-10   Any alphameric characters

   col 11-20 σ_f^1 = group 1 microscopic fission cross-section

   col 21-30 σ_f^2 = group 2 microscopic fission cross-section

   . . . . . .

b) <u>card for the nu-fission cross-section $\nu\sigma_f$</u>

   col 1-10   Any alphameric characters

   col 11-20 $\nu\sigma_f^1$ = group 1 microscopic fission cross-section times average number of neutrons per fission

   col 21-30 $\nu\sigma_f^2$ = group 2 microscopic fission cross-section times average number of neutrons per fission

   . . . .

c) <u>card for the energies per fission e</u>

   col 1-10   Any alphameric characters

   col 11-20 e^1 = energy (Joule) released by one fission in group 1

   col 21-30 e^2 = energy (Joule) released by one fission in group 2

   . . . .

53 - <u>LIST OF ISOTOPES WITH FISSION YIELDS</u>

This set of one or more cards (24I3), present only if NYL $>$ 0, specifies the isotopes for which the fission yields must be input.

54 - <u>FISSION YIELDS</u>

For each isotope i declared in the list 53, there must be one or more cards (7E10.5) containing the fission yields $\gamma^{i \to j}$ of the isotope i under consideration to all fission products j, j going from NIF + 1 to NIF + NIP. See Section IV.

55 - <u>LIBRARY SET / REGION CORRESPONDENCE</u>

Only if NLIB $>$ 1 (more than one library), a library set number must be assigned to each region in I sequential expansion form

(see 17), with each termination point being a region number.
The final termination point must coincide with NR. If NLIB=1,
this assignment is accomplished by the program itself.

SELF-SHIELDING DATA

The data concerning the self-shielding factors, included in the
card sets No. 56, 57, 58, 59, 60, 61, 62, 63 are read by the
program at the beginning of a problem (timestep 0) and at any
time-step K such as NTS(K)=1 (See 9 - LIST OF TIME-STEPS WITH
NEW SELF-SHIELDING DATA).
The self-shielding factors can be directly input or calculated
by the formula:

$$\xi^{i,j} = \sum_{k=0}^{g_p} a_k^{i,j} N_j^k \tag{9-1}$$

i = group index,

j = isotope index,

g_p = polynomial degree,

N_j = number density of the isotope j in a given mesh-element (the
index of this last is omitted).

If, for some isotope and group, overlapping occurs between the
two options (direct input and calculation of the self-shielding
factors by a polynomial formula), the latter overrides the for-
mer.
It is understood that the self-shielding factors of the isotopes
and groups for which no data are supplied, are all equal to 1.

56 - SELF-SHIELDING PARAMETERS

One card (3I3, 11X, 4I3)

col 1- 3 NBS = number of self-shielding blocks.

If NBS = 0 at the time-step 0, all self-shielding fac-
tors are initialized to 1.

If NBS = 0, at any other time-step, the self-shielding
factors are initialized to the values of the previous
time-step.

col 4 -6 NGS = number of groups for which the self-shielding
factors are specified.

col 7- 9   NSS = number of isotopes for which the self-shield-
           ing factors are specified.

It must be NBS · NGS · NSS (total number of self-shielding fac-
tors) ≤ KSELF.

col 10-20 Any alphameric characters

col 21-23 NBL = number of blocks of polynomial coefficients
           a_k^{ij}

           If NBL = 0 at the time-step 0, the polynomial formula
           (9-1) is not used. On the contrary, if NBL = 0 at any
           other time-step, the polynomial coefficients are ini-
           tialized to the values of the previous time-step.

col 24-26 NGL = number of groups for which the polynomial coef-
           ficients are specified (NGL ≤ NG)

col 27-29 NLP = number of isotopes for which the polynomial
           coefficients are specified (NLP ≤ NIS)

col 30-32 NGP = g_p + 1 = polynomial degree plus one (NGP ≤ 7)

It must be: NBL · NGL · NLP · NGP (total number of polynomial
coefficients) ≤ KPØL.

57 - LIST OF GROUPS WITH SELF-SHIELDING FACTORS

One card (24I3), present only if NBS ≠ 0, specifying the NGS
groups for which the self-shielding factors are input.

58 - LIST OF ISOTOPES WITH SELF-SHIELDING FACTORS

One or more cards (24I3), present only if NBS ≠ 0, specifying
the indexes of the NSS isotopes for which the self-shielding
factors are given.

59 - SELF-SHIELDING FACTORS

This set of cards (7E10.5), present only if NBS ≠ 0, must be
repeated/as many times as the number of blocks NBS.

For each block, NGS sets of cards must be supplied, following
the order given in 57.

Each of the NGS sets contains NSS self-shielding factors, follow-
ing the order given in 58. Start with a new card when changing
group.

60 - SELF-SHIELDING BLOCK/REGION CORRESPONDENCE

Only if NBS $\neq$ 0, a self-shielding block must be assigned to each region in I sequential expansion form (see 17), with each ter-mination point being a region number.
The block of index 0 is an implicitly defined block having all the self-shielding factors = 1.

61 - LIST OF GROUPS WITH POLYNOMIAL COEFFICIENTS

One card (24I3), present only if NBL $\neq$ o, specifying the NGL groups for which the polynomial coefficients are input.

62 - LIST OF ISOTOPES WITH POLYNOMIAL COEFFICIENTS

One or more cards (24I3), present only if NBL $\neq$ 0, specifying the indexes of the NLP isotopes for which the polynomial coefficients are given.

63 - POLYNOMIAL COEFFICIENTS

This set of cards (7E10.5), present only if NBL $\neq$ 0, must be re-peated as many times as the number of blocks NBL.

For each block, NGL sets of cards must be supplied, following the order given in 61.

Each set is made up of NLP cards, one per each isotope, contain-ing the polynomial coefficients of the isotope.

N.B. - The specification of the polynomial coefficients for a given group and a given isotope, overrides the specifica-tion of the self-shielding factors previously made with the sets 57 through 60.

64 - POLYNOMIAL COEFFICIENT BLOCK/REGION CORRESPONDENCE

Only if NBL $\neq$ 0, a block of polynomial coefficients must be as-signed to each region in I sequential expansion form (see 17), with termination point being a region number.
If a region is given the block 0, its self-shielding factors are not calculated by the formula (9-1) but keep the explicitly input values.

65 - SHUFFLING LIST

The program reads this set of cards (4I4,4X,8I4,4X,I4) at any time-step K > 0 such as NFU(K)=1.

Each card defines an operation of fuel transfer or replacement (by fresh fuel). As "fuel" of a region we mean exactly the mixture of the burnable isotopes present in that region.

The first five fields (4I4,4X) are devoted to the specification of the rectangular region (block R of mesh-elements) where the number densities of the burnable isotopes are to be replaced.

col 1- 4   IRX1 = column number representing the left boundary
                  of the block

col 5- 8   IRX2 = right boundary of the block

col 9-12   IRY1 = row number representing the upper boundary of
                  the block

col 13-16   IRY2 = lower boundary of the block

col 17-20   These columns are ignored by the program.

The nine successive fields (8I4,4X) are devoted to the specification of the rectangular region (block T) or of the initial composition (fresh fuel) whose time-dependent number densities are to be transferred mesh-element by mesh-element into the region R.

col 21-24   ITX1) integer coordinates (column and row number) of
col 25-28   ITY1) the corner point which must be superposed on
                  the upper left corner point of the block R.

col 29-32   ITX2) integer coordinates of the corner point which
col 33-36   ITY2) must be superposed on the upper right corner
                  point of the block R.

col 37-40   ITX3) integer coordinates of the corner point which
col 41-44   ITY3) must be superposed on the lower left corner
                  point of the block R.

col 45-48   ITX4) integer coordinates of the corner point which
col 49-52   ITY4) must be superposed on the lower right corner
                  point of the block R.

col 53-56   These columns are ignored by the program.

Alternatively, it is possible to replace the burned fuel of the block R by fresh fuel in this manner:

col 21-24   ICT = number of the initial composition, the num-
ber densities of which are to be fed into the
block R.

The fields from 25-28 up to 49-52 included, must be left blank.

The program checks the subsistence of certain conditions of com-
patibility between the coordinates of the corner points of the
block T and between the coordinates of the blocks R and T (e.g.
same number of mesh segments between correspondent corner points,
condition of non-overlapping) and eventually stops if they are
not verified.

Note that the use of eight coordinates for the specification of
the region T allows not only rigid translation but also rotation
and overturning of the region itself.

The last field (I4) is reserved to the specification of the new
region index one wants to assign to the mesh-elements of the
block R.

col 57-60   NREGI = new region number of the mesh-elements be-
longing to the block R. If this field is blank
or zero, the above mesh-elements keep their
own region number.

N.B. (1) It is possible to modify only the region number of a
rectangular block R (pseudo-shuffling). This is the case
when one needs only to replace a control rod by a fol-
lower or viceversa. Obviously, the fields from 21-24 up
to and including 49-52 must be left blank.

(2) One should remember that, generally speaking, a new re-
gion index bears new values for the region dependent va-
riables, such as the number densities of the non-burnable
isotopes, the fuel and moderator temperature, the buck-
ling, the library and self-shielding data.

66 - BLANK CARD

A blank card indicates the end of the shuffling specification.

It is always associated with the card set 65, but it can repre-
sent the shuffling data even alone. This is the case when at some
time-step K, the shuffling data are required (NFU(K)$\neq$0) by the

program but actually no true shuffling is desired to be carried out.

We summarize here, for control's purposes, the format of a NON-RESTART input deck for a lifetime problem (the sets marked by a $*$ may be omitted according to the correspondent options):

1: TITLE
2: GENERAL PARAMETERS
3: OPTIONS
4: MISCELLANEOUS

(TIME DATA)

$*$ 5: LIST OF TIME-STEPS WITH NEW SPECIFICATIONS FOR POINTWISE EDIT (PRESENT ONLY IF NGRINT $>$ 0)

$*$ 6: LIST OF TIME-STEPS WITH NEW BUCKLINGS (ONLY IF NGRINT $>$ 0)

$*$ 7: LIST OF TIME-STEPS WITH NEW CONTROL DATA (ONLY IF NGRINT $>$ 0)

$*$ 8: LIST OF TIME-STEPS WITH A NEW LIBRARY (ONLY IF NGRINT $>$ 0 AND LIBCAL $=$ 0)

$*$ 9: LIST OF TIME-STEPS WITH NEW SELF-SHIELDING DATA (ONLY IF NGRINT $>$ 0 AND LIBCAL $=$ 0)

$*$10: LIST OF TIME-STEPS WITH SHUFFLING (ONLY IF NGRINT $>$ 0)

$*$11: SUBSTEP DIVISION (ONLY IF NGRINT $>$ 0)

$*$12: TIME-STEP LENGTHS (ONLY IF NGRINT $>$ 0)

$*$13: TIME-STEP POWERS

14: χ^1 SPECIFICATION

(GEOMETRIC DATA)

15: ΔX-MESH SPECIFICATION

$*$16: ΔY-MESH SPECIFICATION (ONLY IF IDIAG $=$ 0)

17: COMPOSITION/REGION CORRESPONDENCE

18: REGION DESCRIPTION

19: BLANK CARD

$*$20: SPECIFICATION OF THE ISOTOPIC CHAINS (ONLY IF NUCL $>$ 0)

(COMPOSITION DATA)

21: COMPOSITION DATA PARAMETERS

$*$22: LIST OF ISOTOPES WITH NUMBER DENSITIES GIVEN PER COMPOSITION (ONLY IF NEC $>$ 0)

$*$23: NUMBER DENSITIES PER COMPOSITION (ONLY IF NEC $>$ 0)

$*$24: LIST OF ISOTOPES WITH NUMBER DENSITIES GIVEN PER REGION (ONLY IF NEMIR $>$ 0)

$*$25: NUMBER DENSITIES PER REGION (ONLY IF NEMIR $>$ 0)

$*$26: LIST OF COMPOSITIONS WITH LOGARITHMIC DERIVATIVES (ONLY IF NRC $>$ 0)

*27: LOGARITHMIC DERIVATIVES (ONLY IF NRC > 0)

*28: FUEL TEMPERATURE (ONLY IF LIBCAL=1)

*29: MODERATOR TEMPERATURE (ONLY IF LIBCAL=1)

(COMPOSITION DATA)

*30: BUCKLING

31: CONTROL OPTIONS

32: CONTROL PARAMETERS

33: GROUP FRACTIONS OF DILUTED POISON

34: DILUTED POISON CROSS-SECTIONS

*35: DESCRIPTION OF THE RODDED REGIONS (ONLY IF NCON > 0)

*36: GROUP FRACTIONS OF RODDED POISON (ONLY IF NCON > 0)

(CONTROL DATA)

37: EDIT PARAMETERS

*38: NUMBER DENSITIES BY MESH-ELEMENT (BEFORE SHUFFLING)

*39: NUMBER DENSITIES BY MESH-ELEMENT (AFTER SHUFFLING)

*40: DIFFUSION COEFFICIENTS

*41: ABSORPTION CROSS-SECTIONS

*42: REMOVAL CROSS-SECTIONS

*43: NEUTRON PRODUCTION CROSS-SECTIONS

*44: ENERGY PRODUCTION CROSS-SECTIONS

*45: POINT FLUXES

*46: AVERAGE FLUXES BY MESH-ELEMENT

(POINTWISE EDIT DATA)

47: NUMBER OF LIBRARY SETS

*48: LIBRARY PARAMETERS (ONLY IF NLIB > 0)

*49: LIST OF ISOTOPES WITH σ_{tr}, σ_a, σ_r (ONLY IF NLL > 0)

*50: VALUES OF σ_{tr}, σ_a, σ_r (ONLY IF NLL > 0)

*51: LIST OF ISOTOPES WITH σ_f, $\nu\sigma_f$, e (ONLY IF NFL > 0)

*52: VALUES OF σ_f, $\nu\sigma_f$, e

*53: LIST OF ISOTOPES WITH FISSION YIELDS (ONLY IF NYL > 0)

*54: FISSION YIELDS (ONLY IF NYL > 0)

*55: LIBRARY SET/REGION CORRESPONDENCE (ONLY IF NLIB > 1)

(LIBRARY DATA)

56: SELF-SHIELDING PARAMETERS

*57: LIST OF GROUPS WITH SELF-SHIELDING FACTORS (ONLY IF NBS > 0)

*58: LIST OF ISOTOPES WITH SELF-SHIELDING FACTORS (ONLY IF NBS > 0)

*59: SELF-SHIELDING FACTORS (ONLY IF NBS > 0)

*60: SELF-SHIELDING BLOCK/REGION CORRESPONDENCE (ONLY IF NBS > 0)

*61: LIST OF GROUPS WITH POLYNOMIAL COEFFICIENTS (ONLY IF NBL > 0)

(SELF-SHIELDING DATA)

(SELF-SHIELDING DATA)

*62: LIST OF ISOTOPES WITH POLYNOMIAL COEFFICIENTS
(ONLY IF NBL > 0)

*63: POLYNOMIAL COEFFICIENTS (ONLY IF NBL > 0)

*64: POLYNOMIAL COEFFICIENT BLOCK/REGION CORRESPONDENCE
(ONLY IF NBL > 0)

*65: SHUFFLING LIST

*66: BLANK CARD

Same sets of data pertaining to a same matter have been grouped into blocks. So we have defined the blocks of TIME DATA, GEOMETRIC DATA, COMPOSITION DATA, CONTROL DATA, POINTWISE EDIT DATA, LIBRARY DATA, SELF-SHIELDING DATA.

This grouping is useful to identify at a glance the blocks of data which can be read at each time-step (CONTROL DATA, POINTWISE EDIT DATA, LIBRARY DATA, SELF-SHIELDING DATA) and for the input preparation of RESTART problems where the program can read optionally some of the above mentioned blocks (namely TIME DATA, COMPOSITION DATA).

X. - INPUT DATA FOR RESTART

1 - TITLE

One card (17A4,I4):

col 1-56 Title of the problem (any alphameric characters)
col 57-64 Punch the word: *RESTART
col 65-68 Any alphameric characters
col 69-72 NSTART = time-step from which the problem must be restarted (NSTART ⩾ 1).

2 - OPTIONS

One card (24I3):

col 1- 3 NGRINT = last time-step (see also col 1-3 of card No.3 of the NON-RESTART DECK)
col 4- 6 NRUN = last time-step to be completed (depletion + diffusion calculation) in the present run (NRUN ⩽ NGRINT). See also col 4-6 of card No.3 of the NON-RESTART DECK.
col 7- 9 IPCF = 0 the flux' first approximation, at time-step 0, is supplied by the program (i.e. is calculated by the

modal expansion method)

= 1 the flux' first approximation is supplied by a data set (e.g. a magnetic tape). See Chap. XIII

= 2 the overrelaxation factors, as well as the flux' guess, are supplied by a data set. This option, however, should be checked only if these data were saved during a previous execution of the same diffusion calculation.

col 10-12   ISTEQ = 1 the program requires the block of the TIME DATA cards, namely:

- 5: LIST OF TIME-STEPS WITH NEW SPECIFICATIONS FOR POINTWISE EDIT
- 6: LIST OF TIME-STEPS WITH NEW BUCKLINGS
- 7: LIST OF TIME-STEPS WITH NEW CONTROL DATA
- 8: LIST OF TIME-STEPS WITH A NEW LIBRARY
- 9: LIST OF TIME-STEPS WITH SELF-SHIELDING DATA
- 10: LIST OF TIME-STEPS WITH SHUFFLING
- 11: SUBSTEP DIVISION
- 12: TIME-STEP LENGTHS
- 13: TIME-STEP PØWERS

= 0 the program does not read the above mentioned data.

col 13-15   IDENS = 1 the program reads the block of cards named "COMPOSITION DATA", namely:

- 21: COMPOSITION DATA PARAMETERS
- 22: LIST OF ISOTOPES WITH NUMBER DENSITIES GIVEN PER COMPOSITION
- 23: NUMBER DENSITIES PER COMPOSITION
- 24: LIST OF ISOTOPES WITH NUMBER DENSITIES GIVEN PER REGION
- 25: NUMBER DENSITIES PER REGION
- 26: LIST OF COMPOSITIONS WITH LOGARITHMIC DERIVATIVES
- 27: LOGARITHMIC DERIVATIVES
- 28: FUEL TEMPERATURE
- 29: MODERATOR TEMPERATURE

col 16-18   NAX = number of harmonics (trigonometric eigenfunctions) along the X-axis

col 19-21   NAY = number of harmonics along the Y-axis.

If any of the field 1-3, 4-6, 16-18, 19-21 is blank or zero, the correspondent parameters keep the last specified value (i.d. the

value used in the preceding run).

3 - MISCELLANEOUS

One card (7E10.5):

col 1-10 DEL = δ = pointwise convergence criterion for the flux
calculation. See also col. 1-10 of card No.4
of the NON-RESTART DECK.

col 11-20 HERR = ε_H = allowed error in the harmonics calculation.
See col 11-20 of card No. 4 of the NON-RESTART
DECK.

If any of the fields 1-10 and 11-20 is zero or blank, the correspon-
dent parameters keep the last specified value.

4 - TIME DATA

Place here the block of cards named TIME DATA only if ISTEQ=1 (see
col 10-12 of card No. 2).

5 - COMPOSITION DATA

Place here the block of cards named COMPOSITION DATA only if IDENS=1
(see col 13-15 of card No. 2).

N.B. (1) The logarithmic derivatives and the number densities are
initialized, rather than to zero, to the values read from
the RESTART unit, i.d. the values resulting from the de-
pletion calculation of the time-step from which the pro-
blem is restarted (NSTART). Thus the reading of these cards
provides only a modification of the above values.

(2) Only the number densities of the isotope NUCL+1 can be spe-
cified by region. On the contrary, the number densities of
all isotopes can be specified by composition but, as for
the burnable isotopes, they can be fed into the reactor
as "fresh fuel" only by a shuffling procedure (see 65).

6 - BUCKLING

Place here the card set named BUCKLING if the time-step under consi-
deration requires it (NBK(I)=1 with I=NSTART).

7 - CONTROL DATA

Insert here the block of cards named "CONTROL DATA" if the time-step under considcration (i.d. the time-step from which the problem is restarted) requires it (NCT(I)=1 with I=NSTART).

8 - POINTWISE EDIT DATA

Insert here the block of cards named "POINTWISE EDIT DATA" if the time-step I under consideration requires it (NEDIT(I)=1).

9 - LIBRARY DATA

Insert here the block of cards named "LIBRARY DATA" if the time-step under consideration requires it (NTL(I)=1).

10 - SELF-SHIELDING DATA

Insert here the block of cards named "SELF-SHIELDING DATA" if the time-step I under consideration requires it (NTS(I)=1)

11 - SHUFFLING DATA

Place here the shuffling data if the time-step I under consideration requires it (NFU(I)=1).

N.B. It is understood that the above RESTART data must be followed by the data (see blocks 6-11) required by the time-steps that follow the one (NSTART) from which the problem is restarted and that are to be completed in the present run.

XI. - HOW TO SAVE THE FLUXES

During the execution, CONDOR-3 clearly indicates, through appropriate OFF-LINE messages, on what unit the more up-to-dated fluxes are stored.

If the execution is interrupted, by time overflow or any other cause (even when the program ends regularly), the user has at his disposal the unit containing the last fluxes.

Generally, at the moment when the execution is interrupted, it is not possible to know which of the two logical units 9 and 11 is

the good one, so the practical procedure is the following:

a) hold and label the physical units corresponding to the logical units 9 and 11;

b) the unit containing the fluxes is the one indicated in the last message of this form:

××× FLUXES ARE SAVED ON LOGICAL UNIT 9 (11)

It should be borne in mind that the other unit generally is not good.

XII. - HOW TO SAVE THE DATA FOR RESTART

At any time-step, CONDOR-3 writes on the logical unit 10 all the data necessary to restart the problem, if interrupted, from the point immediately after the calculation of the isotope number densities.

The program prints both ON-LINE and OFF-LINE the following message:

××× RESTART DATA FROM TIME STEP ... ARE ON LOGICAL UNIT 10

At the end of a problem, or if the problem has been interrupted, there are two possible situations:

a) if the problem was a non-restart case, on the logical unit 10 there are as many blocks of data as the times the burn-up calculations were performed (that is, as many blocks of data as the number of time-steps performed, time-step o excluded). The number of such blocks recorded on the logical unit 10 is given exactly by the number of the above messages.

b) If the problem was already a restart case, on the logical unit 10 there are as many blocks of data as the times the burn-up calculations were performed in that run, plus the blocks of data which were already recorded on the logical unit 10 when the problem was started and which referred to the starting time-step and the preceding ones.

Also in this case the number of new blocks recorded on logi-
cal tape 10, during the last run, is given exactly by the
number of printed messages, with the exception of the mes-
sage printed ahead of the output.

N.B. The blocks of data recorded on logical unit 10, relative
to time-steps following the time-step from which the pro-
blem was restarted, are lost.

The practical procedure for saving the data for a RESTART is
simply the following:

Hold and label the physical unit corresponding to the logical
unit 10, at the end of a run.
One should be careful to count exactly the time-steps recorded
on such unit.

It is to be pointed out that the restart data from any time-step
are recorded on the logical unit 10 <u>before the reading of new data</u>
(buckling, control data, library data) eventually required. In-
stead, the newly read values will be found among the restart data
only beginning with the next time-step. Therefore care of this fact
must be taken in a restart case from a time-step at which a read-
ing of new data occurs.

XIII. - <u>HOW TO SPECIFY POINT FLUXES AND NUMBER DENSITIES BY MESH</u>
<u>ELEMENT</u>

The program can read an initial flux approximation from the logi-
cal unit 11. Of course a flux unit saved from an already run CONDOR-3
problem (see Chap. XI) can be used provided that it had the same
number of rows, columns and groups.

Moreover, the program can read number densities per mesh-element
from the logical unit 10 (if NSTEP > 0 on card 21).
In order to exploit this last option, it is necessary to have at
own disposal the physical unit containing the RESTART data among
which the number densities to be read are included. Of course, this
unit will have been saved from a previous CONDOR problem (see Chap.XII).

XIV. - HOW TO MAKE A RESTART

The practical procedure is the following:

a) the physical unit containing the data pertinent to the time-step from which the problem is restarted, must correspond to the logical unit 10.

b) use the special input deck for RESTART (See Chap. X).

c) use a physical unit containing a flux approximation (if available) as logical unit 11. The use of this unit is not compulsory but strongly recommended because it saves a good deal of computational time, even if the fluxes are pertinent to a time-step different from the one from which the problem is restarted.

We recall, that if the restart is made from the time-step i of a previous problem, all blocks of data pertinent to the time-steps > i will be erased on the logical unit 10.

It is not possible to perform a restart from the time-step 0.

In such a case, the best policy is to use the original input deck, plus the flux unit on the logical unit 11.

APPENDIX A - COMPUTATIONAL RESTRICTIONS IN THE SOLUTION
OF THE DEPLETION EQUATIONS

The subroutines which perform the depletion calculations (Cfr.
Chap. IV) have been separately tested in order to check the
soundness of the analytical method therein employed.

One main disadvantage of the method is the following:

The number density of the isotope i is evaluated by the formula:

$$N^i(t) = \sum_{j=1}^{n} b_{ij} e^{a_{jj} t} \qquad (A-1)$$

The coefficients b_{ij} are calculated by the recurrence formulae:

$$b_{ij} = \frac{\sum_{k=i+1}^{n} a_{ik} b_{kj}}{a_{jj} - a_{ii}} \qquad \text{(for } j > i) \qquad (A-2)$$

$$b_{ii} = N^i(0) - \sum_{j=i+1}^{n} b_{ij} \qquad (A-3)$$

$(i = 1,2,...n)$

The coefficients a_{ij} are the matrix elements of the depletion ma-
trix A, relative to the isotopic chain of order n to which the ele-
ment i belongs:

$$\frac{d N^i(t)}{dt} = \sum_{j \leq i}^{n} a_{ij} N^j(t) \qquad (i = 1,2, \ldots n)$$

For the lower isotopes of the chain, the roundoff errors implied
by the recurrence formulae (A-2) and (A-3) propagate as i increases.

Formula (A-1) becomes critical when $N^i(t) - N^i(o)$ is very small,

because it is the result of sums and differences of terms of the same order. Unfortunately, it is not easy to state precisely what is meant by "very small" except that this circumstance verifies when the time-step length t is very short (few hours) or when the flux level is too low.

It is a fortunate circumstance however, that these cases are not important from a physical standpoint.

Nevertheless, it has been adopted in CONDOR, a device preventing not only some N^1 to become negative, as it could happen for small values of t, but also to change when they are positive, but completely random.

In these cases, the number density variation $N^1(t) - N^1(o)$ is automatically set to zero.

APPENDIX B - PERIPHERAL UNIT CONFIGURATION

Logical unit	Physical unit	Function
2	disk	to store the finite difference coefficients
3	disk	
4	disk	banal
8	tape or disk	to store the referrence functions for calculating the library data
9	tape or disk	to store the fluxes
11	tape or disk	
10	tape or disk	to store the data for the RESTART
12	disk	direct access unit

The correspondence between logical and physical units is left to the programmer's choice and is defined by the DD cards (with other information concerning the use of peripheral units).

APPENDIX C - PROGRAM RESTRICTIONS

Two versions of the program CONDOR-3 are now running (November 1969). The first version, with the main program named CNR12K, requires at least 300,000 bytes of main storage. The second version, with the main program named CNR18K, requires 400,000 bytes of main storage.

The limitations for both versions are as follows:

Item	Version 1	Version 2
Maximum number of harmonics	KARM(NG)=100	100 if NG=1,2
	85	100 if NG=3
	72	90 if NG=4
Maximum number of modes along X	KAX=100	100
Maximum number of modes along Y	KAY=100	100
Maximum number of inital compositions	KCD=50	50
Maximum number of rodded regions	KCON=50	50
Maximum number of groups	KGD=4	4
Maximum number of transport, absorption and removal microscopic cross-sections	KIBDA=1000	2000
Maximum number of fuel isotopes	KIF=20	20
Maximum number of fission products	KIP=30	30
Maximum number of isotopes	KIS=50	50
Maximum number of burnable isotopes	KIV=40	40
Maximum number of mesh-points	KPD=12,000	18,000
Maximum number of polynomial coefficients	KPOL=2000	3000
Maximum number of regions	KREG=200	300
Maximum number of time-steps	KRINT=100	100
Maximum number of self-shielding factors	KSELF=2000	2000
Maximum number of microscopic cross-sections σ_f, $\nu\sigma_f$, c	KSIGF=400	800
Maximum number of columns	KXD=100	150
Maximum number of rows	KYD=150	200
Maximum number of fission yields	KYLDE=3000	6000

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This report was written by E. SALINA, but many parts of it are taken bodily from the CONDOR-2 report (14).

| 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 20 | 1 2 3 4 5 6 7 8 9 30 | 1 2 3 4 5 6 7 8 9 40 | 1 2 3 4 5 6 7 8 9 50 | 1 2 3 4 5 6 7 8 9 60 | 1 2 3 4 5 6 7 8 9 70 | 1 2 3 4 5 6 7 8 9 80 |

| TITLE (ANY ALPHANUMERIC) | | | | | BLANKS | | |

NG	NR	NCMP	NPX	NPY	NIS	NUCL	NIF	NIP

NGRINT	NRUN	JGX	JGY	IPCF	IDIAG	IBK	LIBCAL	NAX	NAY	NT	NGD	NTD	LREC	IPRINT

DEL	HERR	TAU	EPSIN	

only if NGRINT>0

NEDIT (1)	NEDIT (2)	. . .	. . .	. . .	NEDIT (NGRINT)
NBK (1)	NBK (2)	. . .	. . .	. . .	NBK (NGRINT)
NCT (1)	NCT (2)	. . .	. . .	. . .	NCT (NGRINT)

only if LIBCAL=0

NTL (1)	NTL (2)	. . .	. . .	. . .	NTL (NGRINT)
NTS (1)	NTS (2)	. . .	. . .	. . .	NTS (NGRINT)
NFU (1)	NFU (2)	. . .	. . .	. . .	NFU (NGRINT)
NSA (1)	NSA (2)	. . .	. . .	. . .	NSA (NGRINT)

DELTAT (1)	DELTAT (2)	. . . .	. . . .	. . . .	. . . .	DELTAT (NGRINT)
W (1)	W (2)	. . . .	. . . .	. . . .	. . . .	W (NGRINT)

χ^1	χ^2	. . . .	χ^{NG}

ΔX	C	ΔX	C	ΔX	C	ΔX	C

only if IDIAG=0

ΔY	r	ΔY	r	ΔY	r	ΔY	r

C	i_r	C	i_r	C	i_r	. . .	. . .							
i_r	C_1	C_2	r_1	r_2		i_r	C_1	C_2	r_1	r_2		i_r	C_1	C_2	r_1	r_2	i_r	C_1	C_2	r_1	r_2
i_r	C_1	C_2	r_1	r_2		i_r	C_1	C_2	r_1	r_2

BLANK CARD

only if NUCL>0

ISØT NAME	N_{c_1}	N_{c_2}	N_β	DECAY CØNST.	ATØMIC WEIGHT	LUMPING FACTØR	
. . .	. . .	. .	. . .	. . .	. . . .	. . .	
ISØT NAME	N_{c_1}	N_{c_2}	N_β	DECAY CØNST	ATØMIC WEIGHT	LUMPING FACTØR	

APPENDIX D – CONDOR-3 INPUT FORM-2

1 2 3	4 5 6 7 8 9	10 1 2 3 4 5 6 7 8 9	20 ...

NEC	NEMIR	NSTEP	NRC	IPUN
I1	I2	I3	I4	... ...

only if NEC>0:

$DENS(I1,1)$	$DENS(I1,2)$	....	....	$DENS(I1,NCMP)$
$DENS(I2,1)$	$DENS(I2,2)$	....	....	$DENS(I2,NCMP)$
$DENS(I3,1)$	$DENS(I3,2)$	....	....	$DENS(I3,NCMP)$
...	...	....	....	....

I1	I2	I3	I4	... ...

only if NEMIR>0:

$DD(I1,1)$	$DD(I1,2)$	$DD(I1,3)$	$DD(I1,4)$	$DD(I1,5)$	$DD(I1,6)$	$DD(I1,7)$
$DD(I1,8)$	...	$DD(I1,NR)$				
$DD(I2,1)$	$DD(I2,2)$	$DD(I2,3)$	$DD(I2,4)$	$DD(I2,5)$	$DD(I2,6)$	$DD(I2,7)$
$DD(I2,8)$	...	$DD(I2,NR)$				
...	...	...	...	...	...	...

L_1	L_2	L_3	... ...

only if NRC>0:

$DL(L1,1)$	$DL(L1,2)$	...	$DL(L1,NG)$
$DL(L2,1)$	$DL(L2,2)$	...	$DL(L2,NG)$
...	...		...

only if LIBCAL=1:

T_f	i_r	T_f	i_r	T_f	i_r		
T_m	i_r	T_m	i_r	T_m	i_r		
B_1^2	i_r	B_1^2	i_r	B_1^2	i_r	B_1^2	i_r

only if IBK=1:

B_2^2	i_r	B_2^2	i_r	B_2^2	i_r	B_2^2	i_r
...	...	...	...	...	...	...	...
B_{NG}^2	i_r	B_{NG}^2	i_r	B_{NG}^2	i_r	B_{NG}^2	i_r

APPENDIX D – CONDOR-3 INPUT FORM-3

IC	NCON	NC	JZX	IRR	

AUT	ETA	TV	T MAX	T MIN	EPS

TD (1)	TD (2)	TD (NG)	

Σ_{dp}	i_r	Σ_{dp}	i_r	Σ_{dp}	i_r	Σ_{dp}	i_r

only if NCON>0

P_{x1}	P_{x2}	P_{y1}	P_{y2}	P_{yv}	Σ_{rp}^{max}	Σ_{rp}	Σ_{rp}^{min}	BANK 1
...					...	...	...	
P_{x1}	P_{x2}	P_{y1}	P_{y2}	P_{yv}	Σ_{rp}^{max}	Σ_{rp}	Σ_{rp}^{min}	

TR (1)	TR (2)	...	TR (NG)

IDEN1	IDEN2	IDIF	IASS	IREM	IUSS	IESS	IFLUX	IFLAV

only if IDEN 1 ≠ 0

NDEN1 (1)	NDEN1 (2)	NDEN1 (3)	...	...	...	...	...	NDEN1 (NUCL)

only if IDEN2 ≠ 0

NDEN2 (1)	NDEN2 (2)	NDEN2 (3)	...	...	...	...	...	NDEN2 (NUCL)

only if IDIF ≠ 0

NDIF (1)	NDIF (2)	...	NDIF (NG)

only if IASS ≠ 0

NASS (1)	NASS (2)	...	NASS (NG)

only if IREM ≠ 0

NREM (1)	NREM (2)	...	NREM (NG)

only if IUSS ≠ 0

NUSS (1)	NUSS (2)	...	NUSS (NG)

only if IESS ≠ 0

NESS (1)	NESS (2)	...	NESS (NG)

only if IFLUX ≠ 0

NFLUX (1)	NFLUX (2)	...	NFLUX (NG)	NFLUX (NG+1)

only if IFLAV ≠ 0

NFLAV (1)	NFLAV (2)	...	NFLAV (NG)	NFLAV (NG+1)	NFLAV (NG+2)

APPENDIX D - CONDOR-3 INPUT FORM -4

1–10	11–20	21–30	31–50	51–60
NLIB				
NLL NFL NYL				
I1 I2 I3 . . .				
ISOT. NAME	$\sigma_{tr}^{I1,1}$	$\sigma_{tr}^{I1,2}$	. . . .	$\sigma_{tr}^{I1,NG}$
ANY ALPHAMERIC	$\sigma_{a}^{I1,1}$	$\sigma_{a}^{I1,2}$	. . . .	$\sigma_{a}^{I1,NG}$
"	$\sigma_{r}^{I1,1}$	$\sigma_{r}^{I1,2}$	. . . .	$\sigma_{r}^{I1,NG}$
ISOT NAME	$\sigma_{tr}^{I2,1}$	$\sigma_{tr}^{I2,2}$		$\sigma_{tr}^{I2,NG}$
ANY ALPHAMERIC	$\sigma_{a}^{I2,1}$	$\sigma_{a}^{I2,2}$		$\sigma_{a}^{I2,NG}$
"	$\sigma_{r}^{I2,1}$	$\sigma_{r}^{I2,2}$	. . . .	$\sigma_{r}^{I2,NG}$
. . . .	. . . .	. . . .		. . . .
. . . .	. . . .	. . . .		. . . .
. . . .	. . . .	. . . .		. . . .
I1 I2 I3 I4 . . .				
ANY ALPHAMERIC	$\sigma_{f}^{I1,1}$	$\sigma_{f}^{I1,2}$	. . . .	$\sigma_{f}^{I1,NG}$
"	$\nu\sigma_{f}^{I1,1}$	$\nu\sigma_{f}^{I1,2}$	. . . .	$\nu\sigma_{f}^{I}$
"	$e^{I1,1}$	$e^{I1,2}$	. . . .	$e^{I1,NG}$
"	$\sigma_{f}^{I2,1}$	$\sigma_{f}^{I2,2}$	. . . .	$\sigma_{f}^{I2,NG}$
"	$\nu\sigma_{f}^{I2,1}$	$\nu\sigma_{f}^{I2,2}$	. . . .	$\nu\sigma_{f}^{I2,NG}$
"	$e^{I2,1}$	$e^{I2,2}$	. . . .	$e^{I2,NG}$
. . . .	. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .	. . . .
I1 I2 I3 . . .				
	$\gamma^{I1\rightarrow1}$	$\gamma^{I1\rightarrow2}$	. . .	$\gamma^{I1\rightarrow NIP}$
	$\gamma^{I2\rightarrow1}$	$\gamma^{I2\rightarrow2}$	. . .	$\gamma^{I2\rightarrow NIP}$
	. . . .	. . . .	. . .	. . . .

Repeat NLIB times

only if NLL > 0

only if NFL > 0

only if NYL > 0

APPENDIX D - CONDOR-3 INPUT FORM-5

Label	Form fields
only if NLIB > 1	L i_r L i_r L i_r ... ...
	NBS NGS NSS NBL NGL NLP NGP
only if NBS > 0	$IGS(1)$ $IGS(2)$ ... $IGS(NGS)$
	$ISS(1)$ $ISS(2)$ ... ... $ISS(NSS)$
Repeat NBS times	$G(1,1)$ $G(1,2)$ $G(1,3)$ ... ... $G(1,NSS)$
	$G(2,1)$ $G(2,2)$ $G(2,3)$ ... ... $G(2,NSS)$
	... ...
	$G(NGS,1)$ $G(NGS,2)$ $G(NGS,3)$ ... ... $G(NGS,NSS)$
	S i_r S i_r S i_r ... ...
only if NBL > 0	$IGL(1)$ $IGL(2)$ ... $IGL(NGL)$
	$ILP(1)$ $ILP(2)$ ... ... $ILP(NLP)$
Repeat NBL times	$A_1(1,1)$ $A_2(1,1)$ $A_3(1,1)$ ... $A_{NGP}(1,1)$
	$A_1(1,2)$ $A_2(1,2)$ $A_3(1,2)$ ... $A_{NGP}(1,2)$
	... ...
	$A_1(1,NLP)$ $A_2(1,NLP)$ $A_3(1,NLP)$ ... $A_{NGP}(1,NLP)$
	$A_1(2,1)$ $A_2(2,1)$ $A_3(2,1)$ ... $A_{NGP}(2,1)$
	$A_1(2,2)$ $A_2(2,2)$ $A_3(2,2)$ ... $A_{NGP}(2,2)$
	... ...
	$A_1(2,NLP)$ $A_2(2,NLP)$ $A_3(2,NLP)$ ... $A_{NGP}(2,NLP)$
	... ...
	... ...
	... ...
	... ...
	$A_1(NGL,1)$ $A_2(NGL,1)$ $A_3(NGL,1)$ ... $A_{NGP}(NGL,1)$
	$A_1(NGL,2)$ $A_2(NGL,2)$ $A_3(NGL,2)$ ... $A_{NGP}(NGL,2)$

APPENDIX D - CONDOR-3 INPUT FORM (RESTART)

Column	1-57	58-62	63-70
	TITLE	* RESTART	NSTART

NGRINT	NRUN	IPCF	ISTEQ	IDENS	MAX	NAY	NT	NDG	NTD

DEL	HERR	TAU	EPSIN

Condition	Data
only if ISTEQ=1	TIME DATA (SHEET 1, LINES 5-13)
only if IDENS=1	COMPOSITION DATA (SHEET 2, LINES 1-19)
only if NBK(I)=1	BUCKLINGS (SHEET 2, LINES 20-23)
only if NCT(I)=1	CONTROL DATA (SHEET 3, LINES 1-8)
only if NEDIT(I)=1	POINTWISE EDIT DATA (SHEET 3, LINES 9-18)
only if NTL(I)=1	LIBRARY DATA (SHEET 4, LINES 1-25 AND SHEET 5, LINE 1)
only if NTS(I)=1	SELF-SHIELDING DATA (SHEET 5, LINES 2-25 AND SHEET 6, LINES 1-3)
only if NFU(I)=1	SHUFFLING DATA (SHEET 6, LINES 4-7)

| 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 20 | 1 2 3 4 5 6 7 8 9 30 | 1 2 3 4 5 6 7 8 9 40 | 1 2 3 4 5 6 7 8 9 50 | 1 2 3 4 5 6 7 8 9 60 | 1 2 3 4 5 6 7 8 9 70 | 1 2 3 4 5 6 7 8 9 80 |

. . .	. . .	. . .	. . .	. . .	
A_1 (NGL, NLP)	A_2 (NGL, NLP)	A_3 (NGL, NLP)	. . .	A_{NGP} (NGL, NLP)	

P	i_r		P	i_r		P	i_r		. . . . . .

IRX1	IRX2	IRY1	IRY2		ITX1	ITY1	ITX2	ITY2	ITX3	ITY3	ITX4	ITY4		NREGI	
IRX1	IRX2	IRY1	IRY2		ITX1	ITY1	ITX2	ITY2	ITX3	ITY3	ITX4	ITY4		NREGI	
. .	. .	. .	. .		. .	. .	. .	. .	. . . .	. .	. .	. .		. .	

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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