STUDIECENTRUM VOOR KERNENERGIE

CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

CASSANDRE : A TWO-DIMENSIONAL MULTIGROUP DIFFUSION CODE FOR REACTOR TRANSIENT ANALYSIS

CODE DESCRIPTION AND USER'S GUIDE

B. ARIEN, J. DANIELS

December 1986

BLG 591

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Summary - CASSANDRE is a two-dimensional (x-y or r-z) finite element neutronics code with thermohydraulics feedback for reactor dynamics prior to the disassembly phase. It uses the multigroup neutron diffusion theory. Its main characteristics are the use of a generalized quasistatic model, the use of a flexible multigroup point-kinetics algorithm allowing for spectral matching and the use of a finite element description. The code was conceived in order to be coupled with any thermohydraulics module, although thermohydraulics feedback is only considered in r-z geometry. In steady state criticality search is possible either by control rod insertion or by homogeneous poisoning of the coolant. This report describes the main characteristics of the code structure and provides all the informations needed to use the code.

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Résumé - CASSANDRE est un code de neutronique aux éléments finis bidimensionnels (x-y ou r-z) tenant compte d'effets rétroactifs thermohydrauliques et destiné à la dynamique des réacteurs durant la phase de prédésassemblage. Le code est basé sur la théorie de diffusion multigroupes et ses caractéristiques principales sont l'utilisation d'un modèle quasistatique généralisé et l'emploi d'un algorithme souple de cinétique ponctuelle multigroupes permettant une reproduction du spectre (spectral matching). Le code est conçu de manière à pouvoir être couplé à n'importe quel module thermohydraulique, quoique la rétroaction thermohydraulique soit limitée à la géométrie r-z. La recherche de l'état critique en régime stationnaire est possible soit par insertion de barre de contrôle, soit par empoisonnement homogène du réfrigérant. Le présent rapport décrit les caractéristiques principales de la structure du code et fournit toutes les informations nécessaires pour l'utilisation du code.

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A TWO-DIMENSIONAL MULTIGROUP DIFFUSION CODE FOR REACTOR TRANSIENTS ANALYSIS.
CODE DESCRIPTION AND USER'S GUIDE

Samenvatting - CASSANDRE is een tweedimensionele (x-y of r-z) eindige elementen neutronencode met thermohydraulische terugkoppeling, die op punt gesteld werd voor de dynamische studie van reactoren vóór de ontmantelingsfase. De code steunt op de multigroep neutronendiffusietheorie. De voornaamste karakteristieken van de code zijn het gebruik van een veralgemeend quasistatisch model, het gebruik van een soepel multigroep puntkinetisch algorithme dat "spectral matching" toelaat en het gebruik van een eindige elementen beschrijving. De code werd opgevat ten einde aan om het even welk thermohydraulisch model te kunnen gekoppeld worden, alhoewel thermohydraulische terugkoppeling beperkt werd tot de r-z geometrie. In stationnair regime is het zoeken naar de criticaliteit mogelijk hetzij door het inbrengen van een controlestaf, hetzij door het homogeen vergiftigen van een koelmiddel. Onderhavig rapport beschrijft de voornaamste karakteristieken van de code en geeft al de nodige inlichtingen voor het codegebruik.

ACKNOWLEDGEMENT

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CONTENTS

1. INTRODUCTION

The CASSANDRE code is a two-dimensional neutronics code using the multigroup diffusion theory for transient analysis in nuclear reactors prior to the disassembly phase.
The temperature dependence of the neutronic cross-sections allows the introduction of the temperature feedback effects by adjunction and coupling of a thermohydraulics module.
Originally conceived and written for fast reactors, CASSANDRE however can be used for general reactor types.

The multigroup neutron diffusion equations are solved in steady and unsteady states.
The finite element method with Lagrangian interpolation polynomials is used for the spatial discretization in x-y or r-z geometries. The time integration of the unstationary equations is performed by means of the generalized quasistatic approach allocating a different amplitude function for each energy group. A flexible multigroup point-kinetics algorithm allows for spectral matching. Steady state solutions of the direct and adjoint problems are obtained by the power method with Chebyshev acceleration technique. Option for criticality search by control rod insertion or homogeneous poisoning of the coolant is also included in the code. In the present report it is many times referred to [1]; this reference provides the detailed theoretical and numerical developments upon which CASSANDRE is based, and it must be a needful complement for a good understanding of these theoretical foundations.

As it will be further precised, the CASSANDRE code has been conceived to permit the introduction and coupling of many possible thermohydraulics modules.
Neutronics and thermohydraulics equations are iteratively solved until convergence criteria are reached.
A very simplified thermohydraulics module described in appendix 7 is included in the version of CASSANDRE furnished outside the C.E.N./S.C.K.-Mol.

The macroscopic neutron cross-sections and their temperature dependence variations are determined in a preprocessing module using a 26 or 40 groups library.
Confidentiality constraints forbid the diffusion of CASSANDRE to external users with this preprocessing module. Nevertheless the code is supplied with an equivalent preprocessing module allowing to introduce easily the neutron cross-sections coming from any other library.

In order to optimize the core memory, a dynamic allocation technique, described in appendix 6, has been introduced in the code.

The present report provides a general description of the code structure and all the informations needed to run the code successfully.

CASSANDRE initially was written in FORTRAN-IV language and it has been afterwards converted for FORTRAN-77 compilers. The code is operational on an IBM 370/168 computer.

Additional informations can be obtained by contacting

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2. THE FUNDAMENTAL ASSUMPTIONS OF THE PHYSICAL MODEL

We recall here the main physical assumptions on which the code CASSANDRE is based.
These assumptions were already taken up in the theoretical report [1].

- The space representation is limited to two dimensions, either in rectangular coordinates (x,y) or in cylindrical coordinates (r,z).

- The multigroup diffusion approximation is used.

- Neutron downscattering as well as upscattering may be considered.

- The boundary conditions are the Neuman-Dirichlet conditions $(\alpha\phi + \beta \frac{\partial\phi}{\partial n} = 0)$.

- The reactor is partitioned in rectangular zones (finite elements) in which the cross-sections are assumed spatially constant.

- The macroscopic cross-sections may depend on a mean temperature of the zone.

- The fission macroscopic cross-sections are distinct for each fuel isotope.

- The delayed neutron precursors are classified in families and are distinct for each fuel isotope.

- The delayed neutron spectrum is identical for all families and all fuel isotopes.

- The transients are initiated from the steady state.

- The thermohydraulic coupling is only considered in r-z geometry.

3. GENERALITIES ON THE STRUCTURE OF CASSANDRE

The structure of CASSANDRE is modular, each module being connected to the other ones only by data files and eventually by the labeled common block COMMON/DIM, as we shall see further.

The code is constituted by 5 modules :

4 neutronics modules : 1) input module
2) preprocessing module
3) static module
4) dynamic module

1 thermohydraulics module : it is supposed that the thermohydraulic calculations are performed in one module, which will be denoted by THERMO for the sake of convenience.

Their essential tasks respectively are :

1) the reading of the input data
2) the determination of the neutronic properties of the materials (cross-sections, compositions of the mixtures, fission spectra, etc.)
3) the steady state calculation
4) the transient calculation
5) the determination of the thermohydraulic behaviour of the reactor.

The neutronics modules constitute in fact the code CASSANDRE itself, the thermohydraulics module being introduced to take into account the feedback effects on the neutronic cross-sections of the materials.

The global structure of the code is conceived to allow in principle the coupling of neutronics with any thermohydraulics module, provided that the physical model is compatible with the elementary assumptions on which CASSANDRE is based.

Figure 3.1 schematizes the interfaces between the various modules of the code.

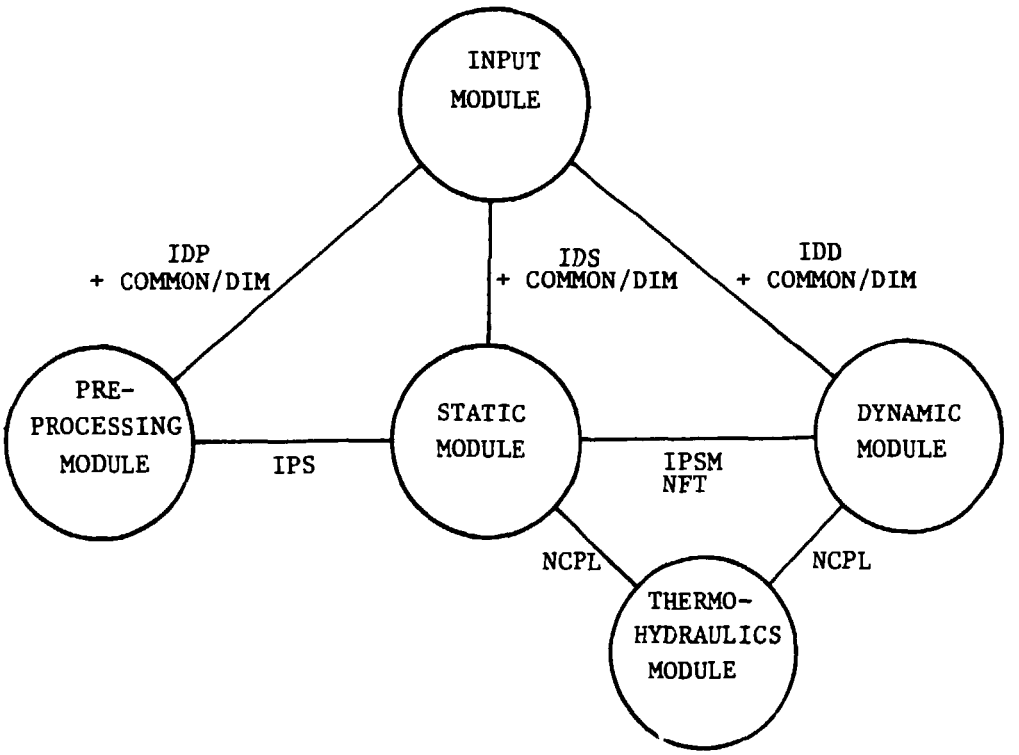


Figure 3.1 : the modules of CASSANDRE and their interfaces

The interface between the preprocessing module and the static module is constituted by file IPS, whereas the interface between the static module and the dynamic module is defined by files IPSM and NFT. It implies in particular that, provided that the right files contain the right informations, a steady state calculation does not require at each time the preliminary running of the preprocessing module and that a transient calculation can start immediately without calling to the static module.

This facility is especially useful if one desires to determine the steady state for various configurations of the reactor; at the first run the preprocessing module computes and stores on file IPS the neutronic properties of the materials, and at the following runs the

code reads these properties on file IPS and begins directly the static calculations. Similarly different transients starting from the same steady state can be studied, the steady state being calculated only once before the first transient.

The preprocessing module, the static module and the dynamic module are connected everyone to the input module by a file (IDP, IDS, IDD, respectively) and by the labeled common COMMON/DIM. This labeled common contains the array L (100), which collects the most important integers used in CASSANDRE (number of energy groups, number of compositions, number of nodes, file numbers, etc.).
The components of L are specified in appendix 5 and the contents of files IDP, IDS, IDD, IPS, IPSM, NFT and NCPL are described in appendix 3.

The calling sequences of these modules are defined in the MAIN and in subroutine MACAS, which are described in the following sections.

4. DESCRIPTION OF THE MAIN

In order to facilitate the implementation of any thermohydraulics module in CASSANDRE, the calling sequence of the neutronics and thermohydraulics units has been isolated as much as possible in the MAIN of the code.

Coupling of neutronics and thermohydraulics obviously requires an interative procedure between the neutronic and thermohydraulic calculations, and this as well in steady state as in unsteady state.

The neutronics part of the code provides to the thermohydraulics module (conventionally called THERMO) the power density distribution in the reactor, whereas THERMO in return furnishes the temperature and density distributions to neutronics. This information exchange is repeated in an iterative manner until a desired level of convergence has been reached.

The flow sheet of the MAIN given hereafter and followed by a nomenclature clearly illustrates the practical realisation of this coupling :

a) routine IDINIT is first called for the dynamic allocation initializations (see appendix 6);

b) the input data are then read in routine INPUTD;

c) if NEXEC ≠ 3, a static calculations has first to be carried out, eventually followed by a dynamic calculation
   if NEXEC = 3, a dynamic calculation is directly started from the results of the preprocessing and static modules obtained in a previous run and stored on files IPSM, NFT as explained in section 3. Subroutine OPENMS is initally called to define the characteristics of the direct access files used by the dynamic module;

d) the interctive processes between neutronics (MACAS) and thermohydraulics (THERMO) are characterized by the iteration loops on ITER as well in steady state as in transient.

The iterations are pursued or stopped according to the value of KCONV, which is determined in the neutronics modules and which indicates the result of the convergence tests.

In transient the iterative procedure between neutronics and thermohydraulics is repeated at each macro time step.

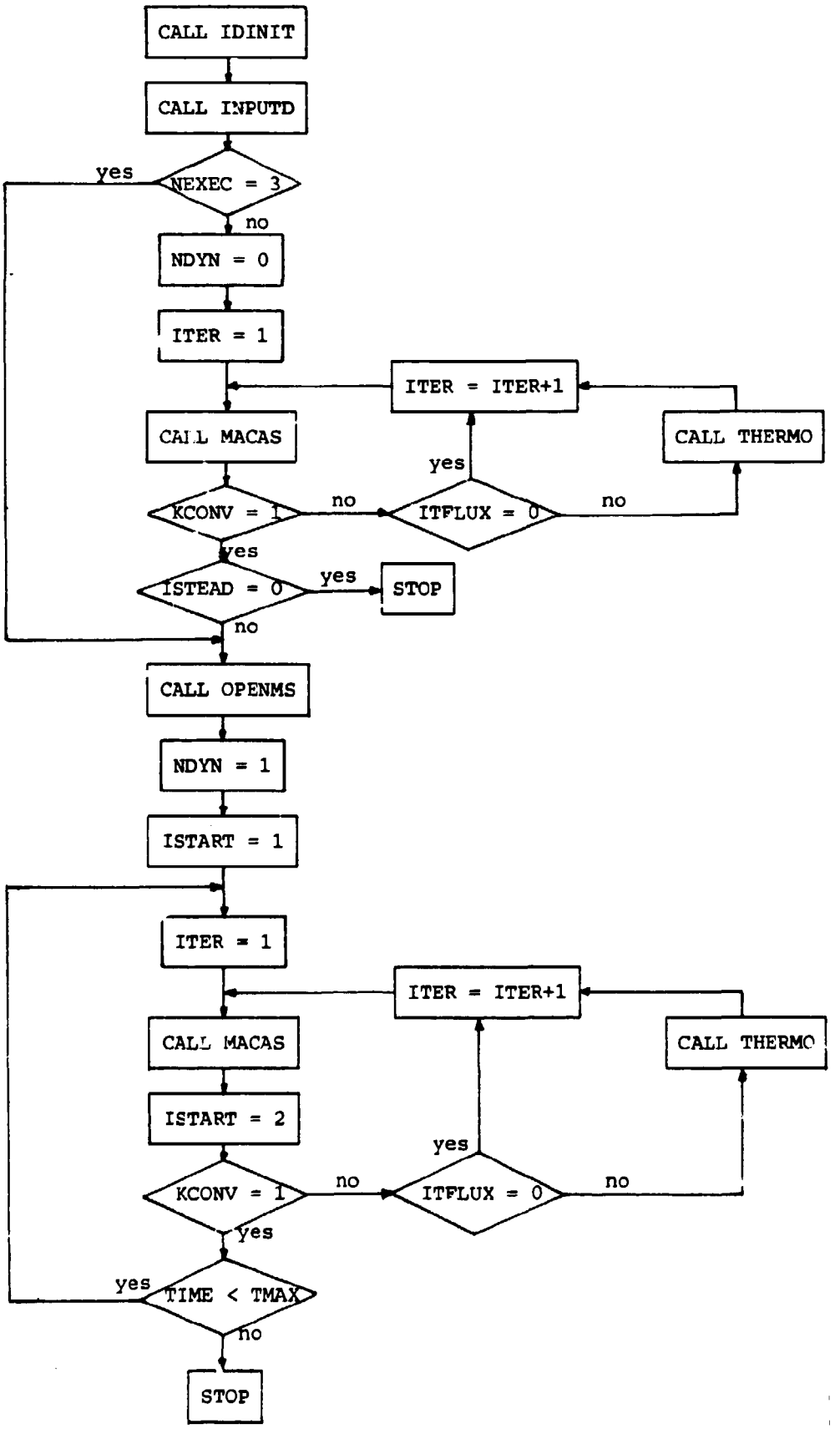
It has to be noted that, even if neutronics is not coupled with thermohydraulics (ITFLUX = 0), the iteration loops subsist (although THERMO is by-passed). The reasons are :

- in steady state : a possibility of criticality search exists in the code and KCONV in fact provides the result of the convergence test not only on the thermohydraulics feedback but also on the criticality; it means that, if criticality search is asked, the iterative process occurs anyway (see explanations of subroutine SPACE for more details);

- in unsteady state : the quasistatic method used for the time integration of the neutronic equations introduces a non-linearity in the problem, requiring an iterative process (Newton-SOR method) at each macro time step; this iterative process is combined with the iterations related to the thermohydraulics coupling in only one iterative scheme, so that the iterations subsist in absence of thermohydraulics feedback (see explanations of subroutine SHAPE for more details).

Remark : in steady state as in unsteady state, the number of iterations is bounded by a maximum value given in input, so that the program cannot cycle in case of non convergence; if this maximum value is reached, the convergence parameter KCONV is automatically put to 1 in SPACE or SHAPE.

Flow sheet of MAIN



Nomenclature

NEXEC : integer determining the 'level' of execution
if NEXEC = 0, the code starts the calculations with the equivalent preprocessing module
if NEXEC = 1, the code starts the calculations with the preprocessing module derived from MULCOS
if NEXEC = 2, the code starts the calculations with the static module
if NEXEC = 3, the code starts the calculations with the dynamic module

NDYN : when NDYN = 0, the code is executing static calculations
when NDYN = 1, the code is executing dynamic calculations

ISTEAD : if ISTEAD = 0, static calculations are not followed by dynamic calculations
if ISTEAD ≠ 0, static calculations are followed by dynamic calculations

ITFLUX : integer related to the thermohydraulics coupling
if ITFLUX = 0, no thermohydraulics coupling
if ITFLUX ≠ 0, neutronics is coupled with thermohydraulics

ITER : iteration number for static or dynamic calculations

KCONV : integer determining the convergence 'state' for [criticality search + thermohydraulics coupling] in steady state or [Newton-SOR iterative procedure + thermohydraulics coupling] in transient
if KCONV ≠ 1, convergence is not reached
if KCONV = 1, convergence is reached

ISTART : integer which is equal to 1 at the first calling to MACAS
> 1 at the next callings to MACAS
when ISTART = 1, it means that the initialization operations have to be performed before starting the dynamic calculations.

It has to be pointed out that in case of restart ISTART is put to a value > 1 in MACAS, because these initialization operations have to be switched.

5. DESCRIPTION OF SUBROUTINE MACAS

MACAS constitutes the actual MAIN of the neutronics part of CASSANDRE.

It manages the calling sequence to the preprocessing, statics and dynamics modules, as it can be seen on the flow sheet given hereafter.

As explained in the previous section, MACAS is called at each iteration on criticality search or thermohydraulics coupling in steady state and at each Newton-SOR iteration in unsteady state.

a) At the first iteration in steady state (ISTART = 1, NDYN = 0), the value of NEXEC is investigated to determine the sequence of the next steps :

   - if NEXEC = 0 or 1, the static calculations must be preceded by the preprocessing calculations; for NEXEC = 0, the code uses the so-called 'equivalent' preprocessing module (CALL PRINC2), whereas for NEXEC = 1, the preprocessing module derived from MULCOS is requested (CALL PRINC1);
   - if NEXEC = 2, the steady state calculations are immediately started with the calling to SPACE, which is the main routine of the statics module, and the preprocessing results obtained in a previous run and stored on file IPS will be used during these calculations.

   (though foreseen in the flow sheet of MACAS, the case NEXEC = 3 is uncompatible with NDYN = 0 and it may not occur).

b) At the first calling to MACAS in transient, i.e. at the first Newton-SOR iteration in the first macro time step (ISTART = 1, NDYN = 1), the program execution is directly switched to the calling to SHAPE, which is the main routine of the dynamics module.

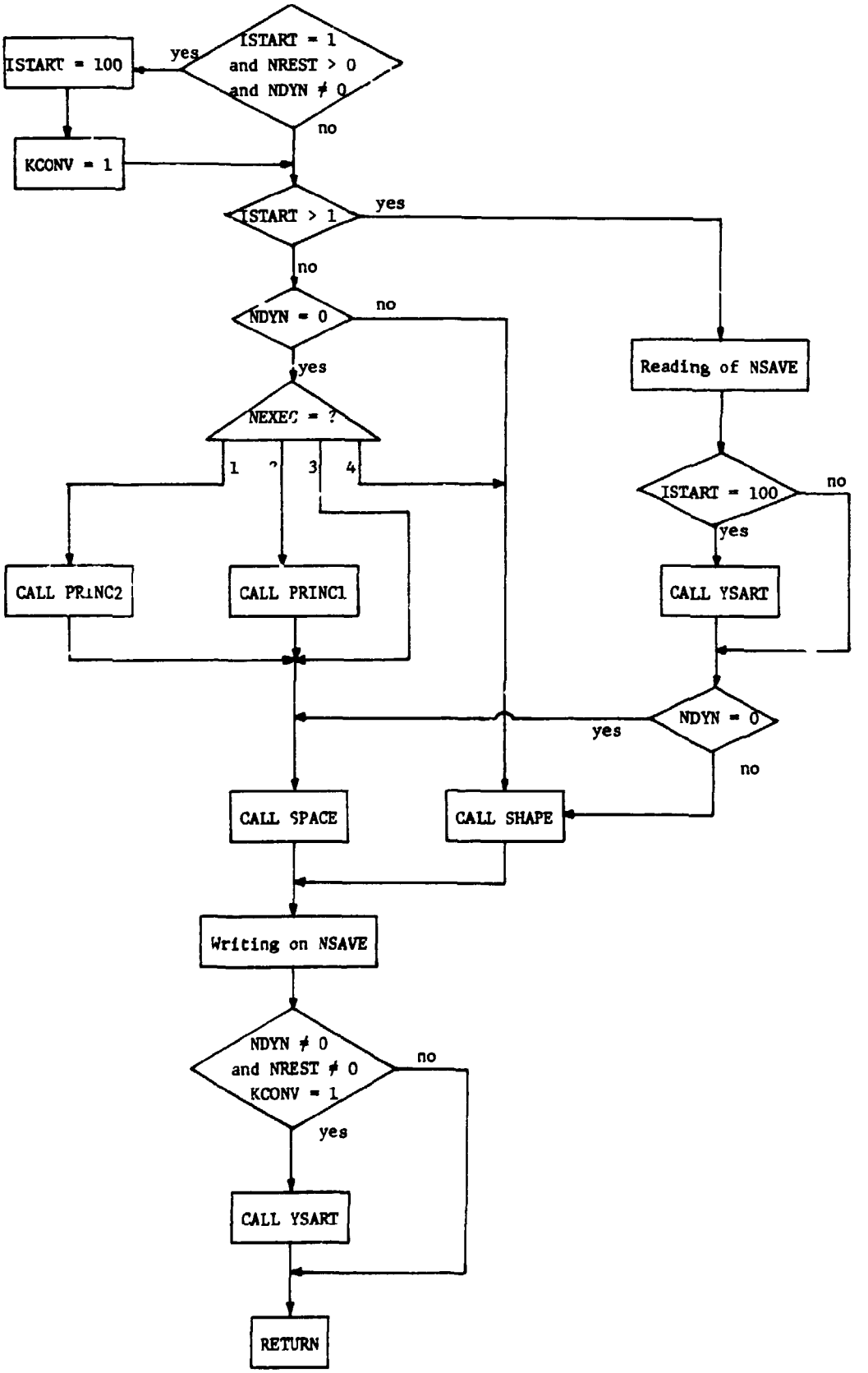
c) At the end of each iteration, as well in steady state as in transient, the dynamic allocation vector A and vector L are stored on file NSAVE.

d) At the second and next iterations (in steady state and in transient), the dynamic allocation vector A and vector L are read on file NSAVE and the program execution is pursued by the calling to SPACE or SHAPE according to the value of NDYN.

e) The storage of vectors A and L on file NSAVE have been introduced to liberate memory space for the thermohydraulics module and also to save results if a restart procedure is foreseen in a next run.

f) When the RESTART procedure is utilized (NREST $\neq$ 0), the saving of vectors A and L is not sufficient and the contents of some files (NTM, NCPL, NFO, NFX1, NADJNT) must be also saved on file NSAVE; this additional saving is obtained by calling to YSART and it is only performed when the calculations related to the current macro time step are ended (KCONV = 1); it means that a problem can be restarted only at the beginning of a new macro time step.
When a problem is restarted (NREST = 1), it is necessary to read on file NSAVE the results saved at the previous run and to reinitialize files NTM, NCPL, NFO, NFX1, NADJNT; this reinitialization is carried out by YSART, which is called when ISTART = 100 (the value 100 for ISTART indicates the first calling to MACAS for a restarted problem and ISTART is put afterwards to 2 in the MAIN for the next callings to MACAS).
As soon as this operation has been realized, the code may directly prosecute from the stopping point of the previous run.

Flow sheet of MACAS



Nomenclature

ISTART : ISTART = 1 at the first calling to MACAS in steady state and in transient

> 1 at the next callings to MACAS

NDYN : when NDYN = 0, the code is executing static calculations

when NDYN = 1, the code is executing dynamic calculations

NEXEC : integer determining the 'level' of execution

if NEXEC = 0, the code starts the calculations with the equivalent preprocessing module

if NEXEC = 1, the code starts the calculations with the preprocessing module derived from MULCOS

if NEXEC = 2, the code starts the calculations with the static module

if NEXEC = 3, the code starts the calculations with the dynamic module

NSAVE : number of the file on which the contents of the dynamic allocation vector are stored at each iteration

NREST : = 0 if the restart procedure is not required

= -1 at the first run of a transient problem starting from the steady state, if the restart procedure is foreseen for next runs

= +1 if the transient problem is restarted from the final results of a previous run.

6. THE INPUT MODULE

The purpose of the input module is the reading of the input data and a preliminary check of their validity. Due to its relatively limited task, this module obviously is the smallest one of the code.

The input module is constituted by 4 routines :

- subroutine INPUTD, which transfers the input data from file n° 5 to file INF5 and which calls to subroutine DATIN;

- subroutine DATIN, which is the most important routine of the input module; the essential operations carried on by DATIN are :
  - reading of the data on file INF5
  - allocation of some variables appearing as arguments in labeled common blocks
  - distribution of the other data between files IDP, IDS, IDD respectively for the preprocessing, static and dynamic modules (it has to be pointed out that the file numbers IDP, IDS, IDD are identical, i.e. they denote the same device, because they are never used simultaneously, but consecutively)
  - check of the validity of some input data and printing of messages in case of errors.

- subroutine TRERR, which is called by DATIN in case of input data error and prints out adequate messages according to the value of a code index;

- subroutine RW, which is called by DATIN and is used to copy a given number of data cards of file INF5 on file IDP, IDS or IDD with the same format.

The general procedure of input data reading is globally governed by the values of the parameters NEXEC and NREAD as schematized on the flow chart hereafter.

- NEXEC, which is an execution parameter taking the value :

  0 if the execution begins by calculations in the equivalent preprocessing module

  1 if the execution begins by calculations in the preprocessing module derived from MULCOS

  2 if the execution begins by calculations in the static module

  3 if the execution begins by calculations in the dynamic module

- NREAD, which is a reading parameter taking the value :

  0 if the input data set begins by data related to the equivalent preprocessing module

  1 if the input data set begins by data related to the preprocessing module derived from MULCOS

  2 if the input data set begins by data related to the static module

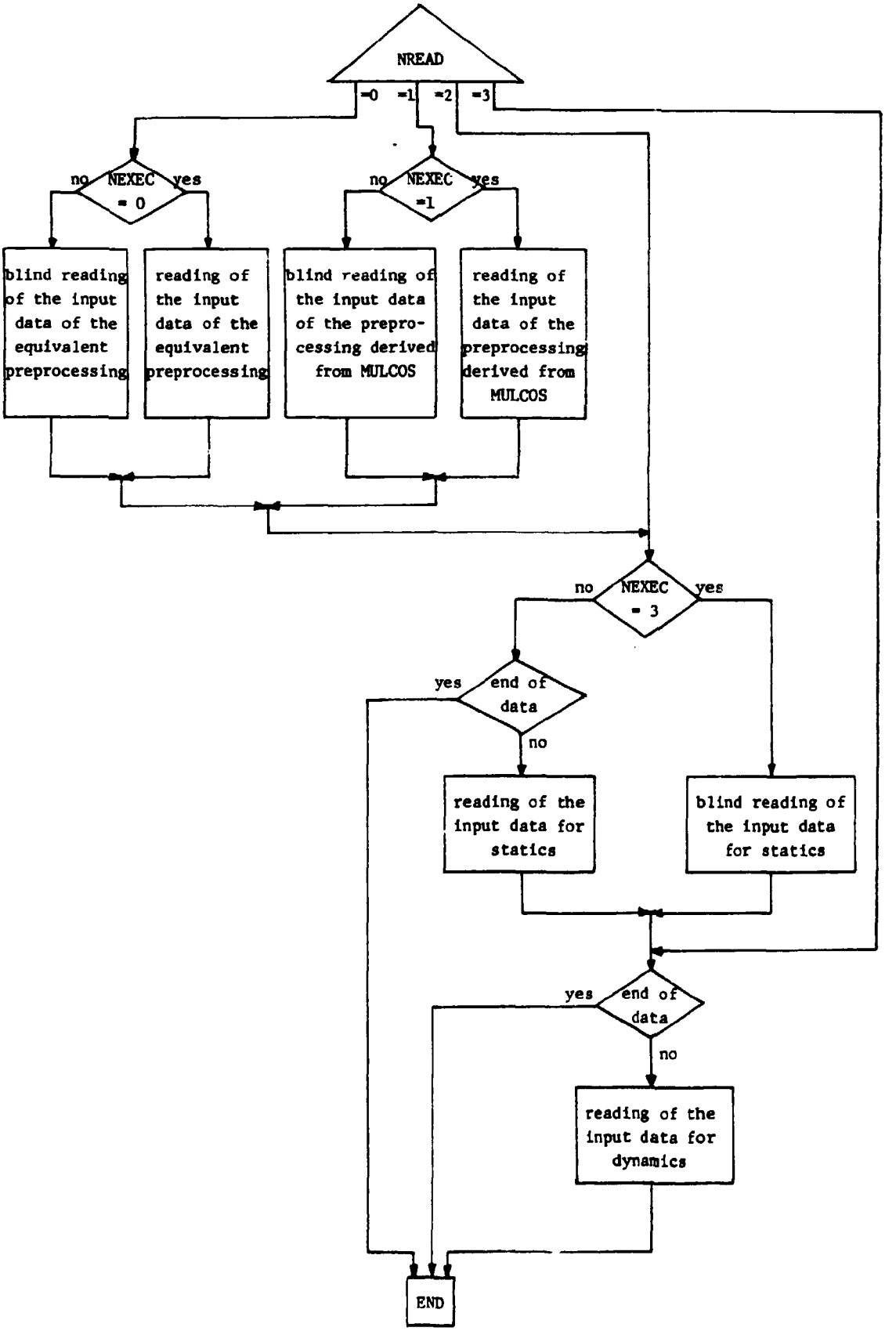
  3 if the input data begins by data related to the dynamic module.

Note that in any case we must have NEXEC $\geq$ NREAD.

In the following flow chart, the expression 'blind reading' means that the reading of the corresponding data set is performed without any effect, i.e. without allocation of the data values to the corresponding variables.

It can be observed in this flow chart that the preprocessing data must not be obligatorily followed by the static data. Nevertheless the structure of the code is conceived in such a way that the preprocessing calculations are supposed to be immediately followed by static calculations (see section 5). If it is wished to run the preprocessing in stand alone, it is then necessary to modify the MAIN and routine MACAS accordingly.

Flow chart for input data reading



7. THE PREPROCESSING MODULE

Before executing a steady or unsteady state calculation, it is necessary to known the neutronic properties of the materials, like the macroscopic cross-sections, the fission spectra, etc.
The determination of these properties is the matter of the preprocessing module.

First of all it can be useful to recall the important concept of mixture and composition, on which the physical model of the preprocessing of CASSANDRE is partially based.

If we observe in details the actual configuration of a given zone of the reactor, we find a certain number of components or mixtures generally heterogeneously reparted (e.g. UO_2-PuO_2, stainless steel, sodium,...); each of these mixtures is a constant and homogeneous combination of isotopes (e.g. U^{235}, U^{238}, O for UO_2-PuO_2, Fe, C, Ni, Cr for stainless steel) and is characterized by a type (fuel, cladding, coolant or structure). From a purely neutronic point of view these mixtures are supposed homogeneously combined in the considered zone and they constitute a composition; moreover their volume fractions may vary through material movements (e.g. control rod withdrawal, coolant voiding, etc.). Another important assumption is the homogeneity of the temperature of each mixture in each zone (or finite element), i.e. the mixture temperatures are spatially averaged in each zone. A same composition obviously can recover several zones, but the temperatures can vary from a zone to another one and we are then led to introduce the notion of 'thermal composition', which is characterized not only by its isotopical composition, but also by its mixture temperatures. Nevertheless this concept of thermal composition is not taken into account by the preprocessing, it is the matter of the static and dynamic modules.

To summarize, a mixture is a constant and homogeneous combination of isotopes

a composition is a variable and homogeneous combination of mixtures

Each mixture is characterized by a type and it has a mean temperature in each zone (or finite element).

The temperature dependence of the macroscopic cross-sections of the mixtures (due to Doppler effect and density variation) is assumed to be given in each energy group by :

$$\Sigma^m_{x,g}(T_m) = \Sigma^m_{x,g}(T_{mo}) + \int_{T_{mo}}^{T_m} \left[\frac{a^m_{x,g}}{\sqrt{T}} + \frac{b^m_{x,g}}{T} + \frac{c^m_{x,g}}{T^2}\right] dT \qquad (7.1)$$

where Σ^m is the macroscopic cross-section of mixture m

T_m is the mean temperature of mixture m in the zone

T_{mo} is a reference temperature

x refers to the physical process (fission, absorption,...)

g refers to the energy group

This law is general enough to cover the most usual cases.

The macroscopic cross-sections related to a composition C are then given by :

$$\Sigma^C_{x,g}(t) = \sum_{m \in C} f_{m,C}(T_m,t)\ \Sigma^m_{x,g}(T_m) \qquad (7.2)$$

where $f_{m,C}$ is the volume fraction of mixture m in composition C

t is the time

$\sum_{m \in C}$ denotes the sum on the mixtures of composition C

The main task of the preprocessing module is to provide the values of $\Sigma^m_{x,g}(T_{mo})$, $a^m_{x,g}$, $b^m_{x,g}$ and $c^m_{x,g}$ in (7.1) for each mixture m, each energy group g and each physical process x. In addition it must give the prompt fission spectrum. More concretely the preprocessing module must set up file IPS exactly as defined in appendix 3, since this file is the only interface between the preprocessing module and the static module.

In order to achieve this goal, two possibilities exist in the code CASSANDRE :

1) use of the preprocessing module derived from MULCOS [2] with the restriction that this module is only available for C.E.N./S.C.K.'s users and not provided outside;

2) use of the equivalent preprocessing module.

- The preprocessing derived from MULCOS computes the values of $\Sigma^m_{x,g}(T_{mo})$, $a^m_{x,g}$, $b^m_{x,g}$, $c^m_{x,g}$ from a multigroup microscopic cross-section library for a maximum of 60 isotopes.
  This library is parted into a 26 groups library and a 40 groups library.
  The macroscopic cross-sections of a mixture are computed from the microscopic cross-sections of the isotopes composing the mixture and from the atomic densities of these isotopes. These computation is carried out for each mixture at 4 given temperatures and according to a formalism taking into account the self shielding effects and detailed in [2]. The values of $\Sigma^m_{x,g}(T_m)$, $a^m_{x,g}$, $b^m_{x,g}$, $c^m_{x,g}$ are then deduced by interpolation.
  The use of the 26 and 40 groups libraries should need excessive computation times for transient problems. Therefore it has been introduces in the preprocessing the possibility to collapse the 26 groups library into a few groups library.
  The code names for the library isotopes, the energy partitioning for the 26 groups library and the best collapsing schemes are given in the section devoted to the input data.

- The equivalent preprocessing option can be applied when the macroscopic cross-sections of the mixtures and the fission spectrum are already known and given as input data. The task of the equivalent preprocessing module simply consists to transfer these input data to file IPS conformably to the description given in appendix 3.

- Any other preprocessing module can be introduced in CASSANDRE provided that this module creates as final results an output file respecting this conformity with file IPS.

8. THE STATIC MODULE

For practical considerations, it is logical to admit that any unsteady behaviour of the reactor is initiated from a steady state. The static module is aimed to determine such steady situations.
The numerical methods used for the steady state calculations are detailed in [1]. We limit here the explanations to the essential features which can be useful in the framework of this user's guide.

In section 4 it was already outlined that the static module offers the possibilities of criticality search and thermohydraulics coupling and that the corresponding iterative loops are introduced in the MAIN, while the convergence tests are performed in the static module itself.
The general principle of the iterative processes are schematized in figure 8.1. In this chart the dotted rectangle represents the static module; criticality search is required if ICRIT $\neq$ 0 and neutronics is coupled with thermohydraulics if ITFLUX $\neq$ 0. The result of the convergence tests is transmitted from the static module to the MAIN through the index KCONV as we shall see further.
It can be seen that the iteration loop on thermohydraulics coupling is inner with respect to the iteration loop on criticality search, i.e. before any change of poisoning in the reactor, convergence on thermohydraulics feedback has to be reached.

Now let us put more emphasis on routine SPACE, which is the main routine of the static module and which manages the calculations of the steady solution for a given reactor poisoning and a given temperature distribution.
As it was done previously for the MAIN and for routine MACAS, we illustrate the description of routine SPACE by its flow sheet followed by a nomenclature.

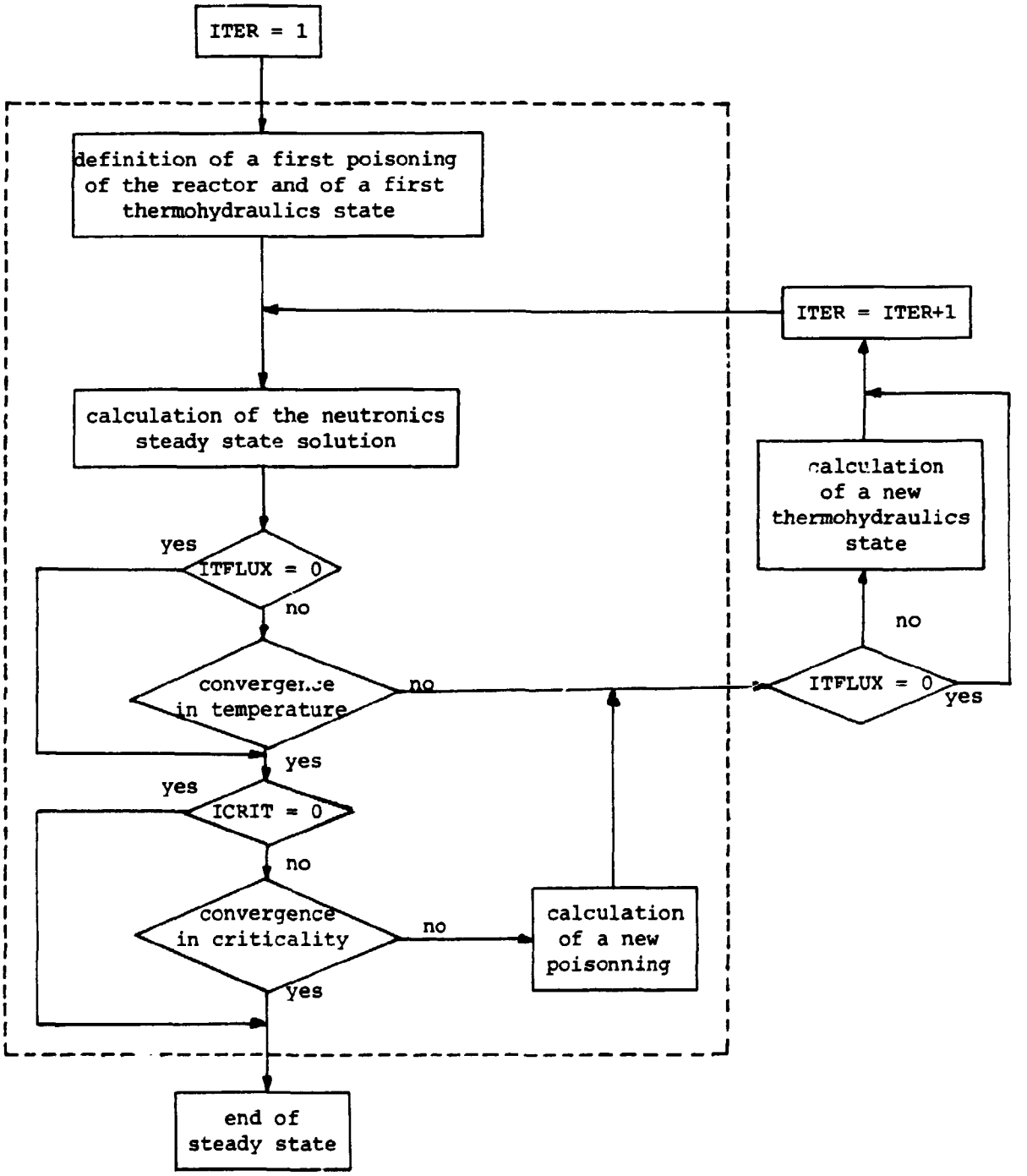

ITER = 1
definition of a first poisoning of the reactor and of a first thermohydraulics state
ITER = ITER+1
calculation of the neutronics steady state solution
calculation of a new thermohydraulics state
yes
ITFLUX = 0
no
convergence in temperature
no
ITFLUX = 0
yes
no
yes
yes
ICRIT = 0
no
convergence in criticality
no
calculation of a new poisonning
yes
end of steady state

FIGURE 8.1.

- At the first iteration (ITER = 1), i.e. at the first calling to SPACE, the program performs the initialization operations. Most of these operations are condensed in subroutine SPACIN : they comprise the initialization of some arrays and some files, the construction of the spatial mesh grid and of the lay-out of the reactor, preparative calculations for criticality search and for thermohydraulics coupling. Some parameters are directly initialized in SPACE (ISK, ISWTCH, KCONV, XKO).

- At the second and next iterations (ITER > 1), the reactor k_{eff} value obtained at the previous iteration is first memorized in XKO and the contents of file IPSM are read (CALL FR46).
  When criticality search is asked and convergence for temperature feedback (if any) has been reached (KCONV = 0), a new poisoning of the reactor is determined in routine HIGNEW to sight criticality, leading to a local change of the volume fractions of the mixtures and therefore of the contents of file IPSM; these new contents are then reinserted on file IPSM (CALL FW46). It has to be noted that, when criticality is searched by control rod insertion, the new position of the control rod(s) may modify the reactor lay-out (if the bottom of a control rod passes from a finite element to another one); in this case the parameter ISWTCH is put to 1 in routine HIGNEW to indicate that the reactor lay-out must be redefined.
  After that point the branches of the flow sheet related to the cases ITER = 1 and ITER > 1 meet again.

- A title related to the current iteration is printed out, when criticality search and/or thermohydraulics coupling are requested (CALL PRITER).

- If ISWTCH ≠ 0, the reactor lay-out modified by the new poisoning (see hereabove) is redefined in routine LAYNEW; at the first iteration (ITER = 1), LAYNEW is called anyway for a first determination of the 'thermal' lay-out of the reactor (see additional informations for file NFT in appendix 3).

- The mean mixture temperatures and densities are assigned to each 'thermal' composition (CALL TEFEED) on the basis of the thermohydraulics results or of the reference temperatures according to the thermohydraulics coupling model.

- All the informations needed for the computation of the macroscopic cross-sections are then available; this computation is performed in routine CROS2D.

- The steady state solution corresponding to this situation is determined in routine DISFLU and the new value of reactor k_{eff} value is put in XKEFF.

- If criticality search and/or thermohydraulics coupling are requested, convergence tests on the value of k_{eff} are performed in the next step; as explained at the beginning of this section, convergence on thermohydraulics coupling (if any) is first tested : if convergence is satisfied, KCONV is put to 0, otherwise it is put to -1 and the convergence test on criticality (if any) is switched off and deferred to next iteration(s); it means that a new poisoning of the reactor is not defined as long as the reactor k_{eff} is not stabilized with regard to the temperature feedback effects. Once this stabilization has been reached, the reactor criticality may be tested and if the k_{eff} value is close enough to 1, the reactor is considered critical (KCONV = 1).

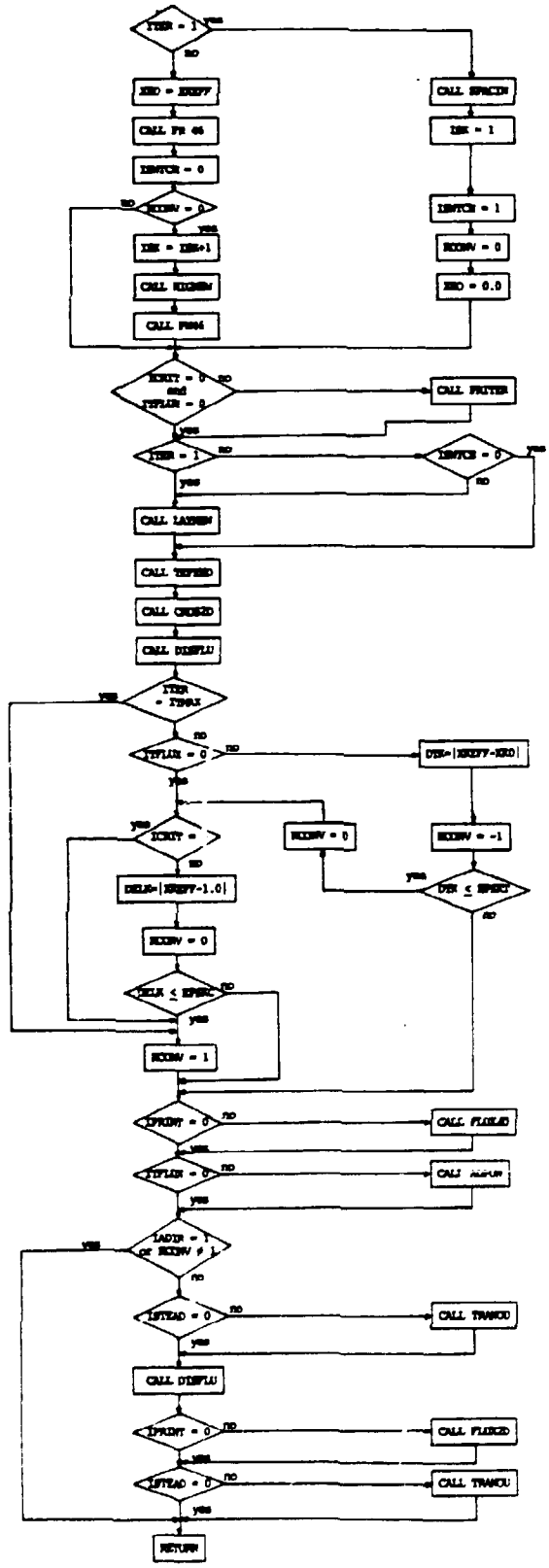
- If the printing of the neutron fluxes and power density distributions is required (IPRINT $\neq$ 0), routine FLUX2D is called.

- If thermohydraulics coupling is present (ITFLUX $\neq$ 0), the power density distribution is stored on file NCPL for the thermohydraulics module (CALL ADPOW).

- When the final steady state has been determined (KCONV), the calculations in SPACE are ended if IADIR = 1; otherwise the solution of the adjoint problem is required and determined in DISFLU. Beforehand, the steady state results are stored on file NFT in routine TRANOU, if a dynamic problem is foreseen afterwards (ISTEAD $\neq$ 0).

Adjoint fluxes are printed out if asked (IPRINT ≠ 0) and they are stored on file NFT for the dynamic calculations if necessary (ISTEAD ≠ 0).

Flow sheet of SPACE



Nomenclature

ITER : iteration number for the criticality search and/or thermohydraulics schemes

ITMAX: maximum permitted number of iterations for criticality search and/or thermohydraulics schemes

ICRIT: if ICRIT = 0, no criticality search
if ICRIT ≠ 0, criticality search by control rod(s) insertion or by homogeneous poisoning of the coolant

ITFLUX: if ITFLUX = 0, neutronics is dependent on thermohydraulics
if ITFLUX ≠ 0, neutronics is coupled with a thermohydraulics module

KCONV: if KCONV = -1, no convergence neither for criticality search nor for thermohydraulics feedback
if KCONV = 0, convergence for thermohydraulics feedback has been reached, but not yet for criticality search
if KCONV = 1, convergence has been reached both for criticality search and thermohydraulics feedback

ISK : iteration number for the criticality search scheme (i.e., without taking into account the iterations on thermohydraulics coupling

ISWTCH: if ISWTCH = 0, the reactor lay-out is not modified
if ISWTCH = 1, the new control rod(s) insertion modifies the reactor lay-out (the bottom of a control rod passes from a finite element to another one)

IADIR: if IADIR = 1, only the direct problem has to be solved
if IADIR = 2, the direct and adjoint problems are solved

ISTEAD: if ISTEAD = 0, the steady state will not be followed by transient calculations

if ISTEAD ≠ 0, a transient calculation will follow the steady state (either during the same run or during a next run)

IPRINT: if IPRINT = 0, printing of neutron fluxes and power densities is not asked

if IPRINT = 1, printing of neutron fluxes and power densities is required

XKEFF: value of the reactor k_{eff} obtained at the current iteration

XKO : value of the reactor k_{eff} obtained at the previous iteration

EPSKC: convergence criterion for criticality search

EPSKT: convergence criterion for thermohydraulics feedback

9. DYNAMIC MODULE

CASSANDRE essentially is a neutronics code for transient analysis and therefore its dynamic module constitutes the most original part of the code.
Any transient situation of a reactor is supposed starting from a steady state previously calculated, either during the same run of the code or during another run. In this last case the steady state results were stored on a permanent file (NFT).
As for the static module, we limit the explanations in this section to the essential features needed for practical uses, all the theoretical developments being detailed in [1].

The main characteristic of the dynamic module is the quasistatic approach for the time integration of the neutronic equations. Briefly the quasistatic method used in CASSANDRE consists in splitting the neutron flux ϕ_g in each energy group as :

$$\phi_g(\bar{r},t) = T_g(t)\ \Psi_g(\bar{r},t),$$

where $T_g(t)$ is a time dependent function called 'amplitude function', containing the major part of the time dependence of ϕ_g, and $\Psi_g(\bar{r},t)$ is a space - time dependent function called 'shape function' giving the space distribution of the flux shape and varying slowly with the time (with regard to T_g).

The original multigroup diffusion equations are then transformed into a set of coupled equations : the multigroup point-kinetics equations and the multigroup shape function equations; the non linearity induced by this coupling implies that the system of equations must be solved iteratively, more precisely by the Newton-SOR method.

Because of the slow variation of the shape functions with respect to the amplitude functions, two different time scales are used for the time integration : a 'macro time step' size H is used for the calculation of the shape functions, whereas the amplitude functions are determined with a 'micro time step' size h, submultiple of H; i.e. at

each macro time step, the point-kinetics equations are successively solved $n = \frac{H}{h}$ times. When temperature feedback effects are taken into account, the iterations on the neutronics-thermohydraulics coupling are combined with the Newton-SOR iterations and this at each time step. A simplified flow chart of the dynamic module is given in figure 9.1. to illustrate this computational strategy.

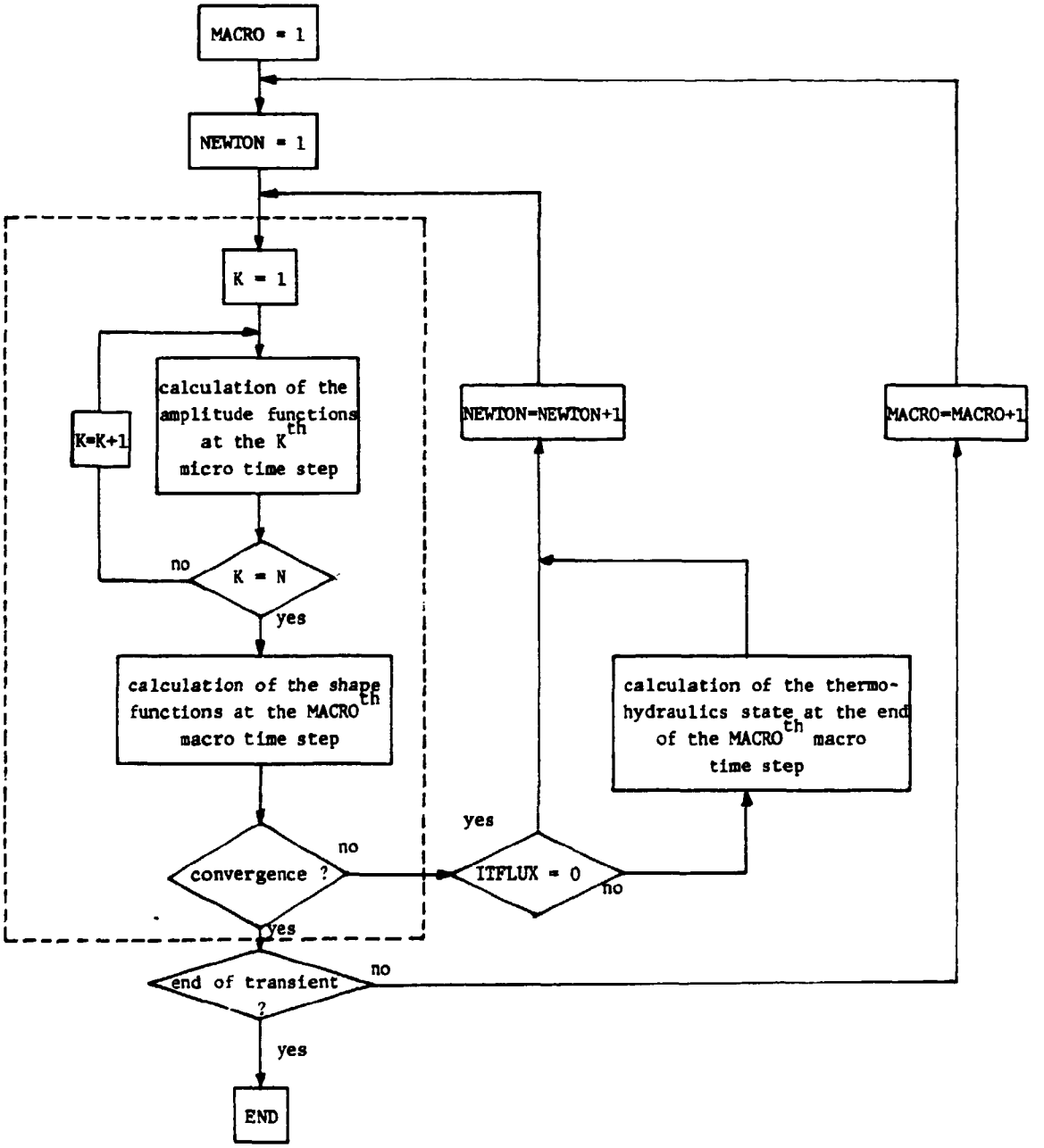

MACRO = 1
NEWTON = 1
K = 1
calculation of the amplitude functions at the K^th micro time step
K=K+1
no
K = N
yes
calculation of the shape functions at the MACRO^th macro time step
convergence ?
no
yes
ITFLUX = 0
yes
no
NEWTON=NEWTON+1
calculation of the thermo-hydraulics state at the end of the MACRO^th macro time step
MACRO=MACRO+1
end of transient ?
no
yes
END

FIGURE 9.1.

The dotted rectangle represents the dynamic module of CASSANDRE. As for the static module, the iterative loops between neutronics and thermohydraulics are introduced in the MAIN, but the convergence tests are performed in the dynamic module itself and the result of these tests is transmitted to the MAIN through the index KCONV (see further).
In the flow chart hereabove, K is the micro time step number, NEWTON is the Newton-SOR iteration number, MACRO is the macro time step number and ITFLUX ≠ 0 if neutronics is coupled with thermohydraulics.

The main routine of the dynamic module is routine SHAPE, which manages the most important steps of the transient neutronics calculations. The flow sheet of SHAPE followed by a nomenclature is given hereafter.

- at the beginning of the transient (ISTART = 1), the program performs the initialization operations for the dynamic calculations. Most of these operations are condensed in subroutine SHAPIN : initialization of some variables and some files, reading of the steady state results, calculation of the initial k_{eff} value, and so on. Some variables are directly initialized in SHAPE (TIME, MACRO, KCONV).

- at the beginning of each macro time step, NEWTON and KCONV are put to 0 (the value of KCONV at the end of the previous macro time step was 1, see further), and the first task is the selection of the macro time step length PMAC according to the value of ICMAP : if ICMAP is equal to 1, PMAC is automatically controlled by the code in subroutine MACON; if ICMAP = 0, PMAC takes the MACROth value specified in the input data (CALL SMAP); if ICMAP = -1, PMAC is constant during the whole transient. The second task is the prediction of the power density distribution at the end of the macro time step (excepted for the first macro time step). This power density prediction is based on a simplified point-kinetics model with temperature feedback, whose coefficient is determined from the results obtained at the previous macro time steps (see [1]). The reasons of the introduction of such prediction model are :

- if the macro time step is automatically controlled by the code, the power prediction allows to check that the macro time step will satisfy the condition on the maximum permitted power variation;
- if neutronics is coupled with thermohydraulics, it is important to have a sufficiently good estimate of the temperature distribution at the end of the macro time step; a bad estimate should yield unaccurate neutronic cross-sections and therefore large oscillations of the results in the Newton-SOR iterative process. Obviously the determination of this temperature distribution necessitates the prediction of the power density distribution.

The power variation during the macro time step is predicted in subroutine POWPRE.
In presence of neutronics-thermohydraulics coupling (ITFLUX $\neq$ 0), the power density distribution is deduced in subroutine PRIWAT. Then the program execution leaves subroutine SHAPE and the neutronics part of the code; it enters in the thermohydraulic module to determine the corresponding temperature distribution and it returns afterwards in SHAPE at the point it left this routine. It has to be noted that this supplementary iteration for temperature prediction is not counted as Newton-SOR iteration.

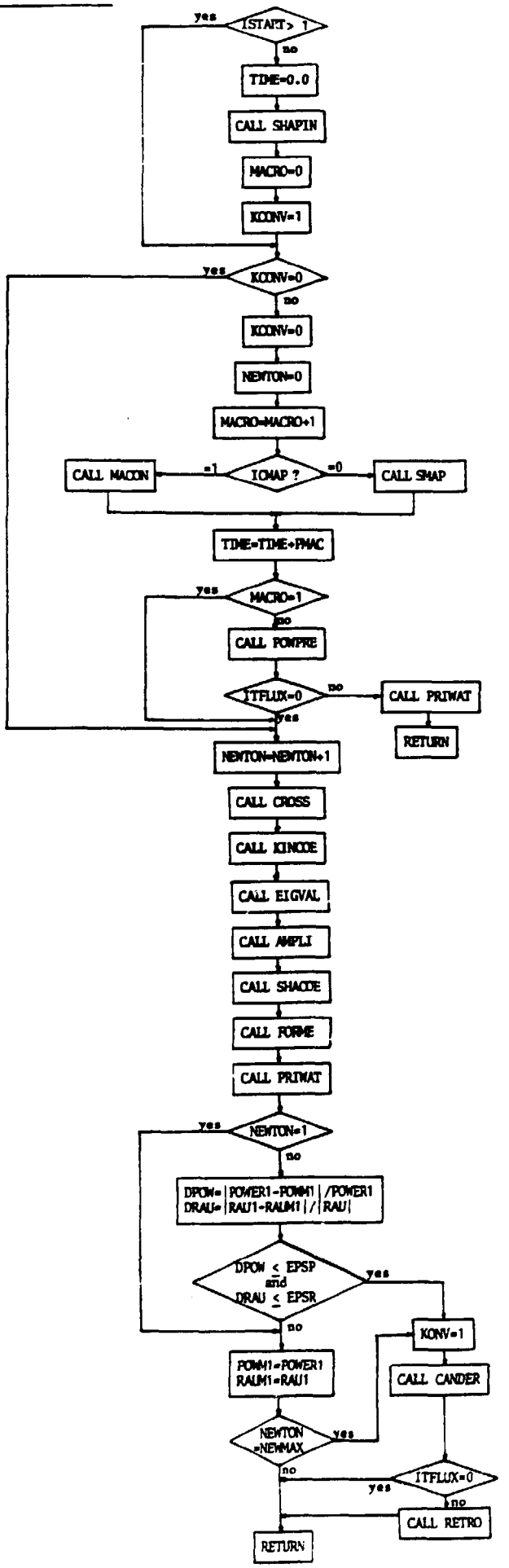
- at each Newton-SOR iteration the following steps are successively performed :
  - computation of the macroscopic cross-sections at the end of the macro time step (CALL CROSS); these cross-sections are computed according to the values of the driving functions and the temperature distribution at the end of the macro time step; if control rods are moving, the reactor lay out is modified if necessary.
  - determination of the multigroup point-kinetics parameters appearing in the amplitude functions equations (CALL KINCOE);
  - calculation of the dominant eigenvalue of the amplitude functions equations (CALL EIGVAL);
  - solution of the amplitude functions equations (CALL AMPLI);
  - computation of some coefficients depending on the amplitude functions values and appearing in the shape functions equations (CALL SHACOE);
  - solution of the shape functions equations (CALL FORME);

- calculation of the power density distribution at each micro time step (if ITFLUX ≠ 0) and printing of the power and neutronic fluxes at the specified times in the macro time step (CALL PRIWAT).

- in order to stop the Newton-SOR iterations, convergence tests are performed on the values of the total reactor power and reactivity. If convergence is obtained or if the maximum number of Newton-SOR iterations is reached, KCONV is put 1 to indicate that the Newton-SOR procedure has to be stopped. In this case routine CANDER is called to determine the shape functions related to the precursors concentrations and to reinitialize some files for the next macro time step. Moreover if neutronics is coupled with thermohydraulics (ITFLUX ≠ 0), the feedback reactivity is determined in routine RFTRO.

Remark : it is important to point out that the fission macroscopic cross-sections are divided by the k_{eff} value of the reactor at time t=0 in order to insure a rigorous stationarity of the initial state. The value taken for k_{eff} is not the value calculated by the static module, but it is recomputed at the beginning of the transient in routine RAU.

Flow sheet of SHAPE



Nomenclature

ISTART : ISTART = 1 at the first calling to SHAPE and at the beginning of the transient
ISTART ≠ 1 otherwise

KCONV : if KCONV = 0, convergence on the Newton-SOR iterations has not yet been reached
if KCONV = 1, convergence on the Newton-SOR iterations has been reached and the calculations for a new macro time step can begin

ITFLUX : if ITFLUX = 0, neutronics is independent on thermohydraulics
if ITFLUX ≠ 0, neutronics is coupled with a thermohydraulics module

MACRO : macro time step number

NEWTON : if NEWTON ≠ 0, NEWTON is the Newton-SOR iteration number in the considered macro time step
if NEWTON = 0, it means that preliminary calculations have to be carried out in the considered macro time step before starting the Newton-SOR process

NEWMAX : maximum permitted number of Newton-SOR iterations in the considered macro time step

ICMAP : if ICMAP = 1, the macro time step length is controlled automatically by the code
if ICMAP ≠ 1, the macro time step length is imposed by the user

TIME : current time

PMAC : macro time step length

POWER1 : total power of the reactor at the end of the current macro time step and at the last Newton-SOR iteration

POWM1 : total power of the reactor at the end of the current macro time step and at the previous Newton-SOR iteration

RAU1 : reactivity of the reactor at the end of the current macro time step and at the last Newton-SOR iteration

RAUM1 : reactivity of the reactor at the end of the current macro time step and at the previous Newton-SOR iteration

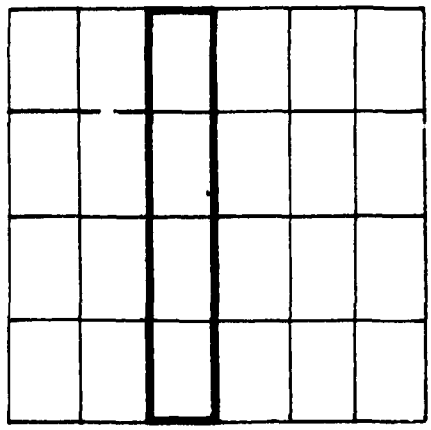
EPSP : convergence criterion on the total power of the reactor for the Newton-SOR iterations

EPSR : convergence criterion on the reactivity of the reactor for the Newton-SOR iterations

10. COUPLING WITH THERMOHYDRAULICS

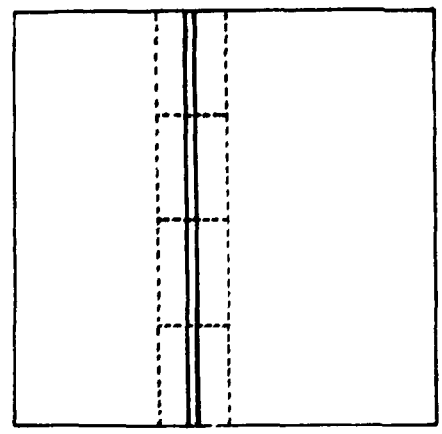
For practical applications, it is necessary to take into account the feedback effects due to the dependence of the macroscopic cross-sections on the temperatures and volume fractions of the materials (e.g. Doppler effect, voiding effect, etc.). It was already outlined in the present report (see sections 2, 3, 4) that in principle any thermohydraulics module may be coupled with the neutronic part of CASSANDRE. The only restriction is that the transients must be limited to the pre-disassembly phase. In order to realize this coupling it is obviously necessary to adapt the thermohydraulics module to the interface requirements, i.e. the numerical values transfered from neutronics to thermohydraulics and reciprocally must be transmitted only through file NCPL in conformity to the specifications detailed in appendix 3. The iterative processes between neutronics and thermohydraulics have been described in section 4.

Since the macroscopic cross-sections are supposed homogeneous in each zone (or finite element), only averaged temperatures of the mixtures in these zones are to be provided by thermohydraulics. It means that the thermohydraulics module must be completed - if necessary - by routine(s) performing the averaging. Let us clarify this aspect by means of the following figures.



neutronic

FIGURE 10.1a



thermohydraulic

FIGURE 10.1b

From the neutronic point of view, we may decompose the core in 'neutronic' assemblies, each assembly being constituted by superposed elements as shown in figure 10.1a.

Now from the thermohydraulic point of view, we may represent this 'neutronic' assembly for example by one fuel rod channel or by one subassembly whose behaviour is supposed to reproduce the mean behaviour of all the channels or subassemblies comprised in the 'neutronic' assembly (see figure 10.1b).

The temperature profiles so obtained have then to be averaged radially and axially in each element of the 'neutronic' assembly to provide the desired temperatures.

In order to illustrate this coupling model, the version of CASSANDRE available for external users is supplied with a very simplified thermohydraulics module based on the single fuel rod channel and detailed in appendix 7.

11. RESTART PROCEDURE

In many cases it can be useful to have the possibility to restart a problem provisionally stopped before the end of the calculations. This capability has been introduced in CASSANDRE for transient calculations. Moreover it is possible to modify some parameters for the restarted problem.
In this section we explain the essential features related to the restart procedure and the practical way to apply it.

The main parameter governing the restart procedure is NREST defined in the first input data card (see section 12).

If NREST = 0, the restart possibility is not utilized.

If NREST $\neq$ 0, the restart procedure is applied

NREST = -1 for the first transient run, i.e. for the job run in which the transient is started at the initial time t = 0

NREST = 1 for the next transient runs, for each of these runs, the transient is restarted from the time at which the problem was stopped in the previous run.

It has to be pointed out that, when NREST $\neq$ 0, the results are stored on file NSAVE at the end of each macro time step and they replace those ones of the previous macro time step. It implies that :

- the whole history of the transient is not stored on NSAVE;
- a problem can restart only at the beginning of a new macro time step and not in the middle of a macro time step (e.g. for a new Newton-SOR iteration of the last macro time step)
- it is possible to restart a problem untimely stopped (e.g. computer failure).

Some input data may be modified for a restarted problem. They are :

1) TMAX : the transient duration (see card 302.0), which is the parameter governing the stop of the job

2) TLOF : constant of the time decrease of the coolant flow rate (see card 302.0)

3) ICMAP : parameter related to the specification of the macro time steps (see card 304.0); this parameter can only be changed to the values 1 or -1 (e.g. the changes 0 → 1 or 1 → -1 are permitted, but not 1 → 0)

4) PMAC : macro time step length (see card 305.0), if ICMAP = -1

5) PMAC1, PMAX, PMIN, FRMIN, DPLIM, RPOM : see card 310.0, if ICMAP = 1

6) NEWMAX : maximum number of Newton-SOR iterations
   NMICI : number of micro time steps
   (see card 311.0 if ICMAP = ± 1)

7) NROD, F0, F1, F2, TS, TF : see card 320.1, if IROD > 0
   NCOM, IMDF, F0, F1, F2, TS, TF : see card 321.1, if IROD < 0

8) EPSF : convergence criterion on the shape functions
   EPSP : convergence criterion on the total reactor power
   EPSR : convergence criterion on the reactor reactivity
   (see card 324.0)

Consequently, it is possible for a restarted problem to modify :
- the characteristics of the driving functions (e.g. velocity of control rod withdrawal)
- some important characteristics related to the time integration
- some convergence criteria.

Finally, when the restart procedure is used, it is necessary to specify that files NSAVE and IPSD must be permanent.

12. INPUT DATA

A description of the input data needed for the execution of a problem is given in this section.

Cards 001.0 → 011.0 are the input data related to the equivalent preprocessing module.

Cards 100.0 → 117.0 are the input data related to the MULCOS preprocessing module.

Cards 200.0 → 233.0 are the input data related to the static module

Cards 300.0 → 328.0 are the input data related to the dynamic module.

Additional comments clarifying the comprehension of these input data are supplied at the end of the section.

PROLOGUE DATA			
Card	Variables	Format	Definition
0.0	NEXEC	3I4	NEXEC is a run variable = 0 : the execution of the job begins with calculations in the equivalent preprocessing module, eventually followed by static and dynamic calculations. = 1 : the execution of the job begins with calculations in the MULCOS preprocessing module, eventually followed by static and dynamic calculations. = 2 : the execution of the job begins directly with calculations in the static module, eventually followed by dynamic calculations. = 3 : the execution of the job begins directly with calculations in the dynamic module (see sections 5, 6)
	NREAD		NREAD is a reading variable = 0 : data are given for equivalent preprocessing, and eventually static and dynamic calculations = 1 : data are given for MULCOS preprocessing and eventually static and dynamic calculations = 2 : data are given only for static and eventually dynamic calculations = 3 : data are given only for dynamic calculations One must have NEXEC $\geq$ NREAD (see section 6)
	NREST		NREST is a restart variable The value of NREST is only used for dynamic calculations = 0 : no possibility of RESTART = -1: a dynamic calculation is started from the initial time with possibility of restart for next runs

			= 1 : a dynamic calculation is restarted from the end of a previous run (see section 11) If NREST = 1, one must have NEXEC = 3.
If NREAD = 0 GO TO CARD 001.0 If NREAD = 1 GO TO CARD 100.0 If NREAD = 2 GO TO CARD 200.0 If NREAD = 3 GO TO CARD 300.0			

EQUIVALENT PREPROCESSING DATA			
Card	Variable(s)	Format	Definition
001.0	ML	5I4	number of mixtures ($1 \leq ML \leq 30$)
	NGM		number of energy groups ($1 \leq NGM \leq 40$)
	NGU		maximum number of energy group jumps by up-scattering
	NGD		maximum number of energy group jumps by down-scattering (see comment 1)
	MT		number of compositions ($1 \leq MT \leq 30$)
002.0	TYPE(ML)	20A4	key-words describing the types of the mixtures = 'bCOM' for fuel = 'bCLD' for cladding = 'bSOD' for coolant = 'bSTR' for structure material
003.1	NMELA(1)	26I3	number of mixtures in composition 1
.			
.	NMEL(1,I), I=1,NMELA(1)		numbers of the NMELA(1) mixtures of composition 1
.			
.			card 003.1 has to be repeated MT times,
003.MT	NMELA(MT)	26I3	i.e. for each composition
	NMEL(MT,I) I=1,NMELA(MT)		
004.1	FRAC(1,I) I=1,NMELA(1)	6E12.4	initial volume fractions of the NMELA(1) mixtures of composition 1
.			
.			card 004.1 has to be repeated MT times,
.			i.e. for each composition
.			
004.MT	FRAC(MT,I), I=1,NMELA(MT)	6E12.4	
005.0	ITK(ML)	16I5	reference temperatures at which the macroscopic cross-sections are given for the ML mixtures (°K)

006.1 . . . 006.IHM . . . 006.IHM*4 . . . 006.IHM*4 *ML	CTOT(1,1,IG,1), IG=1,NGM CTOT(1,1,IG,IHM), IG=1,NGM CTOT(4,1,IG,IHM), IG=1,NGM CTOT(4,ML,IG,IHM) IG=1,NGM	6E12.4 6E12.4 6E12.4 6E12.4	multigroup macroscopic cross-sections of the mixtures (cm^{-1}) (see comment 2) card 006.1 has to be repeated IHM times cards 006.1 → 006.IHM have to be repeated 4 times cards 006.1 → 006.IHM*4 have to be repeated ML times
007.0	VELOC(NGM)	6E12.4	velocities corresponding to the NGM energy groups (cm/sec)
008.0	CHI(NGM)	6E12.4	prompt fission spectrum in the NGM energy groups (see comment 3)
00.9	NL	I4	number of fuel isotopes (or fuel mixtures) (see comment 4)
010.0	NISONL(NL)	10I4	numbers of the NL fuel isotopes (mixtures)
011.0	END	A4	= 'ENDP'
If no data for steady state calculations GO TO CARD 328.0 (see comment 5) If data for steady state calculations GO TO CARD 200.0			

MULCOS PREPROCESSING DATA			
Card	Variable(s)	Format	Definition
100.0	ML	3I4	number of mixtures ($1 \leq ML \leq 30$)
	IPRINT		= 0 if no printing of intermediate preprocessing results
			= 1 if printing of intermediate preprocessing results
	ICROS		= 0 if no printing of the cross-sections
			= 1 if printing of the cross-sections
101.1	TIT	A8	= 'bMIXTURE'
	NMIX(1)	I4	number of the first mixture
101.2	ITK(1,K),K=1,4	4I8,A4,I4	4 base temperatures for the mixture (°K) (see comment 6)
	TYPE(1)		key-word describing the type of the mixture
			= 'bCOM' for fuel = 'bCLD' for cladding = 'bSOD' for coolant = 'bSTR' for structure material
	NIS		number of isotopes in the mixture (≤ 30)
101.3	NAME(1)	A8,4X,E12.4	name of the first isotope in the mixture (see below for the code names)
.			
.			
.	C(1)		atomic density of the first isotope in the mixture (10^{24} at/cm^3)
.			
.			
.			
101.2+NIS	NAME(NIS)		(card 101.3 has to be repeated NIS times, i.e. for each isotope in the mixture)
.	C(NIS)		
.			
.			(cards 101.1 → 101.2+NIS have to be repeated ML times, i.e. for each mixture)
.			
102.0	END	A8	= 'ENDPMbbb'
103.0	MT	I4	number of compositions ($1 \leq MT \leq 30$)
104.1	NMELA(1)=NM	I4	number of mixtures in the first composition (≤ 30)

104.2 . . . . . 104.1+NM	NMEL(1,1) FRAC(1,1) NMEL(1,NM) FRAC(1,NM)	I4,E12.4	number of the first mixture in the composition initial volume fraction of the first mixture in the composition (card 104.2 has to be repeated NM times, i.e. for each mixture in the composition) (cards 104.1 → 104.1+NM have to be repeated MT times, i.e. for each composition)
105.0	END	A8	= 'ENDPCbbb'
106.0	NL	I4	number of fuel isotopes (or fuel mixtures) to be considered separately ($1 \leq NL \leq 10$) (see comment 7)
107.0	NISONL(NL)	10I4	numbers of the N fuel mixtures when the fuel isotopes have been separated
108.0	TIT NGM	3A8,I4	= 'bLIBRARYbKFK-NAP-26bGR.b' 40 if original 26 (or 40)-groups library is used (option A) or = 'bFEWGRbbbbbbbbbbbSCHEMEb' if collapsing is asked (option B) number of energy groups ($NGM \leq 40$)
IF OPTION A GO TO CARD 117.0			
109.0	NUMGR(1,IG),IG=1, NGM	20I4	numbers of the first fine groups
110.0	NUMGR(2,IG),IG=1, NGM	20I4	numbers of the last fine groups (see comment 8)
111.0	TIT IDLIB	2A8,I4	= 'bKFK-NA-26bGR.bb' = 26
112.0	NISL	I4	total number of isotopes
113.0	NAML(NISL)	8(A8,2X)	list of the isotopes (see below for the code names)

114.0	NSPEC	4X,I4	number of spectra to be associated to the compositions for the collapsing (see comment 9)
115.0	NUMSP(MT)	20I4	numbers of the spectra to be associated to the MT composition. (NUMSP (NCOM) is the number of the spectrum associated to composition NCOM)
116.0	FLUX(IG), IG=1,26	6E12.4	first spectrum (card 116.0 has to be repeated NSPEC times, i.e. for each spectrum)
117.0	END	A4	= 'ENDP'
If no data for steady state calculations GO TO CARD 325.0 (see comment 5) If data for steady state calculations GO TO CARD 200.0.			

Code names for the isotopes of the library

Character position	Character position	Character position
1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8
H 0 0 1	C R	U 2 3 8 B L
D 0 0 2	C R B L	P U 2 3 9
H E 0 0 4	F E	P U 2 3 9 B L
L I 0 0 6	F E B L	P U 2 4 0
B E 0 0 9	N I	P U 2 4 1
B 0 1 0	N I B L	P U 2 4 2
B 0 1 1	C U	P F P U 9
C 0 1 2	Z R	X E 1 3 5 * *
C 0 1 2 B L	N B 0 9 3	S M 1 4 9 * *
N 0 1 4	M O	U 2 3 4 * *
O 0 1 6	E U	P A 2 3 3
O 0 1 6 B L	G D	N P 2 3 9 $ $
N A 0 2 3	H F	
N A 0 2 3 B L	T A 1 8 1	
M G	P B	
A L 0 2 7	B I 2 0 9	
S I 0 2 8	T H 2 3 2	
K	U 2 3 3	
C A	U 2 3 5	
C L 0 3 5	U 2 3 5 B L	
T I	U 2 3 6	
V 0 5 1	U 2 3 8	

The second and third characters correspond to the usual symbol for the isotope.

The 3 next characters correspond to the atomic mass of the isotope.

For some isotopes the characters BL are added in positions 7 and 8 and they indicate that the cross-sections have been corrected to take into account the blanket spectrum.

PFPU9 is related to the fission products of Pu^{239}.

Partitioning of the 26 groups library

Group number	Energy range
1	10.5 - 6.5 MeV
2	6.5 - 4.0 MeV
3	4.0 - 2.5 MeV
4	2.4 - 1.4 MeV
5	1.4 - 0.8 MeV
6	800 - 400 keV
7	400 - 200 keV
8	200 - 100 keV
9	100 - 46.5 keV
10	46.5 - 21.5 keV
11	21.5 - 10.0 keV
12	10.0 - 4.65 keV
13	4.65 - 2.15 keV
14	2.15 - 1.0 keV
15	1000 - 465 eV
16	465 - 215 eV
17	215 - 100 eV
18	100 - 46.5 eV
19	46.5 - 21.5 eV
20	21.5 - 10.0 eV
21	10.0 - 4.65 eV
22	4.65 - 2.15 eV
23	2.15 - 1.0 eV
24	1.0 - 0.465 eV
25	0.465 - 0.215 eV
26	0.0253 eV

Optimized collapsing

According to [*] the best few-group condensions are :

12 groups : 1-3, 4-4, 5-5, 6-6, 7-7, 8-9, 10-10, 11-12, 13-13, 14-15, 16-17, 18-26

10 groups : 1-3, 4-4, 5-5, 6-6, 7-7, 8-9, 10-10, 12-12, 13-13, 14-26

8 groups : 1-3, 4-6, 7-7, 8-9, 10-10, 11-12, 13-13, 14-26

7 groups : 1-3, 4-6, 7-7, 8-9, 10-10, 11-13, 14-26

6 groups : 1-3, 4-6, 7-7, 8-9, 10-13, 14-26.

[*] Nuclear Science and Engineering n° 53, Vol. 3, pp. 337.

STEADY STATE DATA			
Card	Variable(s)	Format	Definition
200.0	TITLE(8)	8A8	Title for steady state calculations
201.0	GENER	2A8	= 'bSSbGENERALITIES'
202.0	IPROB	7I3	= 1 for independent source problem = 2 for eigenvalue problem (see comment 10)
	ICRIT		= 0 if no criticality search > 0 for criticality search by control rod insertion < 0 for criticality search by homogeneous poisoning of the coolant with mixture |ICRIT| (see comment 11)
	IBTOT		number of control rods to be considered for the steady and/or unsteady state calculations ($\leq$ 5)
	ISTMAX		maximum number of iterations for criticality search and/or thermohydraulics coupling (put 0 if no criticality search and no thermohydraulics coupling
	ITFLUX		= 0 if neutronics is not coupled with thermohydraulics $\neq$ 0 if neutronics is coupled with a thermohydraulics module and ITFLUX is the number of compositions submitted to thermohydraulics feedback
	ISTEAD		= 0 if the steady state will be followed by a transient $\neq$ 0 if not (see comment 12)
	IADIR		= 1 only direct problem is solved = 2 direct and adjoint problems are solved (see comment 13)
203.0	ICHEB	2I3	= 0 if no Chebychev acceleration for the power method = 1 if power method is accelerated by Chebychev scheme (put 0 if IPROB = 1)

	ITEMAX		maximum number of iterations for the power method (IPROB = 1) or for the rebalancing method (IPROB = 2) (see comment 14)
204.0	GEOM	2A8	= 'bSSbGEOMETRYbbbb'
205.0	NG	4I3	= 0 for rectangular geometry (x-y) = 1 for axisymmetric geometry (r-z)
	NDG		= 1 for bilinear basis functions = 2 for biquadratic basis functions = 3 for bicubic basis functions (see comment 15)
	NR		|NR| = number of mesh nodes along the x(or r axis)
	NZ		|NZ| = number of mesh nodes along the y(or z axis) NR, NZ > 0 : uniform mesh grid NR, NZ < 0 : non-uniform grid
206.0	ALBC,ARBC,ATBC, ABBC	4E12.4	boundary coefficients at the left side, the right side, the top and the bottom of the reactor respectively
207.0	BLBC,BRBC,BTBC, BBBC	4E12.4	idem the boundary conditions are the Neumann-Dirichlet conditions : $a\Phi(\vec{r}_e) + bD(\vec{R}_e)\,\vec{n}_e.\vec{\nabla}\Phi(r_e) = 0$ with a ≡ ALBC,ARBC,ATBC,ABBC b ≡ BLBC,BRBC,BTBC,BBBC
If NR, NZ > 0, GO TO CARD 210.0			
208.0	R(NR)	6E12.4	abscissa of the mesh nodes along the x(or r) axis (cm)
209.0	Z(NZ)	6E12.4	abscissa of the mesh nodes along the y(or z) axis (cm)
GO TO CARD 212.0			
210.0	RMIN,RMAX	2E12.4	minimum and maximum abscissa of the uniform mesh grid along the x(or r) axis (cm)
211.0	ZMIN,ZMAX	2E12.4	minimum and maximum abscissa of the uniform mesh grid along the y(or z) axis (cm)
212.0	LAYOUT NMAX	2A8,I3	= 'bSSbLAYbOUTbbbbb' maximum number of convex zones needed to define the reactor lay-out

213.1	NCOM, IR1,IR2,IZ1,IZ2	5I3	composition number respectively left, right columns and bottom, top rows of the mesh grid enclosing the composition NCOM (each composition definition overrides a previous one if any) (see comment 16)
213.NMAX		5I3	
IF ITFLUX = 0 GO TO *			
214.0	IMTH(ITFLUX)	26I3	numbers of the ITFLUX compositions submitted to thermohydraulics feedback (see comment 17)
* IF ICRIT = 0 and IBTOT = 0 GO TO CARD 220.0 IF ICRIT < 0 and IBTOT = 0 GO TO CARD 217.0			
215.0	RODS	2A8	= 'bSSbCONTR.bRODSb'
216.1	MTABS	6I3	number of the absorbing composition in the first control rod zone
.	IRC1,IRC2,IZC1,IZC2		respectively left, right columns and bottom, top rows of the mesh grid enclosing the first control zone (see comment 18)
	IRZ8		= 0 if the control rod is not used for criticality search (see comment 19) = 1 if the control rod is used for criticality search
216.IBTOT		6I3	card 216.1 has to be repeated IBTOT times, i.e. for each control rod
IF ICRIT ≥ 0 GO TO CARD 220.0			
217.0	POIS	2A8	= 'bSSbPOISONbbbbbb'
218.0	MTFRA	I3,E12.4	number of poisoned compositions
	FRAMAX		maximum permitted dilution of poison in the coolant (see comment 20)
219.0	NCOPO(MTFRA)	24I3	numbers of the MTFRA poisoned compositions
220.0	NUCLEA	2A8,I3	= 'bSSbNUCLEARbbbbb'
	NPREC		= 0 if data are not given for delayed neutrons ≠ 0 if data are given for delayed neutrons (see comment 21)

221.0	NGM	6I3	number of energy groups
	NGU		maximum number of group jumps by upscattering (put 0 if preprocessing derived from MULCOS is used)
	NGD		maximum number of group jumps by downscattering (put NGM-1 if preprocessing derived from MULCOS is used)
	MT		number of compositions
	NL		number of fuel isotopes (i.e. fuel mixtures)
	NI		number of precursor families if any
			(these data must be consistent with the preprocessing data)
IF NPREC = 0 GO TO CARD 224.0			
222.1 . . . 222.NL	BETA(1,I), I=1,NI BETA(NL,I), I=1,NI	6E12.4 6E12.4	delayed neutron fractions β_i^{ℓ} for the first fuel mixture (ℓ = 1) card 222.1 has to be repeated NL times, i.e. for each fuel mixture
223.0	CHID(NGM)	6E12.4	delayed neutron fission spectrum χ_g^d
224.0	CONVER	2A8	= 'bSSbCONVERGENCEb'
225.0	EPSF	4E12.4	convergence criterion on the fluxes for source problems (IPROB = 1)
	EPSK		convergence criterion on k_{eff} for the power method (IPROB = 2)
	EPSKT		convergence criterion on k_{eff} for the neutronics-thermohydraulics coupling iterations (put 0.0 if ITFLUX = 0)
	EPSKC		convergence criterion on k_{eff} for criticality search (put 0.0 if ICRIT = 0)
			(see comment 22)
226.0	ENERG	2A8,E12.4	= 'bSSbENERGYbbbbbb'
	EFISS		energy delivered per fission (joules)
IF IPROB = 1 GO TO CARD 228.1			
227.0	POWNOM	E12.4	nominal power of the reactor (watts)
GO TO CARD 229.0			

228.1 . . . 228.MT	Q(1,IG),IG=1,NGM Q(MT,IG),IG=1,NGM	6E12.4 6E12.4	independent multigroup source in the first composition (n/cm³.sec) card 228.1 has to be repeated MT times, i.e. for each composition
229.0	EDIT	2A8	= 'bSSbEDITINGbbbbb'
230.0	ICROS IPRINT IFLUX NFR NFZ	5I3	= 0 if no printing of cross-sections = 1 if printing of cross-sections = 0 if no printing of fluxes and power densities = 1 if printing of fluxes and power densities if IFLUX = 0, the fluxes and power densities are printed out at points given on cards 231.0, 232.0 if IFLUX ≠ 0, the fluxes and power densities are printed out at IFLUX points per mesh in each direction (see comment 23) number of abscissa along the x (or r) axis where the fluxes and power densities are printed out (put 0 if IFLUX ≠ 0) number of abscissa along the y (or z) axis where the fluxes and power densities are printed out (put 0 if IFLUX ≠ 0)
IF IFLUX ≠ 0 GO TO CARD 233.0			
231.0	RR(NFR)	6E12.4	abscissa along the x (or r) axis where the fluxes and power densities are printed out (cm)
232.0	ZZ(NFZ)	6E12.4	abscissa along the y (or z) axis where the fluxes and power densities are printed out (cm)
233.0	END	A8	= 'bSSbENDb'
IF no data for unsteady state calculation GO TO CARD 328.0 IF data for unsteady state calculation GO TO CARD 300.0			

UNSTEADY STATE DATA			
Card	Variable(s)	Format	Definition
300.0	TITLE(8)	8A8	Title for unsteady state calculations
301.0	GENER	2A8	= 'bUSbGENERALITIES'
302.0	IROD	2I3,2E12.4	if IROD = 0, neither moving control rod nor varying mixture if IROD > 0, IROD control rod are moving ($\leq$ IBTOT) if IROD < 0, |IROD| mixtures are varying with the time
	ITFLUX		= 0 if neutronics is not coupled with thermohydraulics $\neq$ 0 if neutronics is coupled with a thermohydraulics module and ITFLUX compositions are submitted to thermohydraulics feedback (ITFLUX must be consistent with its value in steady state)
	TMAX		transient duration (sec)
	TLOF		constant characterizing the variation of the coolant mass flow rate : $G = G_o e^{-TLOF*t}$ (sec^{-1}) (see comment 24)
303.0	INTEG	2A8	= 'bUSbTIMEbINTEGbb'
304.0	INTERP	5I3	INTERP = 1 : interpolation of the fundamental mode and another mode for the amplitute functions INTERP = 2 : interpolation of the fundamental mode and the mode $e^{o.t}$ for the amplitude functions INTERP = 3 : double interpolation of the mode $e^{o.t}$ for the amplitude functions (see comment 25)
	IEXTR		IEXTR = 0, no Burlish-Stoer's extrapolation for the amplitude function calculation IEXTR = 1, Burlish-Stoer's extrapolation is used for the amplitude function calculation

	ICER		ICER = 0 : no error control for the amplitude function calculation ICER = 1 : error control for the amplitude function calculation (see comment 26)
	ICMP		ICMP = 0 : no automatical control of micro time step ICMP ≠ 0 : automatical control of micro time step (ICMP is the maximum permitted number of micro time steps in each macro time step)
	ICMAP		ICMAP = -1 : the macro time step length is constant ICMAP = 0 : the macro time step length can vary and is specified for each macro step ICMAP = 1 : automatical control of macro time step
IF ICMAP = 0 GO TO CARD 306.0 IF ICMAP = 1 GO TO CARD 310.0			
305.0	PMAC	E12.4	macro time step length (constant) (sec)
GO TO CARD 311.0			
306.0	MACMAX	I3	number of macro time steps used for the transient
307.0	PMA(MACMAX)	6E12.4	values of the macro time step length (sec) (see comment 27)
308.0	NMIC(MACMAX)	24I3	number of micro time steps in the macro time steps at the first Newton-SOR iteration (see comment 28)
309.0	NEWT(MACMAX)	24I3	maximum numbers of Newton-SOR iterations in the macro time steps
GO TO *			
310.0	PMAC1	6E12.4	value of the first macro time step (sec)
	PMAX		maximum permitted value for the macro time steps (sec)
	PMIN		minimum permitted value for the macro time steps (sec)
	FRMIN		minimum value of the reduction factor for the macro time steps
	DPLIM		maximum permitted value of the relative variation of the shape functions over a macro time step

	RPOM		maximum permitted value of the power ratio between beginning and end of each macro time step (see comment 29)
311.0	NEWMAX	2I3	ma. n number of Newton-SOR iterations in each macro time step
	NMICI		number of micro time steps in each macro time step at the first Newton-SOR iteration (see comment 28)
* IF INTERP ≠ 1 GO TO CARD 313.0			
312.0	VP	E12.4	time constant of the second interpolated mode for the amplitude functions, i.e. e^{-VP*t} (sec^{-1})
313.0	NUCLEA	2A8	= 'bUSbNUCLEARbbbbb'
314.0	NGM	4I3	number of energy groups
	NI		number of precursor families
	NL		number of fuel mixtures (isotopes)
	IOBETA		if IOBETA = 1, the values of β_i^ℓ are given if IOBETA = 2, the values of $(\nu_\ell \beta_i^\ell)_g$ are given (see comment 30) (the values of NGM, NI, NL must be consistent with their values in steady state)
315.1 . . . 315.NL	XLAMDA(I,1), I=1,NI XLAMDA(I,NL), I=1,NI	6E12.4 6E12.4	decay constants λ_i^ℓ of the NI precursor families for the first fuel isotope (ℓ=1) (sec^{-1}) card 314.1 has to be repeated NL times, i.e. for each fuel isotope
IF IOBETA = 2 GO TO CARD 317.1			
316.1 . . . 316.NL	BETA(I,1),I=1,NI BETA(I,NL),I=1,NI	6E12.4 6E12.4	delayed neutron fractions β_i^ℓ for the first fuel isotope (ℓ=1) card 315.1 has to be repeated NL times, i.e. for each fuel isotope
GO TO CARD 318.0			
317.1 . . .	XNBET(I,1,1), I=1,NI	6E12.4	values of the $(\nu_\ell \beta_i^\ell)_g$ for the first fuel isotope and the first energy group (ℓ=1, g=1)

317.NGM . . .	XNBET(I,1,NGM), I=1,NI	6E12.4	card 316.1 has to be repeated NGM times, i.e. for each energy group cards 316.1 → 316.NGM have to be repeated NL times, i.e. for each fuel isotope
317.NGM*NL	XNBET(I,NL,NGM), I=1,NI	6E12.4	
318.0	CHID(NGM)	6E12.4	delayed neutron fission spectrum χ_g^d
IF IROD = 0 GO TO CARD 322.0			
319.0	ROD	2A8	= 'bUSbCONTR.bRODSb'
IF IROD < 0 GO TO CARD 321.1			
320.1	NROD	I4,5E12.4	number of the first movi. control rod
. . . . .	F0 F1 F2 TS TF		coefficients characterizing the driving function related to control rod movement : the rod insertion X is supposed to vary with the time T as : X = X0 for T ≤ TS X = X0*(F0+F1*(T-TS)+F2*(T-TS)²) for TS ≤ T ≤ TF where X0 is the initial insertion
320.IROD		I4,5E12.4	card 319.1 has to be repeated IROD times, i.e. for each moving control rod
GO TO CARD 322.0			
321.1	NCOM	2I4,5E12.4	number of the composition for which a mixture is submitted to a driving function number of the mixture submitted to the driving function
. . . . . .	IMDF F0 F1 F2 TS TF		coefficients characterizing the driving function the volume fraction V of mixture IMDF is supposed to vary with the time T as : V = V0 for T ≤ TS V = V0*(F0+F1*(T-TS)+F2*(T-TS)²) for TS ≤ T ≤ TF where V0 is the initial volume fraction (see comment 31)
321.|IROD|		2I4,5E12.4	card 320.1 has to be repeated |IROD| times, i.e. for each varying mixture

322.0	CONVER	2A8	= 'bUSbCONVERGENCEb'
IF IEXTR = 0 GO TO CARD 324.0			
323.0	EPSA	E12.4	if ICER=0, EPSA is the maximum permitted relative error on the amplitude function at the first micro time step in each macro time step if ICER≠0, EPSA is the maximum permitted relative error on the amplitude functions at the end of the transient (see comment 32)
324.0	EPSF	3E12.4	convergence criterion on the shape functions at each Newton-SOR iteration in each macro time step (see comment 33)
	EPSP		convergence criterion on the total reactor power at the end of each macro time step
	EPSR		convergence criterion on the reactor reactivity at the end of each macro time step (see comment 34)
325.0	EDIT	2A8	= 'bUSbEDITINGbbbbb'
326.0	ICROS	3I3	= 0 if no printing of cross-sections = 1 if printing of cross-sections
	IPRINT		= 0 if no printing of fluxes and power densities = 1 if printing of fluxes and power densities
	NT		if NT > 0, the power is printed out NT times in each macro time step; the fluxes and power densities are printed out at the end of each macro time step (if IPRINT = 1) (NT ≥ 2) if NT < 0, the power, fluxes and power densities are printed out at the times TPR given on card 326.0 if NT = 0, the power is only printed out at the end of each macro time step
IF NT ≥ 0 GO TO CARD 328.0			
327.0	TPR(I),I=1,|NT|	6E12.4	times at which the power, fluxes and power densities have to be printed out (sec.)
328.0	END	A4	= 'ENDb'

Comments

1) If g anf g' are the energy group numbers of a neutron, respectively before and after scattering, the number of energy group jumps is defined by $|g-g'|$ and the maximum number of group jumps is the maximum value of $|g-g'|$.

2) Any macroscopic cross-section of a mixture m at temperature T_m (see section 7) is given by :

$$\Sigma^m_{x,g}(T_m) = \Sigma^m_{x,g}(T_{mo}) + \int_{T_{mo}}^{T_m} \left[\frac{a^m_{x,g}}{\sqrt{T}} + \frac{b^m_{x,g}}{T} + \frac{c^m_{x,g}}{T2}\right] dT$$

where x refers to the physical process (fission, absorption,...)

g refers to the energy group

T_{mo} is the reference temperature for mixture m (given by variable ITK)

$$\begin{aligned} CTOT(K,NN,IG,IH) &= \Sigma^m_{x,g}(T_{mo}) && \text{for } K = 1 \\ &= a^m_{x,g} && \text{for } K = 2 \\ &= b^m_{x,g} && \text{for } K = 3 \\ &= c^m_{x,g} && \text{for } K = 4 \end{aligned}$$

NN is the mixture number

IG is the energy group number

IH is related to the cross-section type

IH = 1 → absorption cross-section = Σ_a (capture + fission)

IH = 2 → fission cross-section x number of neutrons generated per fission : $\nu\Sigma_f$

IH = 3 → removal cross-section = $\Sigma_t = \Sigma_a + \sum_{g \neq g'} \Sigma_{g \to g'}$

IH = 4 → inverse of diffusion coefficient in the x(or r) direction : $1/D_x$

IH = 5 → inverse of diffusion coefficient in the y(or z) direction : $1/D_y$

IH = 6 → fission cross-section = Σ_f

IH = IHS-L → upscattering cross section from group IG+L to group IG : $\Sigma_{g+\ell \to g}$

(if g+ℓ>NGM, put 0.0 for the corresponding component of CTOT)

IH = IHS → self scattering cross-section into group IG : $\Sigma_{g \to g}$

IH = IHS+L → downscattering cross-section from group IG to group IG+L : $\Sigma_{g-\ell \to g}$

(if g-ℓ<1, put 0.0 for the corresponding component of CTOT)

For upscattering, L varies from 0 to NGU.

For downscattering, L varies from 0 to NGD.

The maximum value of IH is given by IHM = 7+NGU+NGD.

3) It is assumed that the prompt fission spectrum is identical for all the fissionable (fissile + fertile) isotopes.

4) The fuel mixtures are the mixtures characterized by a type = 'bCOM' (see card 002.0) and having non zero fission cross-sections. See also comment 7.

5) The MAIN and routine MACAS are written in such a manner that the preprocessing calculations are supposed immediately followed by static calculations. On the other hand the input module of the code admits the possibility to provide input data only for the preprocessing.

If the user desires to run the preprocessing module in stand alone, he has two possibilities :

- he modifies the MAIN and routine MACAS to switch off the callings to the static and dynamic module;
- he runs the code without modification; the preprocessing module will work normally and the execution will stop afterwards for want of data for the static module.

In both cases the code will create file IPS, which will be available for static calculations in next runs.

6) As explained in section 7, the proprocessing module derived from MULCOS computes the values of $\Sigma^m_{x,g}(T_{mo})$, $a^m_{x,g}$, $b^m_{x,g}$, $c^m_{x,g}$ in law (7.1) for each mixture, each energy group and each cross-section type. These values are obtained by interpolation of the macroscopic cross-sections calculated at 4 temperatures. ITK(NN,K), K=1,4 are these 4 temperatures for mixture NN. Note that ITK(NN,1) corresponds to T_{mo}.

7) If many types of fissionable (fissile + fertile) isotopes are present in the reactor, as it is generally the case, they are characterized by different fission cross-sections and also by different precursors families. In order to distinguish these 'fuel' isotopes, it is necessary to define the mixtures such that a mixture contains only one type of fuel isotope.
Example : if the fuel is constituted by UO_2-PuO_2, we can define 3 fuel mixtures :
mixture 1 : U^{235} - O^{016}
mixture 2 : U^{232} - O^{016}
mixture 3 : U^{239} - O^{016}

8) If the 26-group library is condensed into 6 groups for instance, according to the following scheme :
1-3, 4-6, 7-7, 8-9, 10-13, 14-26
then the first fine groupe are respectively : 1, 4, 7, 8, 10, 14
and the last fine groups are respectively : 3, 6, 7, 9, 13, 26.

The best few-group condension schemes are proposed pp. 53.

9) The cross-sections are collapsed according to the following relationship :

$$\Sigma_k = \frac{\sum_{i \in k} \Sigma_i \Psi_i}{\sum_{i \in k} \Psi_i}$$

where Σ_i is the macroscopic cross-section in the i^{th} group of the 26-groups library

Σ_k is the macroscopic cross-section in the k^{th} collapsed group

Ψ_i is the spectrum value for the i^{th} group

$\sum_{i\epsilon k}$ denotes the sum on the groups of the 26-group library belonging to the k^{th} collapsed group

This collapsing relationship is applied to each isotope in each composition. The collapsing spectrum Ψ_i then may differ from a composition to another one (see ref. pp. 53 below for more details).

10) Two types of steady state problems can be solved :
- the independent source problem, with multigroup sources given for each composition; possibility of thermohydraulics coupling is not considered in this case
- the eigenvalue problem, i.e. in absence of independent source, which is equivalent to the determination of the k_{eff} value of the reactor; criticality search (k_{eff} = 1) and thermohydraulics coupling are possible.

11) Two ways of criticality search can be applied :
- by control rod insertion, only possible in axisymmetric geometry and with a maximum of 5 control rods; axisymmetry implies that a control rod actually represent a cylindrical ring of absorber which can move vertically
- by homogeneous poisoning of the coolant for light water reactor applications (boric acid diluted in water).

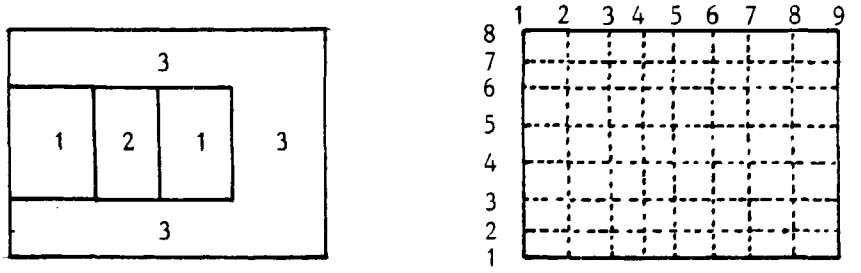
12) If a transient calculation will follow the steady state calculation (either in the same run or in a next run), it is necessary to determine the solution of the adjoint problem and to store the steady state results on file NFT.

13) If a transient calculation will follow the steady state calculation, the determination of the adjoint fluxes is absolutely necessary.

14) The eigenvalue problem is solved by the iterative power method (with or without Chebyshev acceleration), whereas the source problem is solved by the 'rebalancing' method, which is an iterative method using the so called 'rebalancing' (or 'driving') factors. See [1] for more details. For the eigenvalue problem, the use of Chebyshev acceleration is recommended.

15) The flux distribution in any energy group is approximated by bilinear, biquadratic or bicubic polynomials according to the choice of the user. The accuracy of the results obviously increases with the polynomial degree, but on the other hand the space memory and the computation time increase also significantly. The best compromise generally is obtained with NDG=2.

16) To illustrate the lay-out definition procedure, we give the following example :



The left-hand figure gives the general configuration of the reactor with its compositions.

The right-hand figure shows the corresponding finite element mesh grid with the row and column numbers.

We can construct the reactor lay-out in 3 steps (NMAX = 3)

- we fill in the whole reactor with composition 3, from columns 1 to 9 and from rows 1 to 9;
- we fill in with composition 1 the convex region defined by columns 1 → 7 and rows 3 → 6;
- we end with composition 2 in the convex region defined by columns 3 → 5 and rows 3 → 6.

17) The compositions submitted to thermohydraulics feedback are characterized by temperature dependent macroscopic cross-sections. The temperatures of the mixtures present in these compositions are determined from the results of the thermohydraulics module. For the other compositions (i.e. the compositions in regions not considered by the thermohydraulics module), the mixture temperatures are the reference temperatures ITK.

18) The control zone related to a control rod is defined as the region in which the rod can move (either for criticality search in steady state or for reactivity insertion in transient).

19) A control rod may be not used for criticality search state, but it can move during transient situations. It is then necessary to define its characteristics.

20) The coolant (water) can be present in several compositions. In each of these compositions, it is necessary to declare at least one mixture as 'coolant' mixture through the TYPE variable (see input data for preprocessing).
The dilution of poison in the coolant is defined as the ratio of the poison volume fraction to the coolant volume fraction.

21) In steady state the fission term of the diffusion equation in group g is given by :

$$\sum_{\ell}(1-\beta_{\ell})\ \chi^{p}_{\ell,g}\sum_{g'}(\nu\,\Sigma_f)^{\ell}_{g'}\,\phi_{g'} + \sum_{\ell}\sum_{i}\beta^{\ell}_{i}\,\chi^{d,i}_{\ell,g}\sum_{g'}(\nu\,\Sigma_f)^{\ell}_{g'}\,\phi_{g'}$$

$$= \sum_{\ell}\{(1-\beta_{\ell})\chi^{p}_{\ell,g} + \sum_{i}\beta^{\ell}_{i}\,\chi^{d,i}_{\ell,g}\}\sum_{g'}(\nu\,\Sigma_f)^{\ell}_{g'}\,\phi_{g'}$$

If $\chi^{d,i}_{\ell,g} = \chi^{p}_{\ell,g}$ for any i, i.e. if the prompt and delayed fission spectra are identical, the factor in brackets reduces to $\chi^{p}_{\ell,g}$ and data on delayed neutrons are not necessary to calculate the fission term.

22) For source problems, thermohydraulics coupling is not considered and the reactor k_{eff} is not calculated (k_{eff} has no physical sense in this case). Then put EPSK=EPSKT=EPSKC = 0.0.
The iterative procedure for the calculation of the solution is stopped when the maximum relative variation of the fluxes between 2 successive iterations is less then EPSF.

For eigenvalue problems, the steady state solution is calculated by the power iterative method (with or without Chebyshev acceleration) for each reactor poisoning and each temperature distribution.
At each power iteration, lower and upper bounds (k_{min}, k_{max}) for the reactor k_{eff} are computed and the iterations are stopped when $\max(k_{eff}-k_{min}, k_{max}-k_{eff})$ is less than EPSK.
The iterations on thermohydraulics feedback (if any) are stopped when the absolute variation (in modulus) of k_{eff} between 2 successive iterations is less than EPSKT and the criticality search iterations (if any) are stopped when $|k_{eff}-1|$ is less than EPSKC.

23) The abscissa of the IFLUX points in each direction are uniformly reparted in each finite element. There are thus $(IFLUX)^2$ printing points in each element.

24) When neutronics is coupled with a thermohydraulics model (ITFLUX $\neq$ 0), the transient conditions can be characterized by a decrease of the coolant mass flow rate (LOF accident for LMFBR, LOCA for LWR), which is in the present case represented by an exponential law :

$$G = G_o e^{-TLOF*t}$$

where TLOF is the time constant of the flow rate decrease.
This law is utilized by the simplified model for the power prediction called by neutronics at the beginning of each macro time step.
Put TLOF = 0.0, if decrease of coolant mass flow rate is not considered.

25) Maximum accuracy is obtained with INTERP=1 and minimum accuracy with INTERP=3.
Option INTERP=2 practically gives as much accuracy as option INTERP=1; moreover with INTERP=2 it is not necessary to specify a second interpolation mode (see card 312.0).

26) If error control for the amplitude function calculation and/or automatical control of micro time step are asked, use of Burlish-Stoer extrapolation technique is obligatory. Moreover more than 1 Newton-SOR iterations are necessary (see card 309.0 or 311.0).

27) The sum of the macro time steps may not be less than TMAX.

28) When automatical control of micro time step is asked, it is necessary to specify the number of micro time steps at the first Newton-SOR iteration in each macro time step and the micro time step size eventually will be modified by the code for the next Newton-SOR iterations. If automatical control is not asked, the number of micro time steps at the second and next Newton-SOR iterations is the value taken at the first iteration.

29) This criterion for the determination of the macro time step is used by the simplified point-kinetics model for the prediction of the power at the end of the macro time step.
If P_0, P_1 respectively denote the reactor power at the beginning and at the end of the macro time step, the ratio P_1/P_0 (if $P_1 > P_0$) or the ratio P_0/P_1 (if $P_1 < P_0$) must be less than RPOM.

30) In some cases, instead of the β^{ℓ}_i values, the values of $(\nu_\ell\ \beta^{\ell}_i)_g$ are furnished. The code computes then equivalent β^{ℓ}_i values by means of the following formula :

$$\beta^{\ell}_i = \frac{\sum_g \sum_{g'} \int_{\text{reactor}} \chi^p_g\ \phi^*_g(\bar{r},0)\ (\nu_\ell\ \beta^{\ell}_i)_{g'}\ \Sigma_{fg'}\ \Psi_{g'}(\bar{r},0)\,d\bar{r}}{\sum_g \sum_{g'} \int_{\text{reactor}} \chi^p_g\ \phi^*_g(\bar{r},0)\ (\nu\ \Sigma_f)_{g'}\ \Psi_{g'}(\bar{r},0)\,d\bar{r}}$$

where $\Psi_g(\bar{r},0)$ is the shape function in group g at the initial time
$\phi^*_g(\bar{r},0)$ is the steady state adjoint flux in group g

31) When more than one mixture are submitted to a driving function in the same composition, it is necessary to define a driving function for each of these mixtures.
Note that the number of driving functions is limited to 10.

32) If the error control on the amplitude functions is not asked (ICER=0), the value of EPSA at the second and next Newton-SOR iterations is the same as at the first iteration.

33) At each macro time step and at each Newton-SOR iteration, the shape functions are computed by means of an iterative method using pseudo-eigenvalues [1]. The iterative scheme is stopped when the maximum relative variation of the shape functions between 2 successive iterations is less than EPSF.
If convergence is not reached after 30 iterations, the execution is stopped and an error message is printed out.

34) The Newton-SOR iterations at each macro time step are stopped when the relative variations of the reactor power and the reactivity respectively are less than EPSP and EPSR.
The number of iterations is limited to NEWMAX (see card 309.0 or 311.0); if convergence is not reached, the execution goes on.

13. FILE SPECIFICATIONS

Formatted files

File number	Type	Utilization	Record length (bytes)
3	sequential-temporary	P S D	80
50	sequential-temporary	P S D	80

Binary files

File number	Type	Utilization	Record length (bytes)
2	sequential-temporary	S D	8*LBAND*LBAND
4	sequential-temporary	S D	8*LBAND*LBAND
13	sequential-temporary	S	8*NPAR
14	sequential-temporary	S D	8*LBAND
15	sequential-temporary	S	8*MIN(LBAND,LCOMP)
16	sequential-temporary	S	8*NPAR
17	sequential-temporary	S D	8*NPAR for static calculations 8*NCP for dynamic calculations
18	sequential-temporary	S D	8*NPAR
19	sequential-temporary	S D	8*NPAR for static calculations 8*(NCP+1) for dynamic calculations
25	sequential-temporary	S D	8*NDP
29	sequential-temporary	S D	8*NPAR for static calculations 8*NCP for dynamic calculations
31	sequential-temporary	S D	8*MAX (52,NFR,NFZ, NDP,MT*NGM,MTT*ML)
32	sequential-temporary (or permanent)	S D	8*MAX(500,NCP,NDP)
33	direct access-temporary	D	8*LONG
37	direct access-temporary	D	8*NPAR
41	direct access-temporary	D	8*NPAR
42	direct access-temporary	D	8*NPAR
45	sequential-permanent	P S	4*MAX(2*NGM,1+3*ML, 22)
46	sequential-temporary	S D	idem
47	sequential-temporary (or permanent)	D	idem

with LBAND = NDG*LR+NDG+1

LR = 1+NDG*(NR-1)

LZ = 1+NDG*(NZ-1)

NPAR = LR*LZ

LCOMP = $(NDG+1)^2 + (NDG)^2$

NDP = $(NDG+1)^2 * (NR-1) * (NZ-1)$

NCP = 1+NI*NL

LONG = length in words of the virtual buffer of file 33 (= 1625)

where NR is the number of mesh nodes along the x(or r) axis

NZ is the number of mesh nodes along the y(or z) axis

NDG is the degree of the interpolation basis functions (= 1, 2 or 3)

NI is the number of precursor families

NL is the number of fuel isotopes (mixtures)

NFR is the number of abscissa along the x(or r) axis where the fluxes are to be edited

NFZ is the number of abscissa along the y(or z) axis where the fluxes are to be edited

MT is the number of compositions + IBTOT ($\leq$ 35)

MTT is the number of thermal compositions ($\leq$ (NR-1)*(NZ-1))

ML is the number of mixtures ($\leq$ 30)

NGM is the number of energy groups

IBTOT is the number of control rods

- In the column 'utilization', P means that the file is used during the preprocessing calculations
  S means that the file is used during the static calculations
  D means that the file is used during the dynamic calculations

- Note that - file NCPL=25 is not used if neutronics is not coupled with thermohydraulics
  - file NFT=31 is not used if the static calculations are not followed by dynamic calculations (in the same or next run)
  - files 32 and 47 must be permanent if a RESTART procedure is foreseen.

- The values of the record lengths given hereabove are minimum values insuring the normal execution of the I/O operations.

- The other file specifications like the blocksize, the record format, the space, etc. can be freely defined by the user, provided that the file specifications rules are respected, e.g. variable-length records for unformatted sequential files, fixed-length unblocked records (with BLKSIZE=LRECL) for direct-access files.

- The data set of file 33 has direct organization, so that one can put in the DCB parameter DSORG=DA.

- For the direct access files, it is necessary to update the parameters of the FORTRAN 'OPEN' statements accordingly with the corresponding file specifications.

- Complementary informations about the I/O devices can be found in appendix 2.

As illustration we give hereunder the data set statements corresponding to the sample problem proposed in the last section.

```
//GO.FT03F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(CYL,(2,1)),
//      DCB=(RECFM=FB,LRECL=80,BLKSIZE=800,BUFNO=1)
//GO.FT04F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(20,2)),
//     DCB=(RECFM=VBS,LRECL=3528,BLKSIZE=14116,BUFNO=1)
//GO.FT13F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(9,1)),
//     DCB=(RECFM=VBS,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT14F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(20,2)),
//     DCB=(RECFM=VBS,LRECL=168,BLKSIZE=1012,BUFNO=1)
//GO.FT15F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(20,2)),
//     DCB=(RECFM=VBS,LRECL=104,BLKSIZE=628,BUFNO=1)
//GO.FT16F001 DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(20,2)),
//     DCB=(RECFM=VBS,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT17F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(9,1)),
//     DCB=(RECFM=VBS,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT18F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(9,1)),
//     DCB=(RECFM=VBS,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT19F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(9,1)),
//     DCB=(RECFM=VBS,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT25F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(9,1)),
//     DCB=(RECFM=VBS,LRECL=1736,BLKSIZE=1740,BUFNO=1)
//GO.FT29F001  DD UNIT=SYSDA,DISP=(NEW,DELETE),SPACE=(CYL,(9,1)),
//     DCB=(RECFM=VBS,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT31F001 DD DSN=L.TESTPF.BEN2D.SHAPA,DISP=(NEW,KEEP),UNIT=DISK50,
//    VOL=SER=TEST02,SPACE=(CYL,(1,1)),
//    DCB=(RECFM=VBS,LRECL=1728,BLKSIZE=1732)
//GO.FT32F001 DD DSN=L.TESTPF.BEN2D.RESTA,DISP=(NEW,KEEP),UNIT=DISK50,
//    VOL=SER=TEST02,SPACE=(CYL,(9,1)),
//    DCB=(RECFM=VBS,LRECL=4000,BLKSIZE=8004,BUFNO=1)
//GO.FT33F001 DD UNIT=SYSDA,SPACE=(13000,190),
//     DCB=(DSORG=DA,RECFM=F,BLKSIZE=13000)
//GO.FT37F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(3344,(76,1)),
//     DCB=(RECFM=F,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT41F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(3344,(36,1)),
//     DCB=(RECFM=F,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT42F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(3344,(20,1)),
//     DCB=(RECFM=F,LRECL=936,BLKSIZE=5620,BUFNO=1)
//GO.FT45F001 DD UNIT=DISK50,VOL=SER=TEST02,DISP=(NEW,KEEP),
//            DSN=L.TESTPF.BEN2D.PREPA,SPACE=(CYL,(1,1)),
//     DCB=(RECFM=VBS,LRECL=96,BLKSIZE=100)
//GO.FT46F001 DD UNIT=DISK50,VOL=SER=TEST02,DISP=(NEW,KEEP),
//    DSN=L.TESTPF.BEN2D.DYNAA,SPACE=(CYL,(1,1)),
//    DCB=(RECFM=VBS,LRECL=88,BLKSIZE=92)
//GO.FT47F001 DD DSN=L.TESTPF.BEN2D.PRDYN,DISP=(NEW,KEEP),UNIT=DISK50,
//    VOL=SER=TEST02,SPACE=(CYL,(1,1)),
//    DCB=(RECFM=VBS,LRECL=88,BLKSIZE=92,BUFNO=1)
//GO.FT50F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(CYL,(2,1)),
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
```

Data set statements corresponding to the sample problem

```
//GO.FT07F001 DD DSN=F.CNMOPF.KFKNAP.FILE07,DISP=SHR,DCB=BUFNO=1,
//     UNIT=DISK33,VOL=SER=CIEMOL
//GO.FT08F001 DD DSN=F.CNMOPF.KFKNAP.FILE08,DISP=SHR,DCB=BUFNO=1,
//     UNIT=DISK33,VOL=SER=CIEMOL
//GO.FT09F001 DD DSN=F.CNMOPF.KFKNAP.FILE09,DISP=SHR,DCB=BUFNO=1,
//     UNIT=DISK33,VOL=SER=CIEMOL
//GO.FT10F001 DD DSN=F.CNMOPF.KFKNAP.FILE10,DISP=SHR,DCB=BUFNO=1,
//     UNIT=DISK33,VOL=SER=CIEMOL
//GO.FT11F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(3620,(160,1)),
//     DCB=(RECFM=F,LRECL=3620,BLKSIZE=3620,BUFNO=1)
//GO.FT12F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(604,(81,1)),
//     DCB=(RECFM=F,LRECL=604,BLKSIZE=604,BUFNO=1)
//GO.FT22F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(2000,(905,1)),
//     DCB=(RECFM=F,LRECL=2000,BLKSIZE=2000,BUFNO=1)
//GO.FT28F001 DD UNIT=SYSDA,DISP=NEW,SPACE=(648,(960,1)),
//     DCB=(RECFM=F,LRECL=648,BLKSIZE=648,BUFNO=1)
```

Data set statements needed for the files used by the preprocessing module derived by MULCOS.

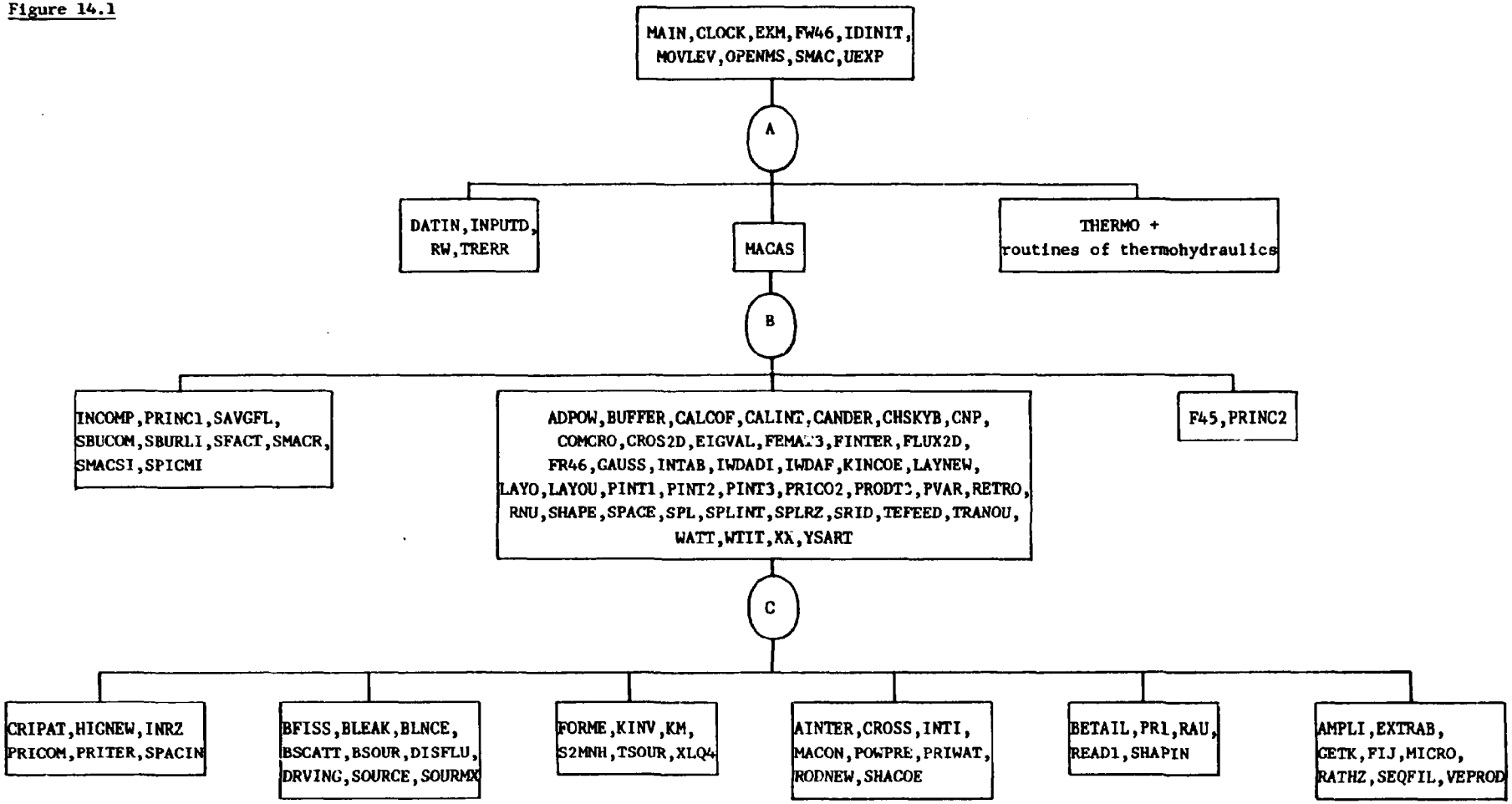
14. OVERLAY STRUCTURE

In order to reduce the main storage requirements of the code, it can be usefull to load the routines in overlay structure.

The general chart of this overlay structure is exhibited in figure 14.1.

The statements related to the overlay structure are given in table 14.1. In this table the thermohydraulics routines are those corresponding to the simplified thermohydraulics module provided with CASSANDRE.

Figure 14.1


MAIN,CLOCK,EXM,FW46,IDINIT,
MOVLEV,OPENMS,SMAC,UEXP
A
DATIN,INPUTD,
RW,TRERR
MACAS
THERMO +
routines of thermohydraulics
B
INCOMP,PRINC1,SAVGFL,
SBUCOM,SBURL1,SFACT,SMACR,
SMACS1,SPICMI
ADPOW,BUFFER,CALCOF,CALINT,CANDER,CHSKYB,CNP,
COMCRO,CROS2D,EIGVAL,FEMA13,FINTER,FLUX2D,
FR46,GAUSS,INTAB,IWDADI,IWDAF,KINCOE,LAYNEW,
LAYO,LAYOU,PINT1,PINT2,PINT3,PRICO2,PRODT2,PVAR,RETRO,
RNU,SHAPE,SPACE,SPL,SPLINT,SPLRZ,SRID,TEFEED,TRANOU,
WATT,WTIT,XX,YSART
F45,PRINC2
C
CRIPAT,HIGNEW,INRZ
PRICOM,PRITER,SPACIN
BFISS,BLEAK,BLNCE,
BSCATT,BSOUR,DISFLU,
DRVING,SOURCE,SOURMX
FORME,KINV,KM,
S2MNH,TSOUR,XLQ4
AINTER,CROSS,INTI,
MACON,POWPRE,PRIWAT,
RODNEW,SHACOE
BETAIL,PR1,RAU,
READ1,SHAPIN
AMPLI,EXTRAB,
GETK,FIJ,MICRO,
RATHZ,SEQFIL,VEPROD

```
ENTRY MAIN
INSERT MAIN,FW46,MOVLEV,IDINIT
INSERT OPENMS,UEXP,EXM,SMAP
INSERT ICLOCK,CLOCK
OVERLAY A
INSERT THERMO,NEACRF,QPOW
OVERLAY A
INSERT INPUTD
INSERT TRERR,DATIN,RW
OVERLAY A
INSERT MACAS
OVERLAY B
INSERT PRINC1,SBUCOM,SBURLI,INCOMP
INSERT SAVGFL,SPICMI,SFACT,SMACR,SMACSI
OVERLAY B
INSERT PRINC2,F45
OVERLAY B
INSERT INTAB,CALCOF,SPLINT,SPL,GAUSS,TEFEED
INSERT PVAR,SPLRZ,FEMAT3,PRODT3,WTIT,ADPOW
INSERT CHSKYB,BUFFER,CROS2D,COMCRO,PRICO2,FLUX2D
INSERT FR46,LAYNEW,SRID,CNP,WATT,YSART
INSERT SHAPE,SPACE,EIGVAL,RNU,CALINT,XX
INSERT IWDADI,CANDER,IWDAF,LAYO,LAYOU,PINT3
INSERT PINT1,PINT2,KINCOE,RETRO,FINTER,TRANOU
OVERLAY C
INSERT PRITER,HIGNEW
INSERT PRICOM,CRIPAT,SPACIN,INRZ
OVERLAY C
INSERT DISFLU,SOURCE,SOURMX,DRVING
INSERT BLNCE,BFISS,BSCATT,BLEAK,BSOUR
OVERLAY C
INSERT KM,S2MNH,TSOUR,KINV,FORME,XLQ4
OVERLAY C
INSERT CROSS,RODNEW,MACON,POWPRE,PRIWAT
INSERT INTI,AINTER,SHACOE
OVERLAY C
INSERT SHAPIN,PR1,BETAIL,RAU,READ1
OVERLAY C
INSERT AMPLI,EXTRAB,VEPROD
INSERT GETK,SEQFIL,FIJ,MICRO,RATH2
```

TABLE 14.1.

15. TIMER ROUTINE

A timer routine CLOCK is used by the code CASSANDRE in several places to provide informations about the CPU time. This timer is not necessary for the calculations and it may be removed of replaced by an equivalent routine.

Routine CLOCK is an assembler language routine of the IBM system used at C.E.N./S.C.K. Mol. The CPU time is obtained by the following statement :

```
CALL CLOCK (ITIME)
```

where ITIME is the CPU time (expressed in hundredth parts of second) since the previous calling to CLOCK.

16. ERROR MESSAGES

A list of error messages printed by CASSANDRE in case of abnormal execution is given hereafter with :

- a code number for each error
- the message text printed by the code
- a brief description of the diagnosis of the error detected by the code
- the action to be undertaken to correct the error.

Excepted for error n° 6, any error detection interrupts the job execution.

Error number	Message text	Diagnosis	Action
1	no correspondance of names in file IPS or IPSM	error of file IPS for steady state or error of file IPSM for transient	check file IPS (in steady state) or file IPSM (in transient)
2	no correspondance of ML,MT,NGM or IHM in file IPS or IPSM	idem	idem
3	criticality search incompatible with source problem	the user has put simultaneously ICRIT≠0 and IPROB=1 in the input data	put ICRIT=0 or IPROB=2
4	criticality search by control rod insertion and thermohydraulics coupling not possible in x-y geometry	the user has put simultaneously NG=0 and ICRIT>0 and (or) ITFLUX≠0	check the value of NG; if cartesian geometry (NG=0) is really used, then put ICRIT≤0 and(or) ITFLUX=0
5	source problem may not be followed by dynamic calculations	the user has put simultaneously ISTEAD≠0 and IPROB=1 in the input data	check the value of IPROB; if source problem (IPROB=1) is really used, than put ISTEAD=0
6	adjoint flux calculation is not possible for source problem Attention ! IADIR put equal to 1	the user has put simultaneously IADIR=2 and IPROB=1 in the input data	the code put automatically IADIR to 1 and the calculations go on
7	adjoint flux calculation is necessary for transient	the user has put simultaneously IADIR=1 and ISTEAD≠0 in the input data	if static calculations will be followed by dynamic calculations, put IADIR=2; if not, put ISTEAD=0
8	control rod(s) not defined for criticality search	the user has put simultaneously ICRIT>0 and IBTOT=0 in the input data	if criticality search by control rod insertion is really asked (ICRIT>0), put IBTOT≠0; if not,change ICRIT
9	thermal compositions not correctly defined	error in the definition of the compositions coupled with thermohydraulics : one or many compositions do not contain fuel mixture	check the numbers of the compositions coupled with thermohydraulics
10	poison not found for criticality search	the mixture defined as poison for criticality search is not found in one or many compositions to be poisoned	check the number of poison mixture (=-ICRIT) or the numbers of the compositions to be poisoned

11	coolant not found in poisoned composition	one or many poisoned compositions for criticality search do not contain any coolant mixture	check the poisoned compositions used for criticality search by poisoning of the coolant
12	poison not homogeneous in the coolant	the dilution fraction of poison in the coolant varies from a composition to another one	check the dilution fraction of poison in the poisoned compositions used for criticality search by poisoning of the coolant
13	more than 2 compositions are found in a control rod zone	the control rod zone(s) is(are) not well defined	check the compositions in the control rod zone(s)
14	control material not found in a control rod zone	the composition defined as the control composition is not found in a control rod zone	check the compositions in the control rod zone(s) or the number of the control composition
15	inverted control rod	the control material are located in the lower region of the control rod zone(s)	idem
16	no moving control rod for criticality search	criticality search is not possible because all the control rods are defined as fixed	define at least one control rod as moving rod
17	criticality is not possible	the control rod insertion(s) or the dilution fraction of poison in the coolant exceeds the maximum permitted value(s) to reach criticality	modify the control material parameters or the reactor composition
18	incorrect fuel mixture	a mixture of a composition is defined as fuel mixture, but it does not belong to the set of fuel isotopes	check the fuel mixtures in the compositions of the set of fuel isotopes
19	movement of control rod and thermo-hydraulics coupling not possible in x-y geometry	the user has put simultaneously NG=0 and IROD>0 and(or) ITFLUX≠0	check the value of NG; if cartesian geometry is really used, then put IROD and(or) ITFLUX=0

20	automatic micro time step control and error control for amplitude functions not possible without Burlish-Stoer extrapolation	the user has put simultaneously IEXTR=0 and ICER and(or) ICMP≠0	put IEXTR=0, ICER=ICMP=0 or IEXTR=1 and ICER and(or) ICMP≠0
21	error control for amplitude functions not possible with only one Newton-SOR iteration	the user has put simultaneously ICER≠0 and NEWMAX or NEWT(K)=1	put ICER=0 or increase the value of maximum number of Newton-SOR iterations (NEWMAX or NEWT(K), K=1, MACMAX)
22	control rod out of range	a control rod is moved outside its zone	modify the driving functions for the control rod(s)
23	abnormal convergence for Kagonove's method	convergence for power prediction with Kagonove's method is not reached after 20 iterations	increase the maximum number of iterations in routine POWPRE (fixed to 20) or decrease the micro and(or) macro time step values
24	abnormal convergence of generalized Newton method for pseudo-eigenvalue calculation	convergence for pseudo-eigenvalue with generalized Newton method is not reached after 30 iterations	increase the maximum number of iterations in routine FORME (fixed to 30) or increase the convergence criterion on the shape functions at each Newton-SOR iteration in each macrostep (EPSF) (see input data) or decrease the macro time step values
25	no correspondance of NPAR, NL or NGM in file NFO	error in file NFO	check file NFO
26	no convergence for initial estimate of dominant eigenvalue	convergence for initial estimate of dominant eigenvalue is not reached after 50 iterations	increase the maximum number of iterations for the calculation of the first estimate of the fundamental eigenvalue (fixed to 50) in routine EIGVAL or increase the convergence criterion (fixed to 10^{-5}) in routine EIGVAL

27	no convergence for calculation of dominant eigenvalue	convergence for the calculation of the dominant eigenvalue is not reached after 50 iterations	increase the maximum number of iterations for the calculation of the fundamental eigenvalue (fixed to 50) in routine EIGVAL or increase the convergence criterion (fixed to 10^{-8}) in routine EIGVAL
28	no convergence in function RNU	convergence of the iterative process in function RNU is not reached after 50 iterations	increase the maximum number of iterations (fixed to 50) or increase the convergence criterion (fixed to 10^{-8}) in function RNU
29	GAUSS detected an ill matrix	the coefficient matrix of the linear system solved in routine GAUSS is not well conditioned	many causes are possible : investigate more deeply the reason of failure
30	non positive definite matrix for Cholesky's method	the coefficient matrix of the linear system solved in routine CHSKYB is non positive definite	check the finite element mesh grid and the cross-section values
31	asked record out of range in file NFO	a record read on the direct access device NFO is not correctly addressed	check file NFO
32	volume fraction out of range	the volume fraction of a variable mixture governed by a driving function is < 0 or > 1	modify the corresponding driving function
33	variable mixture not found	the mixture of which the volume fraction is imposed to vary according to a driving function is not found in the associated composition	check the specifications of the variable mixtures
34	no fuel isotopes	none mixture has been declared as fuel isotope	introduce fuel isotopes

101	card 'END' expected	the last card of the input data set is not card 'END'	check the input data after card 'US EDITING'
102	card 'ENDPM' expected	error in input data before card 'ENDPM' in the preprocessing	check the input data before card 'ENDPM'
103	card 'ENDPC'expected	error in input data between cards 'ENDPM' and 'ENDPC' in the preprocessing	check the input data between cards 'ENDPM' and 'ENDPC'
104	card 'FEWGRP' or 'LIBRARY' expected	error in input data between cards 'ENDPC' and 'FEWGRP' or 'LIBRARY' in the preprocessing	check the input data between cards 'ENDPC' and 'FEWGRP' or 'LIBRARY'
105	card 'ENDP' expected	error in input data between cards 'FEWGRP' or 'LIBRARY' and 'ENDP' in the preprocessing if NREAD=1 or error in input data of the equivalent preprocessing if NREAD=0	check the input data between cards 'FEWGRP' or 'LIBRARY' and 'ENDP' if NREAD=1 or check the input data of the equivalent preprocessing if NREAD=0
106	card 'SS GENERALITIES' expected	error in input data before beginning of steady state data	check the input data before beginning of steady state data
107	card 'SS GEOMETRY' expected	error in input data between cards 'SS GENERALITIES' and 'SS GEOMETRY'	check the input data between cards 'SS GENERALITIES' and 'SS GEOMETRY'
108	card 'SS LAY OUT' expected	error in input data between cards 'SS GEOMETRY' and 'SS LAY OUT'	check the input data between cards 'SS GEOMETRY' and 'SS LAY OUT'
109	card 'SS CONTR.RODS' expected	error in input data between cards 'SS LAY OUT' and 'SS CONTR.RODS'	check the input data between cards 'SS LAY OUT' and 'SS CONTR.RODS'
110	card 'SS POISON' expected	error in input data between cards 'SS LAY OUT' or 'SS CONTR.RODS' and 'SS POISON'	check the input data between cards 'SS LAY OUT' or 'SS CONTR.RODS' and 'SS POISON'

111	card 'SS NUCLEAR' expected	error in input data between cards 'SS LAY OUT' or 'SS CONTR.RODS' or 'SS NUCLEAR'	check the input data between cards 'SS LAY OUT' or 'SS CONTR.RODS' and 'SS NUCLEAR'
112	card 'SS CONVERGENCE' expected	error in input data between cards 'SS NUCLEAR' and 'SS CONVERGENCE'	check the input data between cards 'SS NUCLEAR' and 'SS CONVERGENCE'
113	card 'SS ENERGY' expected	error in input data between cards 'SS CONVERGENCE' and 'SS ENERGY'	check the input data between cards 'SS CONVERGENCE' and 'SS ENERGY'
114	card 'SS EDITING' expected	error in input data between cards 'SS ENERGY' and 'SS EDITING'	check the input data between cards 'SS ENERGY' and 'SS EDITING'
115	card 'SS END' expected	error in input data between cards 'SS EDITING' and 'SS END'	check the input data between cards 'SS EDITING' and 'SS END'
116	card 'US GENERALITIES' expected	error in input data before beginning of unsteady state data	check the input data before beginning of unsteady state data
117	card 'US TIME INTEG' expected	error in input data between cards 'US GENERALITIES' and 'US TIME INTEG'	check the input data between cards 'US GENERALITIES' and 'US TIME INTEG'
118	card 'US NUCLEAR' expected	error in input data between cards 'US TIME INTEG' and 'US NUCLEAR'	check the input data between cards 'US TIME INTEG' and 'US NUCLEAR'
119	card 'US CONTR.RODS' expected	error in input data between cards 'US NUCLEAR' and 'US CONTR.RODS'	check the input data between cards 'US NUCLEAR' and 'US CONTR.RODS'
120	card 'US CONVERGENCE' expected	error in input data between cards 'US NUCLEAR' or 'US CONTR.RODS' and 'US CONVERGENCE'	check the input data between cards 'US NUCLEAR' or 'US CONTR.RODS' and 'US CONVERGENCE'
121	card 'US EDITING' expected	error in input data between cards 'US CONVERGENCE' and 'US EDITING'	check the input data between cards 'US CONVERGENCE' and 'US EDITING'

ERRORS RELATED TO THE DYNAMIC ALLOCATION

Error number	Message text	Diagnosis	Action
201	number of allocated components for vector 'XNAM' is illegal	the number of components of vector XNAM is ≤ 0	correct the value of the number of components N of vector XNAM in IDLOC (N,'XNAM')
202	vector 'XNAM' yet created	the program tries to create a vector XNAM previously created	suppress the exceeding statement IDLOC(N, 'XNAM')
203	number of vector exceeds 'NIDX' with vector 'XNAM'	when vector XNAM is created, the number of vectors in the dynamic allocation *vector A exceeds the maximum permitted* value NIDX	increase the value of NIDX in the dynamic allocation routine IDINIT
204	number of allocated components in vector A exceeds 'IL' with vector 'XNAM'	when vector XNAM is created, the number of components allocated in the dynamic allocation vector A exceeds the dimension IL of vector A	increase the value of IL in the MAIN of the code
205	number of deleted vectors is illegal	the number of deleted vectors in the dynamic allocation vector A is ≤ 0 or larger than the number of vectors existing in vector A	correct the value of the number of deleted vectors M in IDSHOR(M)
206	dynamic allocation vector is empty; vector 'XNAM' does not exist	the program tries to delete or to locate vector XNAM in the dynamic allocation vector A, which is empty	suppress the exceeding statement IDKILL('XNAM') or ID('XNAM')
207	vector 'XNAM' not yet created	the program tries to delete or to locate vector XNAM which does not exist in the dynamic allocation vector A	suppress the exceeding statement IDKILL('XNAM') or ID('XNAM') or create at the right place vector XNAM by IDLOC(N, 'XNAM')

ERRORS RELATED TO THE PREPROCESSING DERIVED FROM MULCOS

Error number	Message text	Diagnosis	Action
301	too many mixtures	the number of mixtures is > 30	reduce the number of isotopes
302	mixture title not found	error in the mixture definition cards 101.1 → 101.NIS+2 for one mixture at least	check the input data for the mixture definition
303	mixture number out of range	a mixture has an incorrect number	check the mixture numbers
304	mixture n° NX was already defined	repetition of the input data cards for the definition of mixture n° NX or incorrect mixture number	check the input data for the definition of mixture n° NX
305	too many isotopes in mixture n° NX	mixture n° NX contains more than 30 isotopes	modify the mixture definition in order to respect the limitation of 30 isotopes for each mixture
306	mixture n° NX is not defined	the input data for the definition of mixture n° NX were not provided	add or correct the input data for the definition of mixture n° NX
307	error in mixture data	card 102.0 was not found	add card 102.0 or correct the input data for the mixture definition
308	too many compositions	the number of compositions is > 30	reduce the number of compositions
309	title 'xxxxxxxx' is not correct	error in the title of card 108.0 or error in the composition definition cards 103.0 105.0 or error for the fuel isotopes	correct the title of card 108.0 or check cards 103.0 → 107.0
310	number of energy groups for multigroup library may not exceed 40	the number of energy groups is > 40	check the value of the number of energy groups or reduce it if necessary

311	number of isotopes for multigroup library may not exceed 40	the number of isotopes is > 40	check the value of the number of isotopes or reduce it if necessary
312	number of collapsing spectra out of range	the number of collapsing spectra is < 0 or > 30	check the value of the number of collapsing spectra or reduce it if necessary
313	composition n° NX is not defined	composition n° NX has been incorrectly defined in the input data (or has not been defined)	check the input data for the definition of composition n° NX
314	isotope 'xxxxxxxx' of composition n° NX not found in the library	isotope 'xxxxxxxx' does not exist in the library	check the isotope name 'xxxxxxxx'
315	isotope 'xxxxxxxx' of composition n° NX not found in the list of isotopes given for collapsing	the list of isotopes for collapsing is incorrect	check the list of isotopes for collapsing (card 113.0)
316	mixture n° NX not found	mixture n° NX does not exist in any composition	check the input data for the definition of the compositions or suppress the input data for the definition of mixture n° NX
317	mixture n° NX not correctly defined	error in the definition of mixture n° NX	check the input data for the definition of mixture n° NX
318	isotope 'xxxxxxxx' of mixture n° NX not found in the library	isotope 'xxxxxxxx' does not exist in the library	check the isotope name 'xxxxxxxx'
319	isotope 'xxxxxxxx' is missing in composition n° NX	incompatibility between the definition of composition n° NX and the definition of the mixtures of composition n° NX	check the input data related to the definition of composition n° NX and those ones related to the definition of the mixtures of composition n° NX

17. OPTIONAL PARAMETERS

Efficiency is certainly the main objective of the development of a numerical code, but also flexibility and easiness of use are very important. However these two last requirements are not always compatible, because flexibility implies a broad range of possibilities or options, which can lead to a relatively complexity of the use of the code. For CASSANDRE, we tried to realize an equilibrium between these exigences and to produce a computational tool with a variable degree of sophistication according to the user's wishes. This degree of sophistication is governed by a certain number of optional parameters given in input data; by optional parameters we mean the set of input data characterizing the range of the possibilities offered by the code as well for the numerical aspects as for the types of problems which can be treated.
In this section we draw up a list of these optional parameters with short comments on their respective effects.

Parameters related to the problem identification

- IPROB = 1 : steady state problem with an independent multigroup source
  = 2 : eigenvalue value steady state problem, i.e. with calculation of k_{eff}

- NG = 0 : cartesian geometry in the x-y plane
  = 1 : axisymmetric geometry

- ITFLUX = 0 : neutronics is independent on thermohydraulics feedback
  neutronics is coupled with a thermohydraulics model

- ICRIT = 0 : no criticality search in steady state
  > 0 : criticality search in steady state by control rod insertion
  < 0 : criticality search in steady state by homogeneous poisoning of the coolant (application to LWR)

- IBTOT = 0 : control rods are not considered
  > 0 : control rods are considered for steady state and/or transient calculations

- IADIR = 1 : only direct steady state problem is required
  = 2 : direct and adjoint steady state problems are required

- ISTEAD = 0 : steady state calculations are not followed by transient calculations
  = 1 : steady state calculations are followed by transient calculations

- IROD = 0 : transient is not induced by core material movement
  > 0 : transient is induced by control rod movement
  < 0 : transient is induced by homogeneous variation of composition(s)

- NPREC = 0 : delayed neutrons are not considered for steady state calculations
  ≠ 0 : delayed neutrons are taken into account in steady state

- NOBETA = 1 : for transient calculation, the values of the β_i^{ℓ} are given for the delayed neutrons
  = 2 : for transient calculation, the values of the $(\nu_{\ell}\ \beta_i^{\ell})_g$ are given for the delayed neutrons

- NGM : number of energy groups

- NGU = 0 : no upscattering
  ≠ 0 : upscattering is considered

- NEXEC = 0 : the execution begins by calculations with the equivalent proprocessing module
  = 1 : the execution begins by calculations with the preprocessing module derived from MULCOS (only for C.E.N./S.C.K.'s users)
  = 2 : the execution begins by steady state calculations
  = 3 : the execution begins by transient calculations

Parameters related to the numerical techniques

- NR, NZ : in moduli, numbers of mesh nodes along the x (or r) axis and y (or z) axis
  > 0 → uniform mesh grid
  < 0 → non uniform mesh grid

- NDG = 1 : bilinear polynomials for the flux approximation
  = 2 : biquadratic polynomials for the flux approximation
  = 3 : bicubic polynomials for the flux approximation

- ICHEB = 0 : the power method is used in steady state for the eigenvalue problem
  = 1 : the power method with Chebyshev acceleration is used in steady state for the eigenvalue problem

- INTERP = 1 : interpolation of the fundamental mode and an arbitrary mode $e^{-\lambda t}$ for the amplitude functions
  interpolation of mode $e^{0.t}$ and $e^{-\lambda t}$ for the shape functions

  = 2 : interpolation of the fundamental mode and mode $e^{0.t}$ for the amplitude functions
  double interpolation of mode $e^{0.t}$ for the shape functions

  = 3 : double interpolation of mode $e^{0.t}$ for the amplitude and shape functions

- IEXTR = 0 : no Burlish-Stoer extrapolation for the amplitude functions calculation
  = 1 : Burlish-Stoer extrapolation for the amplitude functions calculation is required

- ICER = 0 : no error control for the amplitude functions
  = 1 : error control for the amplitude functions is required

- ICMP = 0 : no automatical control of the micro time step size
  ≠ 0 : automatical control of the micro time step size is required

- ICMAP = 0 : no automatical control of the macro time step size
  = 1 : automatical control of the macro time step size is required

- NEWMAX : maximum number of Newton-SOR iterations

Parameters related to the output

- IPRO1 = 0 : no printing of intermediate results of the preprocessing derived from MULCOS
  = 1 : printing of intermediate results of the preprocessing derived from MULCOS is required

- IPRO2 = 0 : no printing of final results of the preprocessing derived from MULCOS
  = 1 : printing of final results of the preprocessing derived from MULCOS is required

- ICROS = 0 : no printing of the cross-sections
  = 1 : printing of the cross-sections is required

- IPRINT = 0 : no printing of fluxes and power densities
  = 1 : printing of fluxes and power densities is required

- IFLUX = 0 : fluxes and power densities are to be printed at given points
  ≠ 0 : fluxes and power densities are to be printed at IFLUX points per mesh

- NT = 0 : fluxes and power densities are not printed in transient
  > 0 : the total power is printed NT times in each macro time step; the fluxes and power densities are printed at the end of each macro time step
  < 0 : the total power, the fluxes and power densities are printed at given times

18. CORE MEMORY AND CPU TIME REQUIREMENTS

The core memory required for a given problem depends essentially on the problem size, i.e. on parameters like the mesh size, the number of energy groups and so on.
The presence of a dynamic allocation technique allows to minimize efficiently this core memory, which can be so divided into 2 contributions : a fixed amount independent on the problem and a variable amount associated to the dynamic allocation vector A (see appendix 6).

Hence $CM = (CM)_f + (CM)_v$ where CM is the total core memory
$(CM)_f$ is the fixed contribution
$(CM)_v$ is the variable contribution

$(CM)_f$ = 960 kbytes
$(CM)_v$ = (8 * IL)bytes, where IL is the dimension of the dynamic allocation vector A.
IL must be specified in the MAIN of the code.

It is very difficult to establish a general relationship between the dimension IL of A and the values of the parameters characterizing the problem size. The most practical way is to proceed empirically. If IL is not large enough, an error message will be printed out and it is necessary then to increase its value. As indication the value IL = 8000 is sufficient to run the sample problem presented in the next section.

The CPU time depends not only on the problem size but also on the transient duration.
As for the core memory it is practically impossible to determine the necessary CPU time in function of the problem size parameters and the transient duration. It can only be stated that the CPU time for transient calculations is approximatively proportional to the transient duration.
Indicative values are provided by the sample problem of section 19.
CPU time for preprocessing + steady state : ± 20 sec.
CPU time for transient : ± 50 sec. (on IBM 370/168)

19. SAMPLE PROBLEM

The present sample problem is a Benchmark exercice proposed in [3]. The reactor configuration is exhibited in figure 19.1.

Reduction of Source Situations :

1. Axisymmetry
2. Two group diffusion theory.
3. Six delayed neutron precursor families.
4. Feedback through changing cross sections.

The equations to be solved are :

1. Neutron kinetics equations :

$$\frac{1}{v_g}\frac{\partial \phi_g}{\partial t} = \vec{\nabla} D_g \vec{\nabla}\phi_g - \Sigma_g^t \phi_g + \chi_g \sum_{g'}(1-\beta)\nu\Sigma_{g'}^f \phi_{g'} + \sum_{g'<g} \Sigma_{g'\to g}\phi_{g'} + \sum_i \chi_g^i \lambda_i C_i$$

$$\frac{\partial C_i}{\partial t} = -\lambda_i C_i + \sum_g \beta_i \nu\Sigma_g^f \phi_g$$

where $D_g = \frac{1}{3\Sigma_g^{tr}}$ with Σ_g^{tr} = macroscopic transport cross-section in group g

The boundary conditions are :

$$\frac{\partial \phi_g}{\partial n} = -\frac{\Sigma_g^{tr}}{0.71}\phi_g$$

2. Temperature equation :

$$\rho c \frac{\partial T}{\partial t} = \vec{q}\ (t) - \vec{q}\ (o)$$

where T is the temperature in zones 1 and 2 supposed uniform

$$\vec{q} = \frac{7.347\ 10^{-12}}{0.335\ V_{1+2}} \int_{V_{+2}} \nu\Sigma_g^f \phi_g\, dV \qquad \left[\frac{cal}{cm^3}\right]$$

3. Feedback equation :

$$\frac{\partial \Sigma_g^i}{\partial T} = a_g^i \frac{300}{T} \qquad i = \text{capture, fission}$$

Data

1. Cross-sections $[cm^{-1}]$

	group	regions 1&2	region 3	region 4	region 5
$\nu\Sigma_g^f$	1	0.007457	0.000835	0.0	0.0
	2	0.011069	0.000328	0.0	0.0
Σ_g^c	1	0.001484	0.002355	0.004821	0.000013
	2	0.007939	0.008551	0.028639	0.000101
Σ_g^f	1	0.002520	0.000303	0.0	0.0
	2	0.003840	0.000135	0.0	0.0
$\Sigma_{g\to g'}$	1→2	0.002085	0.003598	0.003101	0.001294
Σ_g^t	1	0.006089	0.006256	0.007922	0.001307
	2	0.011779	0.008686	0.028639	0.000101
Σ_g^{tr}	1	0.1838	0.2399	0.1670	0.0646
	2	0.3655	0.4157	0.3643	0.1212

2. Neutron spectra and neutron velocities

group	1	2	
χ_g	1.0	0.0	
χ_g^i	1.0	0.0	v[cm/s]
1/v	$1.851\ 10^{-9}$	$1.088\ 10^{-8}$	

3. Precursor parameters

Precursor family	β_i	λ_i
1	$0.81\ 10^{-4}$	0.0129
2	$6.87\ 10^{-4}$	0.0311
3	$6.12\ 10^{-4}$	0.134
4	$11.38\ 10^{-4}$	0.331
5	$5.12\ 10^{-4}$	1.26
6	$1.70\ 10^{-4}$	3.21

$\lambda[s^{-1}]$

β = 0 0032

4. Data for temperature calculation

$\rho = 9.0\ g/cm^3$

$C = 0.07\ cal/g\ °K$

$T(t=0) = 1000\ °K$

5. Feedback data

Type	Group	a_g^i
capture	1	$3.4376\ 10^{-8}$
	2	$2.2759\ 10^{-6}$
fission	1	$2.1677\ 10^{-9}$
	2	$2.8906\ 10^{-7}$

6. Additional data

The initial configuration is exactly critical, deviation from the exact value $k_{eff} = 1.0$ is eliminated by dividing the fission cross-sections by k_{eff}, and the initial precursor concentrations are in equilibrium with the initial flux distribution.
The initial flux can be determined by the initial power :
P(T = 0) = 1000 MW.

Initiating perturbation : the control rod bank (region 4) is axially withdrawn by 6.5 cm in 15 ms and replaced by sodium (region 5).

For this sample test we have limited the transient duration to 13 msec.

Remark :

For this particular sample problem a special thermohydraulics module was developed to calculate the mean temperature of the core. This module is very short because of the simplicity of the model and it is composed by routines NEACRP, QPOW and obviously THERMO, which was adapted accordingly. It is also provided to external users desiring to check the correct running of the code by comparing their results with those ones exhibited hereafter.

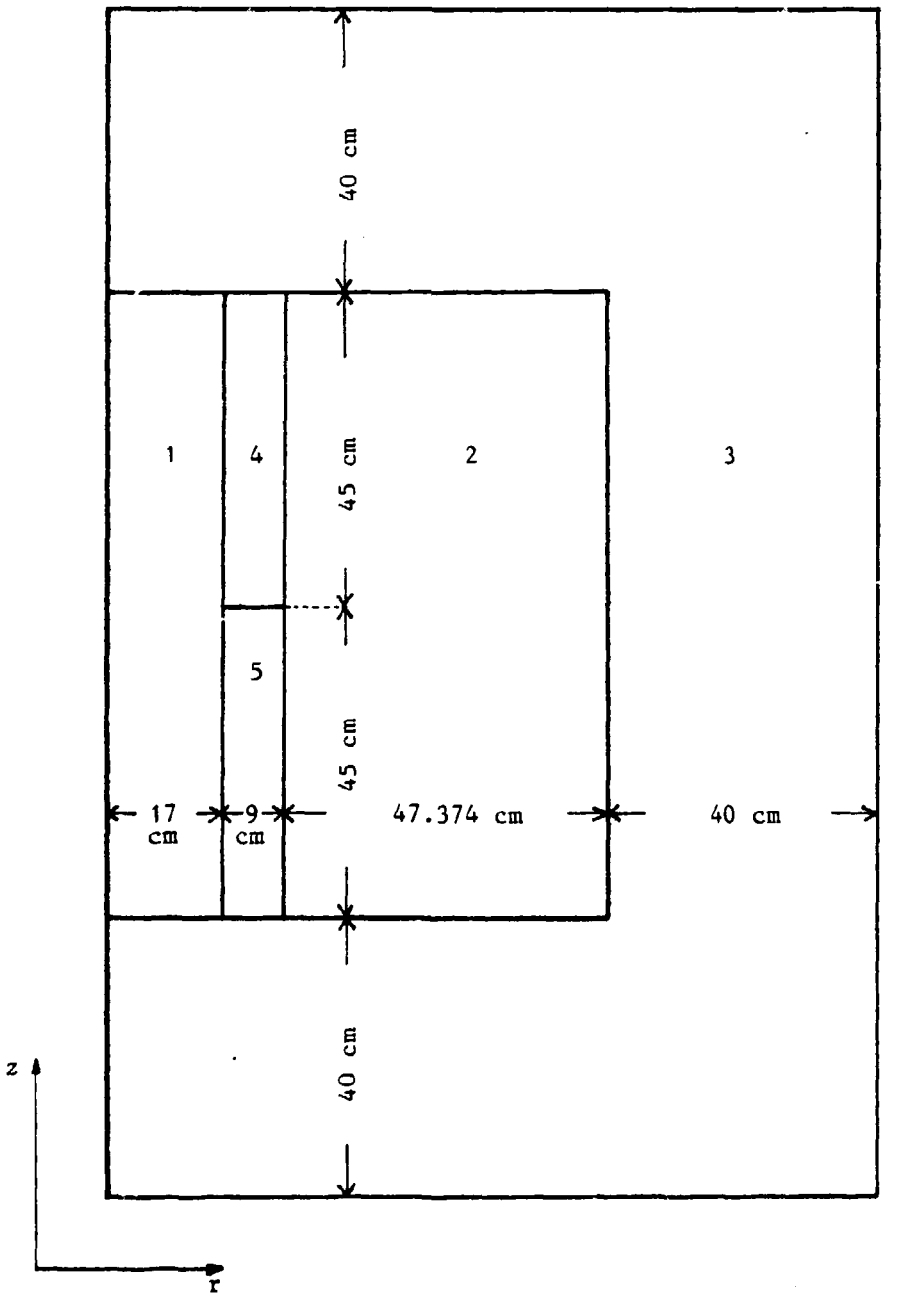


Figure 19.1. : Reactor configuration

Input data for the sample problem

```
  0   0   0
  4   2   0   1   4
COM COM STR SOD
 1  1
 1  2
 1  3
 1  4
 1.0000E 00
 1.0000E 00
 1.0000E 00
 1.0000E 00
1000 1000 1000 1000
 4.0040E-03  1.1779E-02
 7.4570E-03  1.1069E-02
 6.0890E-03  1.1779E-02
 5.5140E-01  1.0965E 00
 5.5140E-01  1.0965E 00
 2.5200E-03  3.8400E-03
 0.0000E 00  0.0
 0.0000E 00  2.0850E-03
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 1.0963E-05  7.6949E-04
 1.9243E-06  2.4797E-04
 1.0963E-05  7.6949E-04
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 6.5031E-07  8.6718E-05
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 2.6580E-03  8.6860E-03
 8.1500E-04  3.2800E-04
 6.2260E-03  8.6860E-03
 7.1970E-01  1.2471E 00
 7.1970E-01  1.2471E 00
 3.0300E-04  1.3500E-04
 0.0000E 00  0.0000E 00
 0.0000E 00  3.5980E-03
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
```

```
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 4.8210E-03  2.8639E-02
 0.0000E 00  0.0000E 00
 7.9220E-03  2.8639E-02
 5.0100E-01  1.0929E 00
 5.0100E-01  1.0929E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  3.1010E-03
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
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 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 0.0000E 00  0.0000E 00
 1.3000E-05  1.0100E-04
 0.0000E 00  0.0000E 00
 1.[illegible]70E-03  1.0100E-04
 1.9190E-01  3.6360E-01
 1.9190E-01  3.6360E-01
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  1.2940E-03
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
 0.0000E 00  0.0
```
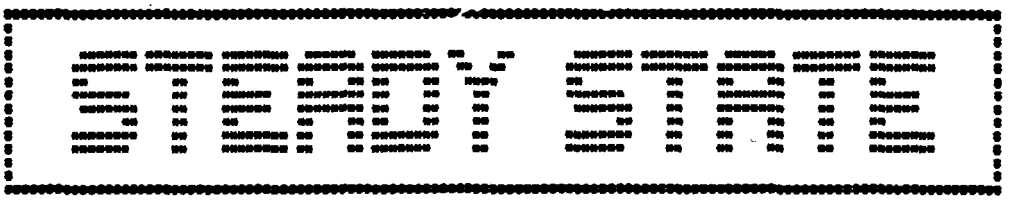

```
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
  0.0000E 00  0.0
5.4624+8SE+089.191176E+07
  1.0000E 00  0.0000E 00
   2
  1   2
ENDP
*** BEN 2D  PROBLEM : CASE 1  -  STEADY STATE  ***
 SS GENERALITIES
  2  0  1  2  1  1  2
  1 25
 SS GEOMETRY
  1  2 -5 -7
 0.000000E 00 1.00000E 00 1.00000E 00 1.00000E 00
 1.000000E 00 2.13000E 00 2.13000E 00 2.13000E 00
 0.000000E 00 1.70000E 01 2.40000E 01 7.33740E 01 1.1337AE 02
 0.000000E 00 4.00000E 01 8.50000E 01 0.82500E 01 9.15000E 01 1.30000E 02
 1.70000E 02
 SS LAY OUT       4
  2  1  5  1  7
  1  1  4  2  6
  3  2  3  3  6
  4  2  3  2  5
  1
 SS CONTR. RODS
  3  2  3  2  6  0
 SS NUCLEAR       0
  2  0  1  4  2  6
 SS CONVERGENCE
  1.0000E-04  1.0000E-04  1.0000E-03  0.0000E 00
 SS ENERGY         3.0760E-12
  1.0000E 09
 SS EDITING
  0  0  0  5  5
  0.0000E 00  1.7000E 01  2.6002E 01  7.3374E 01  1.1337E 02
  0.0000E 00  4.0000E 01  8.5000E 01  1.3000E 02  1.7000E 02
 SS END
*** BEN 2D  PROBLEM : CASE 1  -  TRANSIENT      ***
 US GENERALITIES
  1  1  1.2000E-02  0.0
 US TIME INTEG.
  2  0  0  0  0
 LS
  4.0000E-03  2.0000E-03  1.0000E-03  1.0000E-03  1.0000E-03  1.0000E-03
  1.0000E-03  1.0000E-03  1.0000E-03  1.0000E-03  1.0000E-03  1.0000E-03
  2.0000E-03  4.0000E-03  6.0000E-03
- 4  4  4  4  4  4  4  4  4  4  4  4  4
  3  3  3  5  5  5  5  5  5  4  4  4  3
 US NUCLEAR
  2  6  2  1
  1.2900E-02  3.1100E-02  1.3400E-01  3.3100E-01  1.2600E 00  3.2100E 00
  1.2900E-02  3.1100E-02  1.3400E-01  3.3100E-01  1.2600E 00  3.2100E 00
  8.1000E-05  6.8700E-04  6.1200E-04  1.1380E-03  5.1200E-04  1.7000E-04
  8.1000E-05  6.8700E-04  6.1200E-04  1.1380E-03  5.1200E-04  1.7000E-04
  1.0000E 00  0.0000E 00
= US CONTR. RODS
-  2  1.0000E 00 -9.6297E 00  0.0000E 00  0.0000E 00  1.5000E-02
 US CONVERGENCE
  1.0000E-03  1.0000E-02  1.0000E-02




 US EDITING
  0  0  5
 END
```

Output results for the sample problem

*** BEN 2D PROBLEM : CASE 1 - STEADY STATE ***



*** BEN 2D PROBLEM : CASE 1 - STEADY STATE ***

STEADY STATE PROBLEM IDENTIFICATION

* EIGENVALUE PROBLEM WITHOUT CRITICALITY SEARCH
  NOMINAL POWER OF THE REACTOR : 1.00000E+09 W

* NEUTRONICS IS COUPLED WITH A THERMOHYDRAULICS MODULE
  CONVERGENCE CRITERION ON KEFF FOR THERMOHYDRAULICS COUPLING 1.00C0E-03

THE PREPROCESSING RESULTS ARE STORED ON FILE 45

  NUMBERS OF THE COMPOSITIONS LIMITTED TO THERMOHYDRAULICS FEEDBACK : 1

*** BEN IV PROBLEM : CASE 1 - STEADY STATE ***

GEOMETRICAL DATA

CYLINDRICAL GEOMETRY

LEFT BOUNDARY CONDITION : 1
RIGHT BOUNDARY CONDITION : 2
BOTTOM BOUNDARY CONDITION : 2
TOP BOUNDARY CONDITION : 2

0 ---> ZERO FLUX CONDITION
1 ---> REFLECTIVE CONDITION
2 ---> EXTRAPOLATED FLUX CONDITION

NBER OF R (X) NODES (NR) : 5
NBER OF Z (Y) NODES (NZ) : 7

*** R (X) COORDINATES (CM) ***

0.00000E+00 1.70000E+01 2.60000E+01 7.33740E+01 1.13374E+02

*** Z (Y) COORDINATES (CM) ***

0.00000E+00 4.00000E+01 8.50000E+01 8.62500E+01 9.15000E+01 1.30000E+02 1.70000E+02

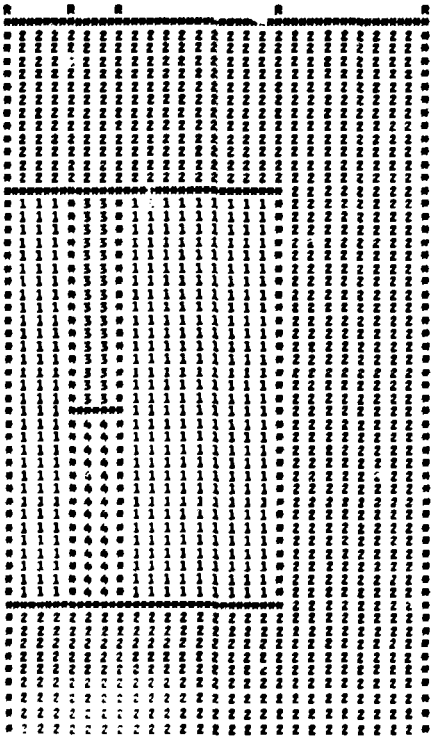
TYPE OF THE FINITE ELEMENTS POLYNOMIALS : BIQUADRATIC

NUMBER OF NODAL PARAMETERS : 117

BAND WIDTH OF F.E.M. MATRICES : 21

*** BEN IV PROBLEM : CASE 1 - STEADY STATE ***

REACTOR LAY-OUT



THE NUMBERS ARE THE COMPOSITION NUMBERS

THE SYMBOLS R,Z INDICATE THE RADIAL AND AXIAL MODE POSITIONS

NUMBER OF CONTROL RODS : 1

ROD NUMBER 1 LOCATED BETWEEN R = 17.00 CM AND R = 25.00 CM
MOVING BETWEEN Z = 40.00 CM AND Z = 130.0C CM
INITIAL INSERTION : 45.00 CM
NUMBER OF THE ABSORBING COMPOSITION : 5
NOT USED FOR CRITICALITY SEARCH

NEW COMPOSITIONS INTRODUCED BY THE CONTROL RODS:

= COMPOSITION NUMBER 5 : MIXTURE OF COMPOSITIONS 4 AND 3

=== GEN 2D PROBLEM : CASE 1 - STEADY STATE ===

NEUTRONIC DATA

NUMBER OF ENERGY GROUPS : 2 (NO UPSCATTERING)

ENERGY DELIVERED PER FISSION : 3.0764E-12 (J)

FISSION SPECTRA

GROUP NBER	PROMPT SPECTRUM	DELAYED SPECTRUM
1	1.000000E+00	NOT GIVEN
2	0.000000E+00	NOT GIVEN

*** DSN 2D PROBLEM : CASE 1 - STEADY STATE ***

DIRECT PROBLEM

ITERATION NUMBER 1

NEUTRONIC RESULTS

CONVERGENCE CRITERION ON KEFF : 1.0000E-04

CPU TIME FOR SOURCE MATRIX CALCULATION : 0.06 SEC
CPU TIME FOR F.E.M. MATRIX CALCULATION : 0.08 SEC

ITERATION NO 1 KEFF= 8.5207213994888E-01 KEFF CONV. RATE 1.8011088E+00 4.796711818E-04 < KEFF < 2.5331807IE+00

OTHER SIGMA ESTIMATE : 2.4999E-04
CPU TIME FOR ITERATION 1 : 0.39 SEC

ITERATION NO 2 KEFF= 9.6754154192622E-01 KEFF CONV. RATE 8.481875E-01 1.195839846E-01 < KEFF < 1.1000615E+00

OTHER SIGMA ESTIMATE : 2.0195E-01
CPU TIME FOR ITERATION 2 : 0.40 SEC

ITERATION NO 3 KEFF= 9.8830488800507E-01 KEFF CONV. RATE 4.32784675E-01 5.555200108E-01 < KEFF < 1.0827623E+00

OTHER SIGMA ESTIMATE : 5.492E-01
CPU TIME FOR ITERATION 3 : 0.40 SEC

ITERATION NO 4 KEFF= 9.9375091695283E-01 KEFF CONV. RATE 1.092217E-01 8.845291137E-01 < KEFF < 1.0287776E+00

OTHER SIGMA ESTIMATE : 5.6794E-01

*** CHEBYSHEV EXTRAPOLATION STARTED WITH SIGMA ESTIMATE : 5.6794E-01 ***

A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE : 5.6794E-01
OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE 0

CPU TIME FOR ITERATION 4 : 0.46 SEC

ITERATION NO 5 KEFF= 9.9448592568886E-01 KEFF CONV. RATE 1.51510899E-02 9.850354068E-01 < KEFF < 1.0096570IE+00

CPU TIME FOR ITERATION 5 : 0.47 SEC

ITERATION NO 6 KEFF= 9.9728605260919E-01 KEFF CONV. RATE 5.587560768E-03 9.943502186E-01 < KEFF < 1.0026436IE+00

OTHER SIGMA ESTIMATE : 6.4789IE-01
CPU TIME FOR ITERATION 6 : 0.40 SEC

```
ITERATION NO   7     KEFF= 9.9729989434764E-01 KEFF CONV. RATE   2.3158781BE-03          9.9698401GE-01 < KEFF <  9.99099958E-01
  OTHER SIGMA ESTIMATE : 6.39576E-01

  A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE :  6.39576E-01
  OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE  5

  CPU TIME FOR ITERATION  7 :   9.45 SEC

ITERATION NO   8     KEFF= 9.9731647292839E-01 KEFF CONV. RATE   9.76346280E-04          9.9634010BE-01 < KEFF <  9.9821754TE-01
  CPU TIME FOR ITERATION  8 :   0.44 SEC

ITERATION NO   9     KEFF= 9.9731599732573E-01 KEFF CONV. RATE   5.08952304E-04          9.9694704BE-01 < KEFF <  9.975930T6E-01
  OTHER SIGMA ESTIMATE : 7.08823E-01
  CPU TIME FOR ITERATION  9 :   0.47 SEC

ITERATION NO  10     KEFF= 9.9734686544346E-01 KEFF CONV. RATE   1.80814828E-04          9.9719605LE-01 < KEFF <  9.9743895ZE-01
  OTHER SIGMA ESTIMATE : 7.28831E-01
  CPU TIME FOR ITERATION 10 :   0.46 SEC

ITERATION NO  11     KEFF= 9.9735070492964E-01 KEFF CONV. RATE   4.3757549GE-05          9.9730699TE-01 < KEFF <  9.9753844ZE-01
  OTHER SIGMA ESTIMATE : 7.04007E-01
```

		LEFT LEAKAGE	RIGHT LEAKAGE	BOTTOM LEAKAGE	TOP LEAKAGE	ABSORPTION	OUT SCATTERING	IN SCATTERING	FISSION	INDEPENDANT SOURCE
GROUP	1	-5.679ZSE-05	-5.5505GE-04	-5.58Z1LE-03	-4.04640E-03	3.44010E+00	2.50900E+00	0.00000E+00	4.98046E+00	0.00000E+00
GROUP	2	-8.7997L9E-05	5.0021PE-04	2.62096E-02	2.0612ZE-02	2.41250E+00	0.00000E+00	2.50900E+00	1.10272E+00	0.00000E+00
TOTAL		-1.4678GE-04	3.5184AE-08	2.0826AE-02	1.5963GE-02	5.8804GE+00	0.00000E+00	0.00000E+00	6.2831BE+00	0.00000E+00

```
KEFF WILAN = 1.061B4E+00

REACTOR SPECTRUM
                          GROUP  1   4.60910E+11
                          GROUP  2   1.107ZDE+11

CONVERGENCE CRITERION OF KEFF FOR THERMOHYDRAULICS COUPLING :  1.0000E-03
CONVERGENCE RATE      OF KEFF FOR THERMOHYDRAULICS COUPLING :  9.9735E-01
```

```
**************************
 THERMOHYDRAULIC RESULTS
**************************

TEMPERATURE IN THE CORE      : 1.00000E+03 (DEG. K)
```

```
*********************
*                   *
*  ITERATION NUMBER  2  *
*                   *
*********************
```

NEUTRONIC RESULTS

CONVERGENCE CRITERION ON KEFF : 1.0000E-04

CPU TIME FOR SOURCE MATRIX CALCULATION : 0.06 SEC
CPU TIME FOR F.E.M. MATRIX CALCULATION : 0.07 SEC

ITERATION NO 1 KEFF= 9.97351770514 1E-01 KEFF CONV. RATE 1.68753010E-05 9.97334895E-01 < KEFF < 9.97346864E-01

OTHER SIGMA ESTIMATE : 5.63999E-09

	LEFT LEAKAGE	RIGHT LEAKAGE	BOTTOM LEAKAGE	TOP LEAKAGE	ABSORPTION	OUT SCATTERING	IN SCATTERING	FISSION	INDEPENDANT SOURCE
GROUP 1	-5.67944E-05	-5.58055E-04	-5.38315E-01	-4.84845E-07	5.44810E+00	2.50708E+00	0.00000E+00	4.98044E+00	0.00000E+00
GROUP 2	-8.79949E-05	5.88219E-04	2.62099E-02	2.08119E-02	2.43250E+00	0.00000E+00	2.50908E+00	1.30272E+00	0.00000E+00
TOTAL	-1.44789E-04	3.31839E-05	2.08268E-02	1.59612F-02	5.88060E+00	0.00000E+00	0.00000E+00	6.28318E+00	0.00000E+00

KEFF BILAN = 1.06284E+00

REACTOR SPECTRUM

GROUP 1 4.60918E+11
GROUP 2 1.10720E+11

ATTENTION ! MAXIMUM OF ITERATIONS IS REACHED FOR CRITICALITY SEARCH AND/OR THERMOHYDRAULICS COUPLING

*** BEN 2D PROBLEM : CASE 1 - STEADY STATE ***.

```
*****************************************************************************
*                                                                           *
*   ADJOINT PROBLEM                                                         *
*                                                                           *
*****************************************************************************
```

CONVERGENCE CRITERION ON KEFF : 1.0000' 04

CPU TIME FOR SOURCE MATRIX CALCULATION : 0.07 SEC
CPU TIME FOR F.E.M. MATRIX CALCULATION : 0.06 SEC

ITERATION NO 1 KEFF= 8.3287215994088E-01 KEFF CONV. RATE 8.29995466E-01 2.0784883SE-05 < KEFF < 1.16984376E+00

OTHER SIGMA ESTIMATE : 1.95401E-04
CPU TIME FOR ITERATION 1 : 0.41 SEC

ITERATION NO 2 KEFF= 9.6784154192621E-01 KEFF CONV. RATE 1.[illegible]E+00 -9.78263083E-01 < KEFF < 1.18838020E+00

OTHER SIGMA ESTIMATE : 1.53628E-01
CPU TIME FOR ITERATION 2 : 0.41 SEC

ITERATION NO 3 KEFF= 9.8830458809387E-01 KEFF CONV. RATE 9.31895383E-01 5.64118017E-02 < KEFF < 1.08812784E+00

OTHER SIGMA ESTIMATE : 6.31398E-01
CPU TIME FOR ITERATION 3 : 0.41 SEC

ITERATION NO 4 KEFF= 9.9378091695285E-01 KEFF CONV. RATE 8.80435151E-01 1.36315766E-01 < KEFF < 1.04872103E+00

OTHER SIGMA ESTIMATE : 5.71208E-01

=== CHEBYSHEV EXTRAPOLATION STARTED WITH SIGMA ESTIMATE : 5.71208E-01 ===

A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE : 5.71208E-01
OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE 0

CPU TIME FOR ITERATION 4 : 0.47 SEC

ITERATION NO 5 KEFF= 9.9649216922115E-01 KEFF CONV. RATE 1.42273016E+00 -6.26236190E-01 < KEFF < 1.18980482E+00

CPU TIME FOR ITERATION 5 : 0.48 SEC

ITERATION NO 6 KEFF= 9.9729549753014E-01 KEFF CONV. RATE 1.49155727E-01 6.47957770E-01 < KEFF < 1.00864678E+00

OTHER SIGMA ESTIMATE : 7.27968E-01
CPU TIME FOR ITERATION 6 : 0.49 SEC

ITERATION NO 7 KEFF= 9.9738230992158E-01 KEFF CONV. RATE 2.42841818E-01 7.84404697E-01 < KEFF < 9.99664982E-01

OTHER SIGMA ESTIMATE : 7.46027E-01

A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE : 7.46027E-01
OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE 1

CPU TIME FOR ITERATION 7 : 0.49 SEC

ITERATION NO 8 KEFF= 9.9731902510418E-01 KEFF CONV. RATE 1.96158066E-02 9.96021672E-01 < KEFF < 1.01693491E+00

CPU TIME FOR ITERATION 8 : 0.48 SEC

ITERATION NO 9 KEFF= 9.9734134626282E-01 KEFF CONV. RATE 5.95953408E-03 9.97011858E-01 < KEFF < 1.00330288E+00

OTHER SIGMA ESTIMATE : 9.97711E-01

CPU TIME FOR ITERATION 9 : 0.48 SEC

ITERATION NO 10 KEFF= 9.9735119821927E-01 KEFF CONV. RATE 1.84571310E-04 9.97220388E-01 < KEFF < 9.97509770E-01

OTHER SIGMA ESTIMATE : 1.00471E+00

A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE : 9.85000E-01
OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE 1

CPU TIME FOR ITERATION 10 : 0.48 SEC

ITERATION NO 11 KEFF= 9.9735361268046E-01 KEFF CONV. RATE 7.92282732E-03 9.97324444E-01 < KEFF < 1.00827664E+00

CPU TIME FOR ITERATION 11 : 0.48 SEC

ITERATION NO 12 KEFF= 9.9735056469502E-01 KEFF CONV. RATE 5.40261665E-02 9.91947950E-01 < KEFF < 9.97402219E-01

OTHER SIGMA ESTIMATE : 1.00010E+00
CPU TIME FOR ITERATION 12 : 0.50 SEC

ITERATION NO 13 KEFF= 9.9734970686454E-01 KEFF CONV. RATE 7.14977944E-03 9.89979927E-01 < KEFF < 9.97411333E-01

OTHER SIGMA ESTIMATE : 9.99860E-01

A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE : 9.99860E-01
OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE 1

CPU TIME FOR ITERATION 13 : 0.49 SEC

ITERATION NO 14 KEFF= 9.9735160212219E-01 KEFF CONV. RATE 6.86548678E-04 9.96665053E-01 < KEFF < 9.97504119E-01

CPU TIME FOR ITERATION 14 : 0.48 SEC

ITERATION NO 15 KEFF= 9.9735435527788E-01 KEFF CONV. RATE 4.96273619E-03 9.97305279E-01 < KEFF < 1.00231709E+00

OTHER SIGMA ESTIMATE : 1.00040E+00
CPU TIME FOR ITERATION 15 : 0.51 SEC

ITERATION NO 16 KEFF= 9.9735460767783E-01 KEFF CONV. RATE 2.97932452E-03 9.97288848E-01 < KEFF < 1.00032485E+00

OTHER SIGMA ESTIMATE : 1.00032E+00
CPU TIME FOR ITERATION 16 : 0.49 SEC

ITERATION NO 17 KEFF= 9.9735200846725BE-01 KEFF CONV. RATE 2.21891911E-04 9.97336371E-01 < KEFF < 9.97563977E-01

OTHER SIGMA ESTIMATE : 1.00001E+00
CPU TIME FOR ITERATION 17 : 0.49 SEC

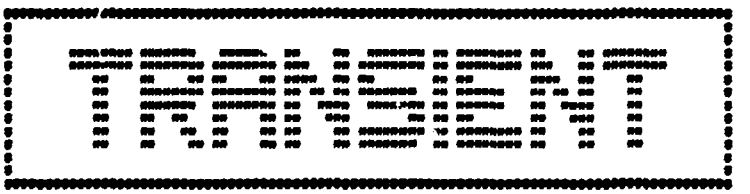
ITERATION NO 18 KEFF= 9.9734974759262E-01 KEFF CONV. RATE 5.69908960E-03 9.91850628E-01 < KEFF < 9.97405596E-01

OTHER SIGMA ESTIMATE : 9.99959E-01
CPU TIME FOR ITERATION 18 : 0.50 SEC

ITERATION NO 19 KEFF= 9.9735104856308E-01 KEFF CONV. RATE 2.81527918E-03 9.96377769E-01 < KEFF < 9.97390103E-01

OTHER SIGMA ESTIMATE : 1.00007E+00

```
 CPU TIME FOR ITERATION 19 :   0.49 SEC

ITERATION NO  20     KEFF= 9.97384324647S9E-01 KEFF CONV. RATE   3.0892S31SE-05          9.97317427E-01 < KEFF <  1.00124388E+00
 OTHER SIGMA ESTIMATE : 1.00000E+00

 A NEW CHEBYSHEV POLYNOMIAL HAS BEEN STARTED WITH NEW SIGMA ESTIMATE :  1.00000E+00
 OLD CHEBYSHEV POLYNOMIAL WAS OF DEGREE  7

 CPU TIME FOR ITERATION 20 :   0.49 SEC

ITERATION NO  21     KEFF= 9.97352861S80A5E-01 KEFF CONV. RATE   9.S32948A5E-06          9.97329692E-01 < KEFF <  9.98306156E-01
 CPU TIME FOR ITERATION 21 :   0.48 SEC

ITERATION NO  22     KEFF= 9.97380946976215E-01 KEFF CONV. RATE   2.69106318E-05          9.96659083E-01 < KEFF <  9.973 01446E-01
 OTHER SIGMA ESTIMATE : 9.99704E-01
 CPU TIME FOR I ERATION 22 :   0.49 SEC

ITERATION NO  23     KEFF= 9.97381117012982E-01 KEFF CONV. RATE   2.61011522E-05          9.96741802E-01 < KEFF <  9.97399234E-01
 OTHER SIGMA ESTIMATE : 9.99795E-01
 CPU TIME FOR ITERATION 23 :   0.50 SEC

ITERATION NO  24     KEFF= 9.97382644613446E-01 KEFF CONV. RATE   4.28722366E-05          9.97309792E-01 < KEFF <  9.97346730E-01
 OTHER SIGMA ESTIMATE : 9.99999E-01

 THE STEADY STATE RESULTS ARE STORED ON FILE  31

IFY1511 VBIOS : 190 RECORDS OF LENGTH 13000 FORMATTED ON FILE FT33F001.
IFY1511 VBIOS : 80 RECORDS OF LENGTH 3344 FORMATTED ON FILE FT37F001.
IFY1511 VBIOS : 40 RECORDS OF LENGTH 3344 FORMATTED ON FILE FT41F001.
IFY1511 VBIOS : 20 RECORDS OF LENGTH 3344 FORMATTED ON FILE FT42F001.

**** BEN 2D  PROBLEM : CASE 1  -  TRANSIENT     ****
```



**** BEN 2D PROBLEM : CASE 1 - TRANSIENT ****

TRANSIENT PROBLEM IDENTIFICATION

* TRANSIENT INDUCED BY CONTROL ROD MOVEMENT
INITIAL POWER OF THE REACTOR : 1.000000E+09 W

* NEUTRONICS IS COUPLED WITH A THERMOHYDRAULICS MODULE

THE MODIFIED PREPROCESSING RESULTS ARE STORED ON FILE 46
THE STEADY STATE RESULTS ARE STORED ON FILE 33

**** BEN 2D PROBLEM : CASE 1 - TRANSIENT ****

****
* GEOMETRICAL DATA *
****

CYLINDRICAL GEOMETRY

LEFT BOUNDARY CONDITION : 1
RIGHT BOUNDARY CONDITION : 2
BOTTOM BOUNDARY CONDITION : 2
TOP BOUNDARY CONDITION : 2

0 ---> ZERO FLUX CONDITION
1 ---> REFLECTIVE CONDITION
2 ---> EXTRAPOLATED FLUX CONDITION

NBER OF R (X) NODES (NR) : 5
NBER OF Z (Y) NODES (NZ) : 7

*** R (X) COORDINATES (CM) ***

0.000000E+00 1.700000E+01 2.600000E+01 7.137400E+01 1.137400E+02

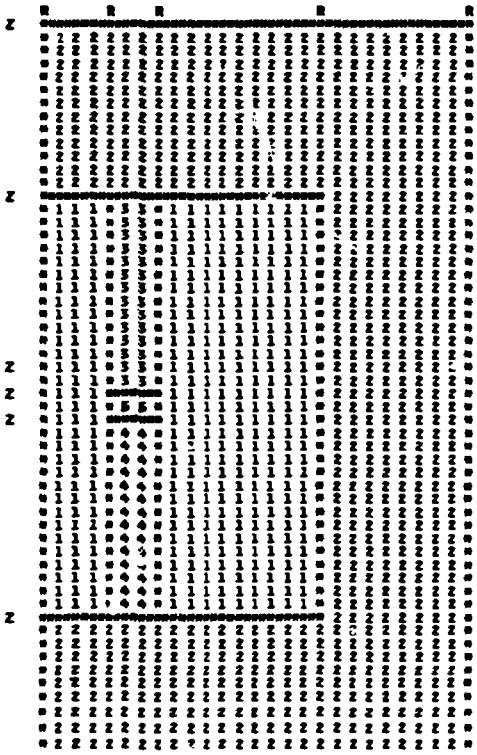
*** Z (Y) COORDINATES (CM) ***

0.000000E+00 4.000000E+01 8.500000E+01 8.625000E+01 9.150000E+01 1.300000E+02 1.700000E+02

TYPE OF THE FINITE ELEMENTS POLYNOMIALS : BIQUADRATIC
NUMBER OF MODAL PARAMETERS : 117
BAND WIDTH OF F.E.M. MATRICES : 21

**** BEN 2D PROBLEM : CASE 1 - TRANSIENT ****

REACTOR LAY-OUT



THE NUMBERS ARE THE COMPOSITION NUMBERS

THE SYMBOLS R,Z INDICATE THE RADIAL AND AXIAL MODE POSITIONS

ROD NUMBER 1 LOCATED BETWEEN R = 17.00 CM AND R = 26.00 CM
MOVING BETWEEN Z = 40.00 CM AND Z = 130.00 CM
INITIAL INSERTION : 46.00 CM
NUMBER OF THE ABSORBING COMPOSITION : 5

*** BEN 2D PROBLEM : CASE 1 - TRANSIENT ***

DRIVING FUNCTIONS

THE ROD INSERTIONS AT TIME T ARE OBTAINED BY MULTIPLYING THE INITIAL ROD INSERTIONS BY THE VALUES OF THE DRIVING FUNCTIONS AT TIME T

ROD NUMBER 1

F=(1.0000E+00) + (-9.6297E+00 * (T-(0.0000E+00)) + (0.0000E+00) * (T-(0.0000E+00))**2

FROM T = 0.0000E+00 (SEC) TO T = 1.5000E-02 (SEC)

*** BEN 2D PROBLEM : CASE 1 - TRANSIENT ***

NEUTRONIC DATA

NUMBER OF ENERGY GROUPS : 2 (NO UPSCATTERING)

ENERGY DELIVERED PER FISSION : 3.0760E-12 (J)

FISSION SPECTRA AND NEUTRON VELOCITIES

GROUP NBER	PROMPT SPECTRUM	DELAYED SPECTRUM	VELOCITY (CM/SEC)
1	1.00000E+00	1.00000E+00	5.40240E+08
2	0.00000E+00	0.00000E+00	9.19118E+07

PRECURSOR DECAY CONSTANTS (SEC-1)

	I = 1	I = 2	I = 3	I = 4	I = 5	I = 6
L = 1	1.29000E-02	3.11000E-02	1.34000E-01	3.31000E-01	1.26[illegible]E+00	5.21000E+00
L = 2	1.29000E-02	3.11000E-02	1.34000E-01	3.31000E-01	1.26000E+00	5.21000E+00

DELAYED NEUTRON FRACTIONS

	I = 1	I = 2	I = 3	I = 4	I = 5	I = 6
L = 1	8.10000E-05	6.87000E-04	6.12000E-04	1.13800E-03	8.12000E-04	1.70000E-04
L = 2	8.10000E-05	6.87000E-04	6.12000E-04	1.13800E-03	8.12000E-04	1.70000E-04

I = PRECURSOR FAMILY NUMBER
L = FUEL ISOTOPE NUMBER

INITIAL VALUE OF KEFF = 9.97357[illegible]946[illegible]0E-01

INSERTED REACTIVITY ($) : -9.9777E-13
FEEDBACK REACTIVITY ($) : 0.0000E+00
TOTAL REACTIVITY ($) : -9.9777E-13

++++++++++++++++++++++++++++++++++++
+ MACRO TIME STEP NO 1 +
++++++++++++++++++++++++++++++++++++

++++++++++++++++++++++++++++++++++++
+ NEWTON-SOR ITERATION NO 1 +
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BEGINNING OF MACRO TIME STEP : 0.0000E+00 (SEC)
END OF MACRO TIME STEP : 4.0000E-03 (SEC)

****
NEUTRONIC RESULTS
****

**** NEW INSERTION OF ROD NO 1 : 4.32667E+01 (CM) ****

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	-9.9777E-13	6.6785E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3106E-07	4.3106E-07
DOMINANT EIGENVALUE (SEC-1)	-9.2711E-14	5.7679E-01

TIME INTERPOLATION PARAMATERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCT.

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 1.00UDE-03

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	6.4152E-01
	2	5.0801E-01
2	1	8.0715E-01
	2	6.3754E-01
3	1	1.0382E+00
	2	8.2034E-01
4	1	1.4631E+00
	2	1.1564E+00

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1 :	5.5891E-01	1.4631E+00
AMPLITUDE VALUE IN GROUP 2 :	4.4109E-01	1.1564E+00

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	2.61488E+09	8.79E-02	1	9.9882E-01	78.79
				2	3.1958E+00	21.21
2	0.21	2.61402E+09	5.87E-03	1	1.0001E+00	78.79
				2	3.1958E+00	21.21
3	0.21	2.61999E+09	2.62E-03	1	9.9954E-01	78.79
				2	3.1958E+00	21.21
4	0.22	2.62044E+09	1.18E-03	1	9.9928E-01	78.79
				2	3.1958E+00	21.21
5	0.21	2.62068E+09	5.54E-04	1	9.9917E-01	78.79
				2	3.1958E+00	21.21

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 8.9851E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.76 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.0000E+03	2.6207E+03

ENERG. RELEASE OVER THE MACROSTEP (MJ) : 6.2659E+00

TIME (SEC)	POWER (MW)
0.00000E+00	1000.00
1.00000E-03	1151.68
2.00000E-03	1444.97
3.00000E-03	1859.04
4.00000E-03	2620.68

THERMOHYDRAULIC RESULTS

TIME = 4.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.0017SE+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 5.9589IE+06 (J)

+ MACRO TIME STEP NO 1 +

+ NEWTON-SOR ITERATION NO 2 +

BEGINNING OF MACRO TIME STEP : 0.0000E+00 (SEC)
END OF MACRO TIME STEP : 4.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	-9.9777E-13	7.1224E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3106E-07	4.3135E-07
DOMINANT EIGENVALUE (SEC-1)	-9.2711E-14	7.6192E-01

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 1.0000E-03

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	6.4988E-01
	2	8.1307E-01
2	1	8.3017E-01
	2	6.8585E-01
3	1	1.0965E+00
	2	8.6648E-01
4	1	1.6179E+00
	2	1.2795E+00

		BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	:	5.8891E-01	1.6179E+00
AMPLITUDE VALUE IN GROUP 2	:	4.6109E-01	1.2795E+00

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.90	2.8926E+09	2.50E-03	1	9.9796E-01	78.78
				2	1.8705E+00	21.22
2	0.21	2.8927E+09	1.29E-04	1	9.9989E-01	78.78
				2	1.8705E+00	21.22

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 8.8291E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.11 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.0000E+03	2.8927E+03
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	6.5546E+00	

TIME (SEC)	POWER (MW)
0.60000E+00	1000.00
1.00000E-03	1162.54
2.00000E-03	1484.84
3.00000E-03	1960.82
4.00000E-03	2892.72

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 9.4044E-02
CONVERGENCE RATE FOR REACTIVITY : 6.2313E-02

THERMOHYDRAULIC RESULTS

TIME = 4.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.0619BE+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 6.25353E+06 (J)

MACRO TIME STEP NO 1

NEWTON-SOR ITERATION NO 3

BEGINNING OF MACRO TIME STEP : 0.0000E+00 (SEC)
END OF MACRO TIME STEP : 4.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	-9.9777E-13	7.1196E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3106E-07	4.3141E-07
DOMINANT EIGENVALUE (SEC-1)	-9.2711E-14	7.6016E-01

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 1.0000E-03

MICROSTEP	GROUP	AMPLITUDE

NODE	NODE	VALUE
1	1	6.4999E-02
	2	5.1514E-01
2	1	8.3039E-01
	2	6.5594E-01
3	1	1.0970E+00
	2	8.6498E-01
4	1	1.6193E+00
	2	1.2804E+00

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1 :	5.5897E-01	1.6193E+00
AMPLITUDE VALUE IN GROUP 2 :	4.4109E-01	1.2804E+00

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.89	2.89508E+09	1.33E-04	1	9.9984E-01	78.78
				2	1.5598E+00	21.22

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 8.829%E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 0.89 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.0000E+03	2.8951E+03
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	6.5571E+00	

TIME (SEC)	POWER (MW)
0.00000E+00	1000.00
1.00000E-03	1162.72
2.00000E-03	1488.18
3.00000E-03	1961.67
4.00000E-03	2895.08

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 8.1588E-04
CONVERGENCE RATE FOR REACTIVITY : 4.2239E-04

INSERTED REACTIVITY ($) : 7.1625E-01
FEEDBACK REACTIVITY ($) : -4.3108E-03
TOTAL REACTIVITY ($) : 7.119%E-01

BEGINNING OF A NEW MACRO TIME STEP

SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 2.0000E-03 (SEC)

VALUES PREDICTED BY THE KABANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 1.1441E+04 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 1.1273E+01 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 6.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.0091E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 1.0927E+07 (J)

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+++++++++++++++++++++++++++++++++++++
+ MACRO TIME STEP       NB  1      +
+++++++++++++++++++++++++++++++++++++

+++++++++++++++++++++++++++++++++++++
+ NEWTON-SOR ITERATION NB  1       +
+++++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP :   0.0000E-01 (SEC)
END       OF MACRO TIME STEP :   5.0000E-01 (SEC)


 NEUTRONIC RESULTS

      ===== NEW INSERTION OF ROD NB  1 :  4.2400E+01 (CM)  =====

POINT-KINETICS PARAMETERS
                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL REACTIVITY ($)                :       7.1194E-01                      1.0441E+00
EFFECTIVE DELAYED NEUTRON FRACTION  :       5.2000E-03                      5.2000E-03
NEUTRON GENERATION TIME (SEC)       :       4.1141E-07                      4.3144E-07

DOMINANT EIGENVALUE (SEC-1)         :       7.6016E-01                      3.3964E+02

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS :  SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
                                               - MODE EXP( 0.00E+00*T)
SHAPE FUNCTIONS     :  DOUBLE INTERPOLATION OF MODE EXP( 0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS     :  4
MICROSTEP VALUE (SEC)    :  5.0000E-04
```

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	2.0470E+00
	2	1.6188E+00
2	1	2.7214E+00
	2	2.1523E+00
3	1	3.8867E+00
	2	3.0728E+00
4	1	6.1569E+00
	2	4.8540E+00

```
                                        BEGINNING OF MACROSTEP          END OF MACROSTEP
AMPLITUDE VALUE IN GROUP  1         :       1.6197E+00                      6.1369E+00
AMPLITUDE VALUE IN GROUP  2         :       1.2804E+00                      4.8540E+00

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS :  1.0000E-01
```

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.90	1.09649E+10	5.44E-03	1	9.9956E-01	78.78
				2	-5.2283E+00	21.22
2	0.21	1.09670E+10	8.47E-05	1	9.9956E-01	78.78
				2	-5.2283E+00	21.22

```
MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP :  4.2758E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION :     1.11 (SEC)

                                        BEGINNING OF MACROSTEP          END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)     :       2.8951E+03                      1.0967E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ)  :   1.1161E+01
```

TIME (SEC)	POWER (MW)
4.00000E-05	2898.00
4.50000E-05	3459.44
5.00000E-05	4064.44
5.50000E-05	4943.01
6.00000E-05	10967.00

THERMOHYDRAULIC RESULTS

TIME = 6.0000E-05 (SEC)

TEMPERATURE IN THE CORE : 1.008962+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 1.96518E+07 (J)

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+++++++++++++++++++++++++++++++++++++
+ MACRO TIME STEP      NB  2   +
+++++++++++++++++++++++++++++++++++++

+++++++++++++++++++++++++++++++++++++
+ NEWTON-SOR ITERATION NB  2   +
+++++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP :  4.0000E-03 (SEC)
END       OF MACRO TIME STEP :  6.0000E-03 (SEC)


==================
 NEUTRONIC RESULTS
==================

POINT-KINETICS PARAMETERS
-------------------------
                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL REACTIVITY ($)                :       7.1194E-01                      1.0444E+00
EFFECTIVE DELAYED NEUTRON FRACTION  :       1.2000E-03                      1.2000E-03
NEUTRON GENERATION TIME (SEC)       :       4.3141E-07                      4.3147E-07

DOMINANT EIGENVALUE (SEC-1)         :       7.6816E-01                      5.4135E+02


TIME INTERPOLATION PARAMETERS
-----------------------------

AMPLITUDE FUNCTIONS :  SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
                                               - MODE EXP( 0.00E+00*T)

SHAPE FUNCTIONS     :  DOUBLE INTERPOLATION OF MODE EXP( 0.00E+00*T)

AMPLITUDE FUNCTIONS
-------------------

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS     :  4
MICROSTEP VALUE (SEC)    :  5.0000E-04


+-------------+-------+-------------+
| MICROSTEP | GROUP |   AMPLITUDE   |
+-------------+-------+-------------+
|   NBER    |  NBER |     VALUE     |
+-----------+-------+---------------+
|     1     |   1   | 2.0472E+00    |
|           |   2   | 1.6189E+00    |
+-----------+-------+---------------+
|     2     |   1   | 2.7221E+00    |
|           |   2   | 2.1529E+00    |
+-----------+-------+---------------+
|     3     |   1   | 3.8868E+00    |
|           |   2   | 3.0742E+00    |
+-----------+-------+---------------+
|     4     |   1   | 6.1430E+00    |
|           |   2   | 4.8588E+00    |
+-----------+-------+---------------+

                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

AMPLITUDE VALUE IN GROUP  1     :       1.6195E+00                      6.1430E+00
AMPLITUDE VALUE IN GROUP  2     :       1.2804E+00                      4.8588E+00

SHAPE FUNCTIONS
---------------

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS :  1.0000E-03

+-------------+---------+---------------+-------------+-------+---------------+---------------+
| ITERATION | CPU TIME |  TOTAL POWER  | CONVERGENCE | GROUP |   PSEUDO-     | POWER FRACTION |
|   NBER    |  (SEC)   |    (WATT)     |    RATE     |  NBER | EIGENVALUE    |      (%)      |
+-----------+---------+---------------+-------------+-------+---------------+---------------+
|     1     |   0.90  | 1.0977E+10    |  9.34E-05   |   1   | 9.9980E-01    |     78.78     |
|           |         |               |             |   2   | -4.3304E+00   |     21.22     |
+-----------+---------+---------------+-------------+-------+---------------+---------------+

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP :  4.2767E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION :     0.90 (SEC)

                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL POWER OF THE REACTOR (MW)     :       2.6951E+03                      1.0978E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ)  :   1.1166E+01
```

TIME (SEC)	POWER (MW)
4.00000E-03	2295.08
4.50000E-03	3459.70
5.00000E-03	4865.69
5.50000E-03	6946.85
6.00000E-03	10977.08

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 9.9142E-04
CONVERGENCE RATE FOR REACTIVITY : 2.6913E-04

INSERTED REACTIVITY ($) : 1.0642E+00
FEEDBACK REACTIVITY ($) : -1.9779E-02
TOTAL REACTIVITY ($) : 1.0444E+00

****

BEGINNING OF A NEW MACRO TIME STEP

****

SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 3.9158E+04 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 2.1204E+01 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 7.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.024B4E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.0407SE+07 (J)

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+ MACRO TIME STEP NO 3 +
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+++++++++++++++++++++++++++++++++++
+ NEWTON-SOR ITERATION NO 1 +
+++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP : 6.0000E-03 (SEC)
END OF MACRO TIME STEP : 7.0000E-03 (SEC)

NEUTRONIC RESULTS

**** NEW INSERTION OF ROD NO 1 : 4.19666E+01 (CM) ****

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	1.0944E+00	1.187SE+00
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3147E-07	4.3147E-07
DOMINANT EIGENVALUE (SEC-1)	3.4153E+02	1.3950E+03

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	0.0018E+00
	2	6.1281E+00
2	1	1.0794E+01
	2	8.4984E+00
3	1	1.4968E+01
	2	1.1827E+01
4	1	2.1724E+01
	2	1.7171E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1 :	6.1418E+00	2.1724E+01
AMPLITUDE VALUE IN GROUP 2 :	4.8808E+00	1.7171E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-05

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	3.0809E+10	5.90E-05	1	9.9969E-01	78.79
				2	5.0590E-01	21.21
2	0.21	3.0809E+10	1.28E-04	1	9.9968E-01	78.79
				2	5.0590E-01	21.21

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.1626E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.12 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.0978E+04	3.0809E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	2.1134E+01	

TIME (SEC)	POWER (MW)
6.00000E-03	10977.88
6.25000E-03	14298.53
6.50000E-03	19197.60
6.75000E-03	26728.14
7.00000E-03	30809.34

THERMOHYDRAULIC RESULTS

TIME = 7.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.024012E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.024022E+07 (J)

+++++++++++++++++++++++++++++++++++++
+ MACRO TIME STEP NO 1 +
+++++++++++++++++++++++++++++++++++++

+++++++++++++++++++++++++++++++++++++
+ NEWTON-SOR ITERATION NO 2 +
+++++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP : 6.0000E-03 (SEC)
END OF MACRO TIME STEP : 7.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	1.0444E+00	1.1867E+00
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3147E-07	4.3140E-07
DOMINANT EIGENVALUE (SEC-1)	3.4133E+02	1.4027E+03

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

SURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NODE	NGER	VALUE
1	1	6.6041E+00
	2	6.3299E+00
2	1	1.0784E+01
	2	8.8063E+00
3	1	1.4998E+01
	2	1.1844E+01
4	1	2.1821E+01
	2	1.7267E+01

			BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP	1	:	6.1430E+00	2.1821E+01
AMPLITUDE VALUE IN GROUP	2	:	4.8568E+00	1.7267E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-05

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (Z)
1	0.00	3.8981E+10	5.62E-05	1	9.9904E-01	78.79
				2	7.4453E-02	21.21

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.1600E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 0.00 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.0978E+04	3.8981E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	2.1177E+01	

TIME (SEC)	POWER (MW)
6.00000E-03	10977.88
6.25000E-03	14302.60
6.50000E-03	19219.12
6.75000E-03	26796.87
7.00000E-03	38981.15

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 4.4127E-03
CONVERGENCE RATE FOR REACTIVITY : 1.0112E-03

INSERTED REACTIVITY ($) : 1.2422E+00
FEEDBACK REACTIVITY ($) : -5.3484E-02
TOTAL REACTIVITY ($) : 1.1887E+00

BEGINNING OF A NEW MACRO TIME STEP

SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 2.1768E+03 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 1.0367E+02 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 0.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.1039ZE+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 1.0019+E+08 (J)

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+ MACRO TIME STEP      NB  4   +
+++++++++++++++++++++++++++++++++++

+++++++++++++++++++++++++++++++++++
+ NENTON-SOR ITERATION NB  1   +
+++++++++++++++++++++++++++++++++++
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BEGINNING OF MACRO TIME STEP : 7.0000E-01 (SEC)
END OF MACRO TIME STEP : 8.0000E-01 (SEC)

NEUTRONIC RESULTS

==== NEW INSERTION OF BID NB 1 : 4.1833IE+01 (CM) ====

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	1.1887E+00	1.2121E+00
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3140E-07	4.3127E-07
DOMINANT EIGENVALUE (SEC-1)	1.4027E+03	1.5761E+03

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	3.2610E+01
	2	2.5697E+01
2	1	4.8043E+01
	2	3.7913E+01
3	1	7.1376E+01
	2	5.6279E+01
4	1	1.0658E+02
	2	8.3967E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.1821E+01	1.0658E+02
AMPLITUDE VALUE IN GROUP 2	1.7247E+01	8.3967E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.90	1.9028E+11	1.17E-02	1	9.9954E-01	78.82
				2	2.2753E+00	21.18
2	0.22	1.9028E+11	4.57E-04	1	9.9961E-01	78.82
				2	2.2933E+00	21.18

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 1.7913E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NENTON-SOR ITERATION : 1.12 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.8981E+04	1.9029E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	9.5259E+01	

TIME (SEC)	POWER (MW)
7.000000E-03	30481.35
7.250000E-03	57091.88
7.500041E-03	89882.39
7.750000E-03	127454.94
8.000000E-03	170289.38

THERMOHYDRAULIC RESULTS

TIME = 8.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.0971SE+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 9.1756SE+07 (J)

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+  MACRO TIME STEP       NO  4    +
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+  NEWTON-SOR ITERATION  NO  2    +
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BEGINNING OF MACRO TIME STEP : 7.0000E-05 (SEC)
END OF MACRO TIME STEP : 8.0000E-05 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	1.1867E+00	1.2140E+00
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3140E-07	4.3098E-07
DOMINANT EIGENVALUE (SEC-1)	1.4827E+03	1.5971E+03

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE
NBER	NBER	VALUE
1	1	5.2430E+01
	2	2.5615E+01
2	1	4.8163E+01
	2	3.8015E+01
3	1	7.1782E+01
	2	5.6618E-01
4	1	1.0767E+02
	2	8.4659E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.1821E+01	1.0767E+02
AMPLITUDE VALUE IN GROUP 2	1.7247E+01	8.4659E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.90	1.9225+E+11	1.9E-03	1	1.0000E+00	78.81
				2	8.5250E-01	21.19
2	0.21	1.9225+E+11	5.2E-05	1	1.0000E+00	78.81
				2	8.5250E-01	21.19

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 1.7832E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.11 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.8981E+04	1.9225E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	9.5721E+01	

TIME (SEC)	POWER (MW)
7.000000E-03	38981.38
7.250000E-03	87926.36
7.500000E-03	84918.46
7.750000E-03	128187.04
8.000000E-03	192254.39

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 1.0110E-02
CONVERGENCE RATE FOR REACTIVITY : 2.1644E-03

****
THERMOHYDRAULIC RESULTS
****

TIME = 8.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.097522E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 9.22027E+07 (J)

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+  MACRO TIME STEP        NB  4    +
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+  NEWTON-SOR ITERATION  NB  3     +
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BEGINNING OF MACRO TIME STEP : 7.0000E-03 (SEC)
END OF MACRO TIME STEP : 8.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	1.1887E+00	1.2140E+00
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3140E-07	4.3102E-07
DOMINANT EIGENVALUE (SEC-1)	1.4027E+03	1.5916E+03

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.0000E-04

MICROSTEP	GROUP	AMPLITUDE
1	1	3.2424E+01
	2	2.5610E+01
2	1	4.8131E+01
	2	3.7990E+01
3	1	7.1674E+01
	2	5.6611E+01
4	1	1.0758E+02
	2	8.4627E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.1621E+01	1.0758E+02
AMPLITUDE VALUE IN GROUP 2	1.7247E+01	8.4627E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	1.9171E+11	0.59E-05	1	9.9996E-01	78.81
				2	8.2276E-01	21.19

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 1.7816E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 0.91 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.8981E+04	1.9172E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	9.5598E+01	

TIME (SEC)	POWER (MW)
7.00000E-03	58981.18
7.25000E-03	87916.91
7.50000E-03	85940.98
7.75000E-03	127989.91
8.00000E-03	191715.73

CONVERGENCE CRITERION FOR POWER : 1.0000E-02 CONVERGENCE RATE FOR POWER : 2.7084E-03
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02 CONVERGENCE RATE FOR REACTIVITY : 8.9492E-04

INSERTED REACTIVITY ($) : 1.4200E+00
FEEDBACK REACTIVITY ($) : -2.0593E-01
TOTAL REACTIVITY ($) : 1.2140E+00

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BEGINNING OF A NEW MACRO TIME STEP

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SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 3.5893E+05 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 3.2402E+02 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 9.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.341864E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 3.088584E+00 (J)

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+ MACRO TIME STEP NO 5 +
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+ NEWTON-SOR ITERATION NO 1 +
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BEGINNING OF MACRO TIME STEP : 8.0000E-03 (SEC)
END OF MACRO TIME STEP : 9.0000E-03 (SEC)

NEUTRONIC RESULTS

**** NEW INSERTION OF ROD NO 1 : 4.11000E+01 (CM) ****

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($) :	1.2140E+00	9.5614E-01
EFFECTIVE DELAYED NEUTRON FRACTION :	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC) :	4.3102E-07	4.3065E-07
DOMINANT EIGENVALUE (SEC-1) :	1.5916E+03	1.0464E+01

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MACROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	1.8185E+02
	2	1.1948E+02
2	1	1.9827E+02
	2	1.4957E+02
3	1	2.1184E+02
	2	1.6875E+02
4	1	2.0895E+02
	2	1.6337E+02

		BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	:	1.0758E+02	2.0895E+02
AMPLITUDE VALUE IN GROUP 2	:	8.4627E+01	1.6337E+02

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-05

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (Z)
1	0.91	3.72657E+11	5.22E-02	1	9.9898E-01	78.88
				2	2.9878E+00	21.12
2	0.22	3.72668E+11	1.09E-03	1	9.9910E-01	78.88
				2	2.9878E+00	21.12
3	0.22	3.72667E+11	2.06E-04	1	9.9909E-01	78.88
				2	2.9878E+00	21.12

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 4.0756E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.35 (SEC)

		BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	:	1.917E+05	3.7267E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	:	3.1652E+02	

TIME (SEC)	POWER (MW)
8.00000E-03	191715.73
8.25000E-03	271066.15
8.50000E-03	339258.10
8.75000E-03	377427.02
9.00000E-03	372667.25

THERMOHYDRAULIC RESULTS

TIME = 9.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.33076E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 5.02059E+08 (J)

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+ MACRO TIME STEP NO 5 +
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+ NEWTON-SOR ITERATION NO 2 +
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BEGINNING OF MACRO TIME STEP : 8.0000E-03 (SEC)
END OF MACRO TIME STEP : 9.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

		BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	:	1.2140E+00	9.5193E-01
EFFECTIVE DELAYED NEUTRON FRACTION	:	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	:	4.3102E-07	4.2993E-07
DOMINANT EIGENVALUE (SEC-1)	:	1.5916E+03	9.0986E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NODE	NODE	VALUE
1	1	1.8163E+02
	2	1.19E9E+02
2	1	1.8921E+02
	2	1.68E9E+02
3	1	1.8895E+02
	2	1.6379E+02
4	1	2.0443E+02
	2	1.5998E+02

		BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP	1 :	1.0738E+02	2.0443E+02
AMPLITUDE VALUE IN GROUP	2 :	8.4427E+01	1.5998E+02

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	3.6446E+11	7.38E-04	1	1.0001E+00	78.87
				2	9.5821E-01	21.13

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 4.0019E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 0.91 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.9172E+05	3.6469E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	5.1385E+02	

TIME (SEC)	POWER (MW)
8.00000E-03	191715.73
8.25000E-03	270674.38
8.50000E-03	337687.61
8.75000E-03	372851.47
9.00000E-03	364685.29

CONVERGENCE CRITERION FOR POWER : 1.0000E-01
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 2.1887E-02
CONVERGENCE RATE FOR REACTIVITY : 4.4278E-03

THERMOHYDRAULIC RESULTS

TIME = 9.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.5367[illegible]E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.9947[illegible]E+08 (J)

MACRO TIME STEP NO 5

NEWTON-SOR ITERATION NO 3

BEGINNING OF MACRO TIME STEP : 8.0000E-03 (SEC)
END OF MACRO TIME STEP : 9.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY (P)	1.2140E+00	9.8521E-01
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3102E-07	4.2998E-07
DOMINANT EIGENVALUE (SEC-1)	1.5916E+03	9.8435E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	1.5176E+02
	2	1.1959E+02
2	1	1.8982E+02
	2	1.4907E+02
3	1	2.1044E+02
	2	1.6496E+02
4	1	2.0700E+02
	2	1.6197E+02

		BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP	1 :	1.8736E+02	2.0700E+02
AMPLITUDE VALUE IN GROUP	2 :	8.4627E+01	1.6197E+02

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.92	3.69270E+11	5.06E-04	1	1.0001E+00	78.87
				2	1.0736E+00	21.13

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 3.9615E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 0.92 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.9172E+05	3.6927E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	3.1837E+02	

TIME (SEC)	POWER (MW)
8.00000E-03	191715.73
8.25000E-03	270898.36
8.50000E-03	358767.15
8.75000E-03	373481.75
9.00000E-03	369269.78

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 1.2615E-02
CONVERGENCE RATE FOR REACTIVITY : 5.4348E-03

THERMOHYDRAULIC RESULTS

TIME = 9.0000E-03 (SEC)

TEMPERATURE IN THE CORE : 1.33789E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 3.0096E+08 (J)

+ MACRO TIME STEP NO 8 +

+ NEWTON-SOR ITERATION NO 4 +

BEGINNING OF MACRO TIME STEP : 8.0000E-03 (SEC)
END OF MACRO TIME STEP : 9.0000E-03 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	1.2140E+00	9.8324E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.3102E-07	4.2999E-07
DOMINANT EIGENVALUE (SEC-1)	1.5916E+03	9.4015E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	1.8164E+02
	2	1.1953E+02
2	1	1.6967E+02
	2	1.4879E+02
3	1	2.0958E+02
	2	1.6428E+02
4	1	2.0852E+02
	2	1.6080E+02

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1 :	1.8758E+02	2.0852E+02
AMPLITUDE VALUE IN GROUP 2 :	8.4427E+01	1.6080E+02

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	1.10	3.6662E+11	2.19E-04	1	1.0001E+00	78.87
				2	1.0875E+00	21.13

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 3.9751E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION . 1.10 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.9172E+05	3.6662E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	5.1448E+02	

TIME (SEC)	POWER (MW)
8.00000E-03	191715.75
8.25000E-03	270770.28
8.50000E-03	338146.88
8.75000E-03	373956.18
9.00000E-03	366623.59

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 7.2177E-03
CONVERGENCE RATE FOR REACTIVITY : 2.0464E-03

INSERTED REACTIVITY ($) : 1.5935E+00
FEEDBACK REACTIVITY ($) : -6.4027E-01
TOTAL REACTIVITY ($) : 9.5324E-01

BEGINNING OF A NEM MACRO TIME STEP

SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEM MACROSTEP : 1.0532E+05 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEM MACROSTEP : 2.3116E+02 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 1.0000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.5130IE+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.△982BE+08 (J)

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+  MACRO TIME STEP      NB  6   +
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+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+  NEWTON-SOR ITERATION  NB  1   +
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BEGINNING OF MACRO TIME STEP : 9.0000E-03 (SEC)
END OF MACRO TIME STEP : 1.0000E-02 (SEC)

NEUTRONIC RESULTS

**** NEW INSERTION OF ROD NB 1 : 4.06666E+01 (CM) ****

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	9.5324E-01	8.5847E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2999E-07	4.2984E-07
DOMINANT EIGENVALUE (SEC-1)	9.4615E+00	2.3475E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	1.8572E+02
	2	1.4515E+02
2	1	1.6048E+02
	2	1.2544E+02
3	1	1.3316E+02
	2	1.0384E+02
4	1	1.0579E+02
	2	8.2404E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.0852E+02	1.0579E+02
AMPLITUDE VALUE IN GROUP 2	1.6080E+02	8.2404E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.92	1.884046E+11	1.84E-02	1	9.9965E-01	78.90
				2	6.5943E+00	21.10
2	0.22	1.885599E+11	7.33E-04	1	9.9956E-01	78.90
				2	6.5943E+00	21.10

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.3715E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.14 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.6662E+05	1.8860E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	2.8522E+02	

TIME (SEC)	POWER (MW)
9.00000E-05	3444E3.59
9.25000E-05	331253.81
9.50000E-05	284842.98
9.75000E-05	237432.42
1.00000E-02	188598.89

****
THERMOHYDRAULIC RESULTS
****

TIME = 1.0000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.8829E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.6938AE+08 (J)

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+ MACRO TIME STEP      NO  6   +
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+ NEWTON-SOR ITERATION NO  2   +
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BEGINNING OF MACRO TIME STEP : 9.0000E-03 (SEC)
END OF MACRO TIME STEP : 1.0000E-02 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	9.5324E-01	7.9878E-01
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2999E-07	4.2930E-07
DOMINANT EIGENVALUE (SEC-1)	9.4015E+00	1.4222E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	1.8342E+02
	2	1.4331E+02
2	1	1.8268E+02
	2	1.1910E+02
3	1	1.1865E+02
	2	9.2359E+01
4	1	8.5998E+01
	2	6.6901E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.0552E+02	8.5998E+01
AMPLITUDE VALUE IN GROUP 2	1.6080E+02	6.6901E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.92	1.53293E+11	9.07E-03	1	1.0003E+00	78.91
				2	2.6086E+00	21.09
2	0.23	1.53295E+11	1.15E-04	1	1.0003E+00	78.91
				2	2.6086E+00	21.09

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 3.2706E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.15 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.6662E+05	1.5329E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	2.6766E+02	

TIME (SEC)	POWER (MW)
9.00000E-03	366423.89
9.25000E-03	327141.53
9.50000E-03	272214.03
9.75000E-03	211361.77
1.00000E-02	163294.88

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 2.3030E-01
CONVERGENCE RATE FOR REACTIVITY : 7.0977E-02

THERMOHYDRAULIC RESULTS

TIME = 1.0000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.561112+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.546022+08 (J)

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+ MACRO TIME STEP      NB  6   +
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+ NEWTON-SOR ITERATION  NB  3   +
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BEGINNING OF MACRO TIME STEP : 9.0000E-03 (SEC)
END OF MACRO TIME STEP : 1.0000E-02 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	9.8324E-01	8.1632E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2999E-07	4.2920E-07
DOMINANT EIGENVALUE (SEC-1)	9.4018E+00	1.6328E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE
NBER	NBER	VALUE
1	1	1.8409E+02
	2	1.4384E+02
2	1	1.5495E+02
	2	1.2091E+02
3	1	1.2264E+02
	2	9.5849E+01
4	1	9.1388E+01
	2	7.1096E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.0582E+02	9.1358E+01
AMPLITUDE VALUE IN GROUP 2	1.6080E+02	7.1096E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-05

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	1.6285E+11	2.77E-03	1	1.0004E+00	78.91
				2	1.8988E+00	21.09
2	0.21	1.6285E+11	3.74E-05	1	1.0003E+00	78.91
				2	1.8988E+00	21.09

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.9975E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.12 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.6662E+05	1.6285E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	2.7202E+02	

TIME (SEC)	POWER (MW)
9.00000E-03	344623.89
9.25000E-03	328332.09
9.50000E-03	276315.75
9.75000E-03	218653.61
1.00000E-02	162854.68

CONVERGENCE CRITERION FOR POWER : 1.0000E-02 CONVERGENCE RATE FOR POWER : 5.8701E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02 CONVERGENCE RATE FOR REACTIVITY : 2.1407E-02

THERMOHYDRAULIC RESULTS

TIME = 1.0000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.84442E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.88731E+06 (J)

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+  MACRO TIME STEP      NO  6   +
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+  NEMTON-SOR ITERATION  NO  4   +
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BEGINNING OF MACRO TIME STEP : 9.0000E-03 (SEC)
END OF MACRO TIME STEP : 1.0000E-02 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	9.8324E-01	8.1143E-01
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2999E-07	4.2922E-07
DOMINANT EIGENVALUE (SEC-1)	9.4015E+00	1.8698E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE
1	1	1.8390E+02
	2	1.4369E+02
2	1	1.5431E+02
	2	1.2040E+02
3	1	1.2168E+02
	2	9.4663E+01
4	1	8.9832E+01
	2	6.9902E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.0862E+02	8.9832E+01
AMPLITUDE VALUE IN GROUP 2	1.6080E+02	6.9902E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	1.09	1.6015E+11	5.36E-04	1	1.0004E+00	78.91
				2	1.9680E+00	21.09

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 3.0510E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.09 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	3.6662E+05	1.6015E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)	2.7079E+02	

TIME (SEC)	POWER (MW)
9.00000E-03	366423.59
9.25000E-03	327999.66
9.50000E-03	278148.16
9.75000E-03	216594.00
1.00000E-02	160133.25

CONVERGENCE CRITERION FOR POWER : 1.0000E-02 CONVERGENCE RATE FOR POWER : 1.6998E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02 CONVERGENCE RATE FOR REACTIVITY : 6.0191E-03

****
THERMOHYDRAULIC RESULTS
****

TIME = 1.0000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.54548E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 2.57566E+08 (J)

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+  MACRO TIME STEP      NB  6    +
+++++++++++++++++++++++++++++++++++

+++++++++++++++++++++++++++++++++++++++
+  NEWTON-SOR ITERATION NB  5        +
+++++++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP :   9.0000E-03 (SEC)
END       OF MACRO TIME STEP :   1.0000E-02 (SEC)


====================
 NEUTRONIC RESULTS
====================

POINT-KINETICS PARAMETERS
-------------------------
                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL REACTIVITY ($)                :       9.5324E-01                      8.1282E-01
EFFECTIVE DELAYED NEUTRON FRACTION  :       3.2000E-03                      3.2000E-03
NEUTRON GENERATION TIME (SEC)       :       4.2999E-07                      4.2922E-07

DOMINANT EIGENVALUE (SEC-1)         :       9.4018E+00                      1.3872E+00

TIME INTERPOLATION PARAMETERS
-----------------------------

AMPLITUDE FUNCTIONS :  SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
                                               - MODE EXP( 0.00E+00*T)

SHAPE FUNCTIONS     :  DOUBLE INTERPOLATION OF MODE EXP( 0.00E+00*T)

AMPLITUDE FUNCTIONS
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BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS      :  4
MICROSTEP VALUE (SEC)     :  2.5000E-04

+-------------+-------+---------------+
| MICROSTEP | GROUP |   AMPLITUDE   |
+-------------+-------+---------------+

+-------------+-------+---------------+
|  NBER     |  NBER |     VALUE     |
+-------------+-------+---------------+
|     1     |   1   |  1.8198E+02   |
|           |   2   |  1.4374E+02   |
+-------------+-------+---------------+
|     2     |   1   |  1.5449E+02   |
|           |   2   |  1.2055E+02   |
+-------------+-------+---------------+
|     3     |   1   |  1.2181E+02   |
|           |   2   |  9.4919E+01   |
+-------------+-------+---------------+
|     4     |   1   |  9.0262E+01   |
|           |   2   |  7.0238E+01   |
+-------------+-------+---------------+

                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

AMPLITUDE VALUE IN GROUP  1       :       2.0552E+02                      9.0262E+01
AMPLITUDE VALUE IN GROUP  2       :       1.6080E+02                      7.0238E+01

SHAPE FUNCTIONS
---------------

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS :  1.0000E-03

+-------------+-----------+-----------------+-------------+-------+---------------+---------------+
| ITERATION | CPU TIME |  TOTAL POWER  | CONVERGENCE | GROUP |    PSEUDO-    | POWER FRACTION |
|   NBER    |  (SEC)   |    (WATT)     |    RATE     |  NBER |  EIGENVALUE   |      (%)      |
+-------------+-----------+-----------------+-------------+-------+---------------+---------------+
|     1     |   1.09   |  1.6090E+11   |   9.71E-05  |   1   |  1.0004E+00   |     78.91     |
|           |          |               |             |   2   |  2.0708E+00   |     21.09     |
+-------------+-----------+-----------------+-------------+-------+---------------+---------------+

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP :  3.0577E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION :     1.09 (SEC)

                                        BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL POWER OF THE REACTOR (MW)     :       3.6662E+05                      1.6090E+05
ENERGY RELEASE OVER THE MACROSTEP (MJ)  :   2.7114E+02
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TIME (SEC)	POWER (MW)
9.000000E-03	344623.89
9.250000E-03	328094.00
9.500000E-03	278498.48
9.750000E-03	217177.81
1.000000E-02	148899.84

CONVERGENCE CRITERION FOR POWER : 1.0000E-02 CONVERGENCE RATE FOR POWER : 4.7644E-03
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02 CONVERGENCE RATE FOR REACTIVITY : 1.7040E-03

INSERTED REACTIVITY ($) : 1.7632E+00
FEEDBACK REACTIVITY ($) : -9.5040E-01
TOTAL REACTIVITY ($) : 8.1282E-01

****

BEGINNING OF A NEW MACRO TIME STEP

****

SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 6.7836E+04 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 9.9662E+01 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 1.1000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.6195E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 9.8615E+07 (J)

++++++++++++++++++++++++++++++++++
+ MACRO TIME STEP NO 7 +
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++++++++++++++++++++++++++++++++++
+ NEWTON-SOR ITERATION NO 1 +
++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP : 1.0000E-02 (SEC)
END OF MACRO TIME STEP : 1.1000E-02 (SEC)

NEUTRONIC RESULTS

**** NEW INSERTION OF ROD NO 1 : 4.0233E+01 (CM) ****

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	8.1282E-01	8.7871E-01
EFFECTIVE DELAYED NEUTRON FRACTION	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2922E-07	4.2920E-07
DOMINANT EIGENVALUE (SEC-1)	1.5872E+00	5.0027E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	6.8554E+01
	2	5.0984E+01
2	1	4.9507E+01
	2	3.6485E+01
3	1	3.8912E+01
	2	3.0253E+01
4	1	3.1848E+01
	2	2.4732E+01

		BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP	1 :	9.0262E+01	3.1848E+01
AMPLITUDE VALUE IN GROUP	2 :	7.0238E+01	2.4732E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	5.6747E+10	5.61E-02	1	1.0001E+00	78.93
				2	-6.2989E+00	21.07
2	0.22	5.6745E+10	5.0E-04	1	1.0000E+00	78.93
				2	-6.2989E+00	21.07

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.0113E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-RAR ITERATION : 1.13 (SEC)

		BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	:	1.6090E+05	5.6745E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ)	:	9.5809E+01	

TIME (SEC)	POWER (MW)
1.00000E-02	160899.84
1.02500E-02	116842.64
1.05000E-02	88228.51
1.07500E-02	69338.88
1.10000E-02	56745.23

THERMOHYDRAULIC RESULTS

TIME = 1.1000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.6157SE+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 9.1132ZE+07 (J)

+ MACRO TIME STEP NO 7 +

+ MEMTON-SOR ITERATION NO 2 +

BEGINNING OF MACRO TIME STEP : 1.0000E-02 (SEC)
END OF MACRO TIME STEP : 1.1000E-02 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	8.12ZIE-01	8.ZZ96E-01
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2922E-07	4.2897E-07
DOMINANT EIGENVALUE (SEC-1)	1.5872E+00	5.1232E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	6.8602E+01
	2	5.1020E+01
2	1	4.9440E+01
	2	3.8599E+01
3	1	3.9165E+01
	2	3.0440E+01
4	1	3.2243E+01
	2	2.5032E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1 :	9.0262E+01	3.2243E+01
AMPLITUDE VALUE IN GROUP 2 :	7.0238E+01	2.5032E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.92	5.79463E+10	1.15E-03	1	1.0004E+00	78.93
				2	-1.9204E+00	21.07
2	0.22	5.79465E+10	5.82E-05	1	1.0004E+00	78.93
				2	-1.9204E+00	21.07

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.0112E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NENTON-SOR ITERATION : 1.14 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.6090E+05	5.7946E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	9.6107E+01	

TIME (SEC)	POWER (MW)
1.00000E-02	160899.84
1.02500E-02	116927.40
1.05000E-02	88500.50
1.07500E-02	69823.76
1.10000E-02	57445.95

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 1.2198E-02
CONVERGENCE RATE FOR REACTIVITY : 4.8108E-03

THERMOHYDRAULIC RESULTS

TIME = 1.1000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.615946E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 9.141857E+07 (J)

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+++++++++++++++++++++++++++++++++
+ MACRO TIME STEP      NO  7   +
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+ NEWTON-SOR ITERATION NO  3   +
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BEGINNING OF MACRO TIME STEP : 1.0000E-02 (SEC)
END OF MACRO TIME STEP : 1.1000E-02 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	8.1282E-01	8.6269E-01
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2912E-07	4.2894E-07
DOMINANT EIGENVALUE (SEC-1)	1.5872E+00	3.1102E+00

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)
SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	6.8597E+01
	2	5.1016E+01
2	1	4.9643E+01
	2	3.8584E+01
3	1	3.9155E+01
	2	3.0617E+01
4	1	3.2200E+01
	2	2.4999E+01

		BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	:	9.0262E+01	3.2200E+01
AMPLITUDE VALUE IN GROUP 2	:	7.0238E+01	2.4999E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-05

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	5.7370E+10	2.83E-05	1	1.0006E+00	78.93
				2	-1.7818E+00	21.07

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.0117E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 0.91 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	1.6090E+05	5.7370E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	9.6075E+01	

TIME (SEC)	POWER (MW)
1.00000E-02	160899.84
1.02500E-02	116917.98
1.05000E-02	88478.94
1.07500E-02	69771.35
1.10000E-02	57370.28

CONVERGENCE CRITERION FOR POWER : 1.0000E-02 CONVERGENCE RATE FOR POWER : 1.3189E-03
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02 CONVERGENCE RATE FOR REACTIVITY : 5.0814E-04

INSERTED REACTIVITY ($) : 1.9319E+00
FEEDBACK REACTIVITY ($) : -1.0493E+00
TOTAL REACTIVITY ($) : 8.8269E-01

BEGINNING OF A NEW MACRO TIME STEP

SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 4.6621E+04 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 4.7893E+01 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 1.2000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.65186E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 4.67530E+07 (J)

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+  MACRO TIME STEP      NB  8     +
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+++++++++++++++++++++++++++++++++++
+  NEWTON-SOR ITERATION NB  1     +
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BEGINNING OF MACRO TIME STEP : 1.1000E-02 (SEC)
END OF MACRO TIME STEP : 1.2000E-02 (SEC)

NEUTRONIC RESULTS

==== MEN INSERTION OF ROD NB 1 : 5.90000E+01 (CM) ====

POINT-KINETICS PARAMETERS

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	8.8264E-01	1.0829E+00
EFFECTIVE DELAYED NEUTRON FRACTION	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	4.2894E-07	4.2893E-07
DOMINANT EIGENVALUE (SEC-1)	5.1102E+00	7.5889E+01

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

GURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	2.7906E+01
	2	2.1458E+01
2	1	2.5770E+01
	2	1.9993E+01
3	1	2.5275E+01
	2	1.9605E+01
4	1	2.6236E+01
	2	2.0342E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	5.2100E+01	2.6236E+01
AMPLITUDE VALUE IN GROUP 2	2.4999E+01	2.0342E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	4.6725E+10	7.09E-03	1	9.9991E-01	78.95
				2	-7.1798E+00	21.05
2	0.22	4.6725E+10	2.13E-04	1	9.9990E-01	78.95
				2	-7.1798E+00	21.05

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.0083E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.13 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW)	5.7370E+04	4.6726E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ)	4.8172E+01	

TIME (SEC)	POWER (MW)
1.10000E-02	57370.28
1.12500E-02	49714.77
1.15000E-02	45904.67
1.17500E-02	45017.30
1.20000E-02	46725.59

THERMOHYDRAULIC RESULTS

TIME = 1.20000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.65191E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 4.58214E+07 (J)

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+ MACRO TIME STEP      NO  8   +
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+ NEWTON-SOR ITERATION NO  2   +
+++++++++++++++++++++++++++++++++++

BEGINNING OF MACRO TIME STEP :   1.1000E-02 (SEC)
END       OF MACRO TIME STEP :   1.2000E-02 (SEC)


====================
 NEUTRONIC RESULTS
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POINT-KINETICS PARAMETERS
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                                    BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL REACTIVITY ($)              :       0.8269E-01                    1.0030E+00
EFFECTIVE DELAYED NEUTRON FRACTION :      3.2000E-03                    3.2000E-03
NEUTRON GENERATION TIME (SEC)     :       4.2894E-07                    4.2879E-07

DOMINANT EIGENVALUE (SEC-1)       :       5.1102E+00                    7.3961E+01


TIME INTERPOLATION PARAMETERS
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AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
                                              - MODE EXP( 0.00E+00*T)

SHAPE FUNCTIONS     : DOUBLE INTERPOLATION OF MODE EXP( 0.00E+00*T)

AMPLITUDE FUNCTIONS
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BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS      : 4
MICROSTEP VALUE (SEC)     : 2.5000E-04

+-------------+-------+---------------+
| MICROSTEP | GROUP |   AMPLITUDE   |
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MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	2.7904E+01
	2	2.1685E+01
2	1	2.5761E+01
	2	1.9985E+01
3	1	2.5254E+01
	2	1.9585E+01
4	1	2.6198E+01
	2	2.0310E+01

```
                                    BEGINNING OF MACROSTEP          END OF MACROSTEP

AMPLITUDE VALUE IN GROUP  1       :       3.2200E+01                    2.6198E+01
AMPLITUDE VALUE IN GROUP  2       :       2.4999E+01                    2.0310E+01


SHAPE FUNCTIONS
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CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS :  1.0000E-03
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ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	4.66557E+10	2.26E-03	1	1.0001E+00	78.9%
				2	-2.0345E+00	21.0%
2	0.22	4.66559E+10	1.58E-06	1	1.0001E+00	78.9%
				2	-2.0345E+00	21.0%

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MAXIMUN RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP :  2.0144E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION :     1.15 (SEC)

                                    BEGINNING OF MACROSTEP          END OF MACROSTEP

TOTAL POWER OF THE REACTOR (MW)   :       5.7370E+04                    4.6656E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ)  :  4.8148E+01
```

TIME (SEC)	POWER (MW)
1.10000E-02	57370.28
1.12500E-02	49710.11
1.16000E-02	45887.13
1.17500E-02	44979.47
1.200[illegible]-02	44655.93

CONVERGENCE CRITERION FOR POWER : 1.0000E-02 CONVERGENCE RATE FOR POWER : 1.4951E-03
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02 CONVERGENCE RATE FOR REACTIVITY : 1.0066E-04

INSERTED REACTIVITY ($) : 2.0996E+00
FEEDBACK REACTIVITY ($) : -1.0965E+00
TOTAL REACTIVITY ($) : 1.0030E+00

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BEGINNING OF A NEW MACRO TIME STEP

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SELECTION MODE FOR MACRO TIME STEP : TIME STEP FIXED BY THE USER

MACRO TIME STEP VALUE : 1.0000E-03 (SEC)

VALUES PREDICTED BY THE KAGANOVE METHOD :

ESTIMATED POWER AT THE END OF THE NEW MACROSTEP : 8.7343E+04 (MW)
ESTIMATED ENERGY RELEASE DURING THE NEW MACROSTEP : 6.1339E+01 (MJ)

THERMOHYDRAULIC RESULTS

TIME = 1.3000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.69810E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 5.86040E+07 (J)

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+ MACRO TIME STEP NO 9 +
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+ NEWTON-SOR ITERATION NO 1 +
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BEGINNING OF MACRO TIME STEP : 1.2000E-02 (SEC)
END OF MACRO TIME STEP : 1.3000E-02 (SEC)

NEUTRONIC RESULTS

==== NEW INSERTION OF ROD NO 1 : 5.75666E+01 (CM) ====

POINT-KINETICS PARAMETERS

		BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	:	1.0030E+00	1.1102E+00
EFFECTIVE DELAYED NEUTRON FRACTION	:	5.2000E-03	5.2000E-03
NEUTRON GENERATION TIME (SEC)	:	4.2879E-07	4.2876E-07
DOMINANT EIGENVALUE (SEC-1)	:	7.5951E+01	8.3228E+02

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SIMPLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP NBER	GROUP NBER	AMPLITUDE VALUE
1	1	2.8861E+01
	2	2.2134E+01
2	1	3.2544E+01
	2	2.5228E+01
3	1	3.8784E+01
	2	3.0034E+01
4	1	4.8214E+01
	2	3.7322E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1	2.6198E+01	4.8214E+01
AMPLITUDE VALUE IN GROUP 2	2.0310E+01	3.7322E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS : 1.0000E-03

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	8.5829E+10	2.32E-03	1	9.9972E-01	78.97
				2	1.0442E+00	21.03
2	0.22	8.5828E+10	8.05E-05	1	9.9971E-01	78.97
				2	1.0442E+00	21.03

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.0461E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.13 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	4.6656E+04	8.5828E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	6.0921E+01	

TIME (SEC)	POWER (MW)
1.20000E-02	46656.93
1.22500E-02	50859.32
1.25000E-02	57985.15
1.27500E-02	69048.32
1.30000E-02	85828.42

THERMOHYDRAULIC RESULTS

TIME = 1.3000E-02 (SEC)

TEMPERATURE IN THE CORE : 1.69767E+03 (DEG. K)
ENERGY RELEASED IN THE CORE : 5.80589E+07 (J)

MACRO TIME STEP NO 9

NEWTON-SOR ITERATION NO 2

BEGINNING OF MACRO TIME STEP : 1.2000E-02 (SEC)
END OF MACRO TIME STEP : 1.3000E-02 (SEC)

NEUTRONIC RESULTS

POINT-KINETICS PARAMETERS

		BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL REACTIVITY ($)	:	1.0030E+00	1.1113E+00
EFFECTIVE DELAYED NEUTRON FRACTION	:	3.2000E-03	3.2000E-03
NEUTRON GENERATION TIME (SEC)	:	4.2879E-07	4.2861E-07
DOMINANT EIGENVALUE (SEC-1)	:	7.3951E+01	8.3516E+01

TIME INTERPOLATION PARAMETERS

AMPLITUDE FUNCTIONS : SINGLE INTERPOLATION OF - FUNDAMENTAL MODE
- MODE EXP(0.00E+00*T)

SHAPE FUNCTIONS : DOUBLE INTERPOLATION OF MODE EXP(0.00E+00*T)

AMPLITUDE FUNCTIONS

BURLISCH-STOER EXTRAPOLATION PROCEDURE IS NOT ASKED
AUTOMATICAL MICROSTEPSIZE CONTROL IS NOT ASKED
ERROR CONTROL FOR AMPLITUDE FUNCTIONS IS NOT ASKED

NUMBER OF MICROSTEPS : 4
MICROSTEP VALUE (SEC) : 2.5000E-04

MICROSTEP	GROUP	AMPLITUDE

NBER	NBER	VALUE
1	1	2.6844E+01
	2	2.2134E+01
2	1	5.2578E+01
	2	2.5227E+01
3	1	5.8814E+01
	2	3.0058E+01
4	1	6.6281E+01
	2	3.7575E+01

	BEGINNING OF MACROSTEP	END OF MACROSTEP
AMPLITUDE VALUE IN GROUP 1 :	2.6198E+01	6.6281E+01
AMPLITUDE VALUE IN GROUP 2 :	2.0310E+01	3.7575E+01

SHAPE FUNCTIONS

CONVERGENCE CRITERION FOR SHAPE FUNCTION ITERATIONS . 1.0000E-05

ITERATION NBER	CPU TIME (SEC)	TOTAL POWER (WATT)	CONVERGENCE RATE	GROUP NBER	PSEUDO-EIGENVALUE	POWER FRACTION (%)
1	0.91	8.59498E+10	1.74E-03	1	9.9999E-01	78.97
				2	5.2582E-01	21.03
2	0.23	8.59496E+10	2.90E-05	1	9.9993E-01	78.97
				2	5.2582E-01	21.03

MAXIMUM RELATIVE CHANGE OF THE SHAPE FUNCTIONS OVER THE MACROSTEP : 2.0417E-02

TOTAL CPU TIME USED FOR SHAPE FUNCTION CALCULATION IN THIS NEWTON-SOR ITERATION : 1.14 (SEC)

	BEGINNING OF MACROSTEP	END OF MACROSTEP
TOTAL POWER OF THE REACTOR (MW) :	4.6656E+04	8.5950E+04
ENERGY RELEASE OVER THE MACROSTEP (MJ) :	6.0956E+01	

TIME (SEC)	POWER (MW)
1.20000E-02	46656.93
1.22500E-02	50864.28
1.25000E-02	56006.46
1.27500E-02	69103.94
1.30000E-02	65949.56

CONVERGENCE CRITERION FOR POWER : 1.0000E-02
CONVERGENCE CRITERION FOR REACTIVITY : 1.0000E-02

CONVERGENCE RATE FOR POWER : 1.4695E-05
CONVERGENCE RATE FOR REACTIVITY : 9.6782E-04

INSERTED REACTIVITY ($) : 2.2664E+00
FEEDBACK REACTIVITY ($) : -1.1551E+00
TOTAL REACTIVITY ($) : 1.1113E+00

NORMAL END AND SCORE/E

REFERENCES

[1] ARIEN B., SIEBERTZ A., DEVOOGHT J., MUND E., : "CASSANDRE : A Two-Dimensional Multigroup Diffusion Code for Reactor Transients Analysis". C.E.N./S.C.K. report BLG 571, September 1984.

[2] MINSART G., : "MULCOS : Formalism used in the Preprocessing". C.E.N./S.C.K. internal report 63-176/75-166, September 1975.

[3] VATH L. and al., : "Survey of the Results of a Two-Dimensional Kinetic Benchmark Problem Typical for a Fast Reactor". Proc. Joint NEACRP/CSNI Specialists' Meeting. New Developments in Three-Dimensional Neutron Kinetics and Review of Kinetics Benchmark Calculations; Garching, FRG, January 22-24, 1975, CONF-750134, p. 501, IAEA (1975).

APPENDIX 1 : ROUTINE DESCRIPTION

A list of the routines composing CASSANDRE is given in this section with a short description for each of them.

The following informations are provided :

- the routine name
- the routines to which this routine calls
- the routines from which this routine is called
- a brief description of the routine objective.

A few routines are not taken up in this list :

1) the routines related to the preprocessing module derived from MULCOS. These routines are : INCOMP, PRINC1, SAVGFL, SBUCOM, SBURLI, SFACT, SMACR, SMACSI, SPICMI. We refer the readers to the reports related to MULCOS for more details;

2) the routine OPENMS used for the direct access files definition;

3) the timer routine CLOCK of the IBM system (see section 15);

4) the dynamic allocation routine IDINIT described in appendix 6;

5) the routine related to the thermohydraulic module, excepted for THERMO (see appendix 7).

Routine name :	ADPOW
Calls to :	none
Called from :	PRIWAT, SPACE
Objective :	Calculation of the power density distributions.

Routine name :	AINTER
Calls to :	EXM, UEXP
Called from :	INTI
Objective :	Computation of the values of the interpolation functions within a microtime step for a given time.

Routine name :	AMPLI
Calls to :	EXTRAB, MOVLEV, UEXP
Called from :	SHAPE
Objective :	Management of the calculation of the amplitude functions over a macro time-step.

Routine name :	BETAIL
Calls to :	IWDAF (entry IRDAF), PINT1
Called from :	SHAPIN
Objective :	Computation of the β_i^ℓ values when the $(\nu_\ell \ \beta_i^\ell)_g$ values are given as input data.

Routine name :	BFISS
Calls to :	None
Called from :	BLNCE, DISFLU
Objective :	Computation of the fission contribution to the neutronic bilan in steady state.

Routine name :	BLEAK
Calls to :	None
Called from :	BLNCE
Objective :	Computation of the leakage contribution to the neutronic bilan in steady state.

Routine name :	BLNCE
Calls to :	BFISS, BLEAK, BSCATT, BSOUR
Called from :	DISFLU
Objective :	Collection of the various contributions to the neutronic bilan in steady state.

Routine name :	BSCATT
Calls to :	None
Called from :	BLNCE
Objective :	Computation of the scattering contribution to the neutronic bilan in steady state.

Routine name :	BSOUR
Calls to :	None
Called from :	BLNCE
Objective :	Computation of the source contribution to the neutronic bilan in steady state.

Routine name :	BUFFER
Calls to :	None
Called from :	CANDER, FORME FEMAT3 (entry WDA) PRODT3 (entry RDA) CANDER, KM, S2MNH (entry CLOSE)
Objective :	Management of reading and writing operations on direct access device NFS.

Routine name :	CALCOF
Calls to :	None
Called from :	INTAB
Objective :	Determination of coefficients needed to define the basis interpolation functions used in the FEM formalism.

Routine name :	CALINT
Calls to :	UEXP, XX
Called from :	PRIWAT, SHACOE
Objective :	Computation of some integrals of products of time interpolation basis polynomials.

Routine name :	CANDER
Calls to :	BUFFER (+ entry CLOSE), FEMAT3 IWDADI (+ entry IRDAD, IRDADI, IWDAD, IWDADC), IWDAF (+ entry IRDAF), PRODT3, UEXP
Called from :	SHAPE, SHAPIN
Objective :	Calculation of the precursor concentrations at the end of a macrostep and reinitialization of files NFO, NTM for the next macrostep.

Routine name :	CHSKYB
Calls to :	None
Called from :	ADJNT,DISFLU, FORME, KINV
Objective :	Solution of the FEM systems by the Cholesky method.

Routine name :	CNP
Calls to :	None
Called from :	ADJNT, DISFLU
Objective :	Calculation of the value of the Chebyshev polynomial of degree n at any point.

Routine name :	COMCRO
Calls to :	None
Called from :	CROS2D
Objective :	Calculation of the cross-sections and diffusion lengths for a given composition.

Routine name :	CRIPAT
Calls to :	FR46, FW46, LAYO
Called from :	SPACIN
Objective :	Initialization of the layout and preparative calculations for criticality search and for thermohydraulic coupling.

Routine name :	CROSS
Calls to :	CROS2D, FR46, FW46, LAYNEW, RODNEW, TEFEED
Called from :	SHAPE
Objective :	Determination of the cross-sections and diffusion lengths in unsteady state at each Newton-SOR iteration.

Routine name :	CROS2D
Calls to :	COMCRO, PRICO2
Called from :	CROSS, RETRO, SHAPIN, SPACE
Objective :	Determination of the cross-sections and diffusion lengths of all the compositions.

Routine name :	DATIN
Calls to :	RW, TRERR
Called from :	INPUTD
Objective :	Reading of input data and creation of files IDP, IDS, IDD.

Routine name :	DISFLU
Calls to :	BFISS, BLNCE, CHSKYB, CNP, DRVING, FEMAT3, SOURCE, SOURMX
Called from :	SPACE
Objective :	Determination of the direct and adjoint fluxes for fixed neutronic and thermal configurations of the reactor in steady state.

Routine name :	DRVING
Calls to :	GAUSS
Called from :	DISFLU
Objective :	Calculation of the driving factors in steady state.

Routine name :	EIGVAL
Calls to :	RNU
Called from :	SHAPE, SHAPIN
Objective :	Calculation of the fundamental eigenvalue of the multigroup point-kinetics equations.

Routine name :	EXM
Calls to :	None
Called from :	AINTER, FINTER
Objective :	Calculation of $e^{i_1 x + i_2 y + i_3 z} - 1$

Routine name :	EXTRAB
Calls to :	FIJ, MICRO, RATH2, SEQFIL
Called from :	AMPLI
Objective :	Calculation of the amplitude functions over a microstep with Burlish-Stoer extrapolation algorithm if desired.

Routine name :	FEMAT3
Calls to :	BUFFER (entry WDA)
Called from :	ADJNT, CANDER, DISFLU, KM, SOURMX, S2MNH
Objective :	Calculation of the finite element matrices and vectors for a given energy group.

Routine name :	FIJ
Calls to :	None
Called from :	EXTRAB
Objective :	Calculation of the product of the elements of a Burlish-Stoer's sequence.

Routine name :	FINTER
Calls to :	EXM
Called from :	INTI, MICRO
Objective :	Calculation of the values of the interpolation functions within a macrostep.

Routine name :	FLUX2D
Calls to :	SPLRZ
Called from :	PRIWAT, SPACE
Objective :	Editing of the fluxes and power densities.

Routine name :	FORME
Calls to :	BUFFER, CHSKYB, IRDADI, IWDAF (+ entry IRDAF), KINV, KM, PRODT3, S2MNH, TSOUR, WATT, XLQ4
Called from :	SHAPE
Objective :	Management of the shape functions determination at each Newton-SOR iteration.

Routine name :	FR46
Calls to :	None
Called from :	CRIPAT, CROSS, RETRO, SHAPIN, SPACE
Objective :	Reading of the neutronic properties and characteristics of the materials.

Routine name :	FW46
Calls to :	None
Called from :	CRIPAT, CROSS, F45, SHAPIN, SPACE
Objective :	Writing of the neutronic properties and characteristics of the materials.

Routine name :	F45
Calls to :	FW46
Called from :	PRINC2
Objective :	Creation of a file containing the neutronic properties and characteristics of the materials in the initial configuration of the reactor.

Routine name :	GAUSS
Calls to :	None
Called from :	DRVING, KINV, MICRO
Objective :	Solution of linear algebraic system by Gauss elimination.

Routine name :	GETK
Calls to :	UEXP
Called from :	MICRO
Objective :	Calculation of coefficients used for the amplitude functions determination.

Routine name :	HIGNEW
Calls to :	None
Called from :	SPACE
Objective :	Calculation of the new control rod positions or the new poisoning in the criticality search process, and modification of the related volume fractions.

Routine name :	INPUTD
Calls to :	DATIN, TRERR
Called from :	MAIN
Objective :	Copy of the input data on file INF5 and calling to DATIN.

Routine name :	INRZ
Calls to :	None
Called from :	SPACIN
Objective :	Creation of the spatial mesh grid.

Routine name :	INTAB
Calls to :	CALCOF, SPLINT
Called from :	SHAPIN, SPACIN
Objective :	Tabulation of elementary integrals used for the setting up of the finite element matrices and vectors.

Routine name :	INTI
Calls to :	AINTER, FINTER
Called from :	PRIWAT
Objective :	Calculation of the time interpolation functions for the power.

Routine name :	IWDADI
Calls to :	None
Called from :	CANDER (+ entry IWDAD, IWDADC, IRDADI, IRDAD), FORME (entry IRDADI, IRDAD), KM (entry IWDAD, IRDAD), PRIWAT (entry IRDAD)
Objective :	Reading and writing on file NFO, which contains informations and values related to the shape functions at the beginning of the considered macro timestep.

Routine name :	IWDAF
Calls to :	None
Called from :	BETAII (entry IRDAF), CANDER (+ entry IRDAF), FLUX2D (entry IRDAF), FORME (+ entry IRDAF), KINCOE (entry IRDAF), KINV(+ entry IRDAF), KM (entry IRDAF), POWPRE (+ entry IRDAF), PRIWAT (+ entry IRDAF), PR1, RAU (+ entry IRDAF) RODNEW (entry IRDAF), TSOUR (entry IRDAF)
Objective :	Reading and writing on file NFX1, which contains the shape functions values in unsteady state for each energy group.

Routine name :	KINCOE
Calls to :	IWDAF (entry IRDAF), PINT1, PINT2
Called from :	RETRO, SHAPE, SHAPIN
Objective :	Calculation of the multigroup point-kinetics parameters.

Routine name :	KINV
Calls to :	CHSKYB, GAUSS, IWDAF (entry IRDAF), PINT1, PRODT3, TSOUR
Called from :	FORME
Objective :	Calculation of the initial values of the pseudo-eigenvalues used for the shape functions determination.

Routine name :	KM
Calls to :	BUFFER (entry CLOSE), FEMAT3, IWDADI (entry IRDAD), IWDAF (entry IRDAF)
Called from :	FORME
Objective :	Calculation of the source vectors of the multigroup shape functions equations.

Routine name :	LAYNEW
Calls to :	SRID
Called from :	CROSS, SPACE
Objective :	Construction of the thermal lay-out and modification of the material lay-out.

Routine name :	LAYO
Calls to :	LAYOU
Called from :	CRIPAT, PR1
Objective :	Determination of some parameters used by LAYOU and calling to LAYOU

Routine name :	LAYOU
Calls to :	None
Called from :	LAYO
Objective :	Printing of geometrical characteristics

Routine name :	MACAS
Calls to :	PRINC1, PRINC2, SHAPE, SPACE, YSART
Called from :	MAIN
Objective :	Constitutes the main of CASTANDRE

Routine name :	MACON
Calls to :	None
Called from :	SHAPE
Objective :	Determination of the macro-time step value when automatical macrostep control is required.

Routine name :	MICRO
Calls to :	FINTER, GAUSS, GETK, MOVLEV, VEPROD
Called from :	EXTRAB
Objective :	Calculation of the amplitude functions at a given micro-time step.

Routine name :	MOVLEV
Calls to :	None
Called from :	AMPLI, MICRO, SHACOE, SHAPE, SHAPIN
Objective :	Transfer of a vector to another one.

Routine name :	PINT1
Calls to :	None
Called from :	BETAIL, KINCOE, KINV, RAU, XLQ4
Objective :	Computation of $\int_R \Phi_g^*(\bar{r})\ \Sigma_x\ \Psi_g(\bar{r},t)\,d\bar{r}$ for any energy group and for any cross-section Σ_x.

Routine name :	PINT2
Calls to :	None
Called from :	KINCOE, RAU
Objective :	Computat on of $\int_R \Phi_g^*(\bar{r})\left(-\bar{\nabla}.\mathcal{D}(\bar{r})\bar{\nabla}\right)\ \Psi_g(\bar{r},t)\,d\bar{r}$ for any energy group g.

Routine name :	PINT3
Calls to :	SPLRZ
Called from :	HIGNEW, RODNEW
Objective :	Computation of the factor $\frac{\delta}{1+\delta}$ defined in appendix 1 of [1].

Routine name :	POWPRE
Calls to :	*IWDAF (+ entry IRDAF)*
Called from :	SHAPE
Objective :	Reactor power prediction and flux shape extrapolation by means of a simplified point-kinetics model when thermohydraulic coupling exists.

Routine name :	PRICOM
Calls to :	None
Called from :	SPACIN
Objective :	Reading and printing of neutronic data.

Routine name :	PRICO2
Calls to :	None
Called from :	CROS2D
Objective :	Printing of cross-sections and diffusion lengths.

Routine name :	PRINC2
Calls to :	F45
Called from :	MACAS
Objective :	Main of the simplified preprocessing module.

Routine name :	PRITER
Calls to :	None
Called from :	SPACE
Objective :	Printing of iteration number in steady state and of the control material values.

Routine name :	PRIWAT
Calls to :	ADPOW, CALINT, IWDADI (entry IRDAD), IWDAF (+ entry IRDAF), FLUX2D, INTI, UEXP.
Called from :	SHAPE
Objective :	Calculation and printing of the reactor power and power density distribution at given times.

Routine name :	PRODT3
Calls to :	BUFFER (entry RDA)
Called from :	CANDER, FORME, KINV, KM, SOURCE, TSOUR
Objective :	Calculation of the product of a FEM matrix by a vector.

Routine name :	PR1
Calls to :	IWDAF, LAYO
Called from :	SHAPIN
Objective :	Initialization of some variables for transient calculations and from steady state results.

Routine name :	PVAR
Calls to :	None
Called from :	FEMAT3
Objective :	Computation of the total contribution of a neighbouring node j of node i in the finite element equation related to node i.

Routine name :	RATH2
Calls to :	None
Called from :	EXTRAB
Objective :	Set up a new line of the Burlisch and Stoer's extrapolation table.

Routine name :	RAU
Calls to :	IWDAF (+ entry IRDAF), PINT1, PINT2, WATT.
Called from :	SHAPIN
Objective :	Computation of the initial k_{eff} value, normalization of the adjoint fluxes and initialization of the shape and amplitude functions for transient calculations.

Routine name :	READ1
Calls to :	None
Called from :	SHAPIN
Objective :	Reading of some nuclear characteristics and of the driving functions on file IDD.

Routine name :	RETRO
Calls to :	CROS2D, FR46, KINCOE
Called from :	SHAPE, SHAPIN
Objective :	*Calculation of the feedback reactivity* in transient.

Routine name :	RNU
Calls to :	None
Called from :	EIGVAL
Objective :	Computation of the fundamental eigenvalue of $F2^{-1}$ F1, where F1, F2 are specified matrices.

Routine name :	RODNEW
Calls to :	IWDAF (entry IRDAF), PINT3
Called from :	CROSS
Objective :	Calculation of the new rod insertion in transient and modification of the related volume fractions.

Routine name :	RW
Calls to :	None
Called from :	DATIN
Objective :	Reading of input data on file INF5 and writing on file IPS, IDS or IDD, according to the case.

Routine name :	SEQFIL
Calls to :	None
Called from :	EXTRAB
Objective :	Determination of a Burlisch-Stoer sequence.

Routine name :	SHACOE
Calls to :	CALINT, MOVLEV, UEXP, XX
Called from :	SHAPE
Objective :	Computation of the shape function coefficients in the shape function equations.

Routine name :	SHAPE
Calls to :	AMPLI, CANDER, CROSS, EIGVAL, FORME, KINCOE, MACON, MOVLEV, POWPRE, PRIWAT, RETRO, SHACOE, SHAPIN, SMAP.
Called from :	MACAS
Objective :	Constitutes the MAIN of the transient module - management of the unsteady state calculations.

Routine name :	SHAPIN
Calls to :	BETAIL, CANDER, CROS2D, EIGVAL, FR46, FW46, INTAB, KINCOE, MOVLEV, OPENMS, PR1, RAU, READ1, RETRO, SMAP, WTIT.
Called from :	SHAPE
Objective :	Management of the initialization operations in unsteady state.

Routine name :	SMAP
Calls to :	None
Called from :	SHAPE, SHAPIN
Objective :	Allocation of some parameters related to the time integration.

Routine name :	SOURCE
Calls to :	PRODT3
Called from :	DISFLU
Objective :	Assembling of the various contributions to the total source in each group (fission source + scattering source + external source) in steady state for the direct and adjoint problems.

Routine name :	SOURMX
Calls to :	FEMAT3
Called from :	DISFLU
Objective :	Organisation of the calculation and storage of the prompt and delayed fission sources and of the scattering source in each energy group in steady state for the direct and adjoint problems.

Routine name :	SPACE
Calls to :	ADPOW, CROS2D, DISFLU, FLUX2D, FR46, FW46, HIGNEW, LAYNEW, PRITER, SPACIN, TEFEED, TRANOU (+ entry TRANFL), WTIT
Called from :	MACAS
Objective :	Constitutes the MAIN of the steady state module-management of the steady state calculations.

Routine name :	SPACIN
Calls to :	CRIPAT, INRZ, INTAB, PRICOM, WTIT
Called from :	SPACIN
Objective :	Management of the initializations in steady state.

Routine name :	SPL
Calls to :	None
Called from :	SPLRZ
Objective :	Computation of the values of the basis Lagrange functions at any point in a given element.

Routine name :	SPLINT
Calls to :	None
Called from :	INTAB
Objective :	Calculation of elementary integrals of the basis Lagrange functions.

Routine name :	SPLRZ
Calls to :	SPL
Called from :	FLUX2D, PINT3
Objective :	Computation of the flux at any point in the reactor.

Routine name :	SRID
Calls to :	None
Called from :	LAYNEW
Objective :	Allocation of a given component of an integer array to a given value.

Routine name :	S2MNH
Calls to :	BUFFER (entry CLOSE), PRODT3
Called from :	FORME
Objective :	Set up of the coefficient matrix of the linear system for the flux shape functions calculation.

Routine name :	TEFEED
Calls to :	None
Called from :	CROSS, SPACE
Objective :	Allocation of the mixture temperatures and densities in each composition from the thermohydraulic results.

Routine name :	THERMO
Calls to :	Thermohydraulic routines
Called from :	MAIN
Objective :	Constitutes the main of the thermo-hydraulic module.

Routine name :	TRANOU
Calls to :	None
Called from :	SPACE (+ entry TRANFL.)
Objective :	Writing of steady state results on file NFT for transient calculations.

Routine name :	TRERR
Calls to :	None
Called from :	DATIN, INPUTD
Objective :	Printing of error messages for the input data.

Routine name :	TSOUR
Calls to :	IWDAF (entry IRDAF), PRODT3
Called from :	FORME, KINV
Objective :	Calculation of the prompt and delayed fission sources in transient.

Routine name :	UEXP
Calls to :	None
Called from :	AINTER, AMPLI, CALINT, CANDER, GETK, PRIWAT, SHACOE
Objective :	Computation e^x for any x by putting $e^x = 0$ if x < negative bound.

Routine name :	VEPROD
Calls to :	None
Called from :	MICRO
Objective :	Computation of the product of a matrix by a vector.

Routine name :	WATT
Calls to :	None
Called from :	FORME, RAU
Objective :	Computation of the reactor power in a given energy group.

Routine name :	WTIT
Calls to :	None
Called from :	SHAPIN, SPACE, SPACIN
Objective :	Printing of titles.

Routine name :	XLQ4
Calls to :	PINT1
Called from :	FORME
Objective :	Computation of the pseudo-eigenvalues used for the flux shape functions calculation.

Routine name :	XX
Calls to :	None
Called from :	CALINT, SHACOE
Objective :	Calculation of $\frac{e^{-x} - 1}{x}$ and its 3 first derivatives.

Routine name :	YSART
Calls to :	IWDADI, IWDAF (+ entry IRDAF)
Called from :	MACAS
Objective :	Reading and writing on NSAVE of the contents of files NCPL, NTM, NFX1, NADJNT, NFO.

Routine name :	
Calls to :	
Called from :	
Objective :	

APPENDIX 2 : FILE DESCRIPTION

In this section a list of the files used in CASSANDRE is given with a short description for each of them.
The following informations are provided :

- the file name(s) : each file is denoted in the source program by one or several names

- the L component(s) : as mentioned previously, the main integers are collected in an array L(100); this is done in particular for the file numbers.
  Ex. INF5 = L(92)

- the routine(s) of number definition : the file numbers are defined in the source program. We give here the routine(s) where these definitions can be found.
  Ex. : the assignation INF5 = 50 is made in routine INPUTD

- the type : a file can be sequential or direct access, temporary or permanent

- the object : a brief description of the contents and the role is given for each file

- writing and reading operations are performed on each file. We give here the routines where these operations are executed.

FILE NUMBER 2

Name(s) : NFTRIA, NF3

L component(s) : 35

Routine of number definition : DATIN

Type : sequential-temporary

Object : the nodal flux (or shape function) values are determined by solving a linear algebraic system. The coefficient matrix of this system is factorized in routine CHSKYB according to the Cholesky method. The result of this factorization is stored on NF3 (or NFTRIA).

Writing routines : CHSKYB

Reading routines : CHSKYB, KINV

FILE NUMBER 3

Name(s) : INF3, IDP, IDS, IDD

L component(s) : 69, 70, 71, 93 (93 → INF3; 69 → IDP; 70 → IDS; 71 → IDD)

Routine of number definition : DATIN

Type : sequential-temporary

Object : conversion of the input data file INF5 into a more useful file (IPP → related to preprocessing; IDS → related to statics; IDD → related to dynamics)

Writing routines : DATIN

Reading routines : CRIPAT, F45, INCOMP, INRZ, PRICOM, PRINC1, PRINC2, READ1, SBUCOM, SBURLI, SHAPIN, SPACIN

FILE NUMBER 4

Name(s) : NFWORK, NF2

L component(s) : 34

Routine of number definition : DATIN

Type : sequential-temporary

Object : work file used in routine CHSKYB

Writing routines : CHSKYB

Reading routines : CHSKYB

FILE NUMBER 13

Name(s) : NFX1, NFX2, NFB1, NFB3

L component(s) : 26, 28, 29, 49 (28 → NFX1; 29 → NFX2; 26 → NFB1; 49 → NFB3)

Routine of number definition : DATIN

Type : sequential-temporary

Object : contains the normalized or non-normalized, direct or adjoint fluxes (group after group) at a given power iteration in steady state

Writing routines : ADJNT. DIRECT

Reading routines : ADJNT, BFISS, BLEAK, BSCATT, DIRECT, FLUX2D, HIGNEW, SOURCE, SRCADJ, TRANOU, ADPOW

FILE NUMBER 14

Name(s) : NFEMAT

L component(s) : 30

Routine of number definition : DATIN

Type : sequential-temporary

Object : storage of the 'absorption' finite element matrices in steady and unsteady states. The matrices are stored group after group.

Writing routines : FEMAT3

Reading routines : CHSKYB

FILE NUMBER 15

Name(s) : NFS

L component(s) : 31

Routine of number definition : DATIN

Type : sequential-temporary

Object : storage of the 'source' finite element matrices (fission + scattering $g' \rightarrow g$) in steady state. The matrices are stored group after group.

Writing routines : FEMAT3

Reading routines : PRODT3

FILE NUMBER 16

Name(s) : NFSF

L component(s) : 33

Routine of number definition : DATIN

Type : sequential-temporary

Object : storage of the independent source finite element vectors in steady state. The vectors are stored group after group.

Writing routines : ADJNT, DIRECT

Reading routines : SOURCE, SRCADJ

FILE NUMBER 17

Name(s) : NFX1, NFX2, NFB1, NFB3, NTM1, NTM2

L component(s) : 26, 28, 29, 49, 66, 68 (26 → NFB1; 28 → NFX1; 29 → NFX2; 49 → NFB3; 66 → NTM1; 68 → NTM2)

Routines of number definition : DATIN, SHAPIN

Type : sequential-temporary

Object : in steady state : identical to file 13
in unsteady state : identical to file 29

Writing routines : AMPLI, POWPRE, ADJNT, DIRECT

Reading routines : AMPLI, PRIWAT, SHACOE, ADJNT, BFISS, BLEAK, BSCATT, DIRECT, FLUX2D, HIGNEW, SOURCE, SRCADJ, TRANOU ,ADPOW

FILE NUMBER 18

Name(s) : NFX1, NFX2, NFB1, NFB3, NFKM

L component(s) : 26, 28, 29, 40, 49 (26 → NFB1; 28 → NFX1; 29 → NFX2; 40 → NFKM; 49 → NFB3)

Routines of number definition : DATIN, SHAPIN

Type : sequential-temporary

Object : in steady state : identical to file 13
in unsteady state : contains the known terms of the linear algebraic system for the calculation of the nodal shape function values at each Newton-SOR iteration (group after group)

Writing routines : KM, ADJNT, DIRECT

Reading routines : FORME, KINV, XLQ4, ADJNT, BFISS, BLEAK, BSCATT, DIRECT, FLUX2D, HIGNEW, SOURCE, SRCADJ, TRANOU , ADPOW

FILE NUMBER 19

Name(s) : NFB2, NTM

L component(s) : 27, 65 (27 → NFB2; 65 → NTM)

Routines of number definition : DATIN, SHAPIN

Type : sequential-temporary

Object : in steady state : contains the fission source finite element vectors $\underset{\sim}{\Sigma}_g$, F_g, $\bar{\phi}_g$, (group after group)
in unsteady state : contains informations and values concerning the calculation of the amplitude functions (with or without BURLISCH-STOER extrapolation)

Writing routines : AMPLI, CANDER, SHAPIN, SOURCE, SRCADJ, YSART

Reading routines : AMPLI, CANDER, POWPRE, SOURCE, SRCADJ, YSART

FILE NUMBER 25

Name(s) : NCPL

L component(s) : 60

Routine of number definition : DATIN

Type : sequential-temporary

Object : storage of the thermohydraulic results (temperature and density for each zone and each material type). This file is the interface between neutronics and thermohydraulics.

Writing routines : PR1, SPACIN, TEFEED, THERMO , ADPOW, YSART

Reading routines : TEFEED, THERMO, TRANOU , ADPOW, YSART

FILE NUMBER 29

Name(s) : NFX1, NFX2, NFB1, NFB3, NTM1, NTM2

L component(s) : 26, 28, 29, 49, 66, 68 (26 → NFB1; 28 → NFX1; 29 → NFX2; 49 → NFB3; 66 → NTM1; 68 → NTM2)

Routines of number definition : DATIN, SHAPIN

Type : sequential-temporary

Object : in steady state : identical to file 13
in unsteady state : contains the amplitude functions values at each microstep in the considered macrostep, alternatively at the last and previous Newton-SOR iterations.

Writing routines : ADJNT, AMPLI, DIRECT, POWPRE

Reading routines : ADJNT, AMPLI, BFISS, BLEAK, BSCATT, DIRECT, FLUX2D, HIGNEW, PRIWAT, SHACOE, SOURCE, SRCADJ, TRANOU, ADPOW

FILE NUMBER 31

Name(s) : NFT

L component(s) : 41

Routine of number definition : DATIN

Type : sequential-permanent

Object : storage of static results, which are necessary for dynamic calculations

Writing routines : TRANOU

Reading routines : PR1, SHAPIN

FILE NUMBER 32

Name(s) : NSAVE

L component(s) : 32

Routine of number definition : MACAS

Type : sequential-temporary (permanent for RESTART procedure)

Object : CASSANDRE works in iterative manner with a thermohydraulics module. At each iteration (in steady or unsteady states) the neutronics data and results are saved on file NSAVE before leaving the neutronics module, and they are read on NSAVE as soon as return in neutronics module.

Writing routines : MACAS , YSART

Reading routines : MACAS , YSART

FILE NUMBER 33

Name(s) : NFS

L component(s) : 31

Routine of number definition : SHAPIN

Type : direct access-temporary

Object : storage of the 'source' finite element matrices (fission + scattering g' → g) in unsteady state. The matrices are stored group after group.

Writing routines : BUFFER (entry WDA) (called by FEMAT3)

Reading routines : BUFFER (entry RDA) (called by PRODT3)

FILE NUMBER 37

Name(s) : NFO

L component(s) : 36

Routine of number definition : SHAPIN

Type : direct access-temporary

Object : contains informations and values related to the shape functions at the beginning of the considered macrostep.

Writing routines : IWDADI (entry IWDAD, IWDADC) (called by CANDER), YSART

Reading routines : IWDADI (entry IRDADI, IRDAD) (called by CANDER, FORME, KM, PRIWAT), YSART

FILE NUMBER 41

Name(s) : NFX1

L component(s) : 28

Routine of number definition : SHAPIN

Type : direct access-temporary

Object : contains the nodal shape functions values in unsteady state (group after group)

Writing routines : IWDAF (called by CANDER, FORME, KINV, POWPRE, PRIWAT, PR1, RAU)

Reading routines : KINV, IWDAF (entry IRDAF) (called by BETAIL, CANDER, FLUX2D, FORME, KINCOE, KINV, KM, POWPRE, PRIWAT, RAU, RODNEW, TSOUR)

FILE NUMBER 42

Name(s) : NADJNT

L component(s) : 37

Routine of number definition : SHAPIN

Type : direct access-temporary

Object: storage of the nodal adjoint fluxes values (group after group

Writing routines : PR1, RAU, YSART

Reading routines : BETAIL, KINCOE, KINV, RAU, XLQ4, YSART

FILE NUMBER 45

Name(s) : IPS

L component(s) : 87

Routines of number definition : DATIN, PRINC1

Type : sequential-permanent

Object : storage fo the output of the preprocessing (corresponding to the initial configuration of the reactor)

Writing routines : FW46 (called by F45), PRINC1

Reading routines : FR46 (called by CRIPAT), MACAS, PRINC1, PRINC2

FILE NUMBER 46

Name(s) : IPSM

L component(s) : 88

Routine of number definition : DATIN

Type : sequential-permanent

Object : conversion of file IPS into a similar one for static calculations with criticality search and thermohydraulics coupling

Writing routines : FW46 (called by CRIPAT and SPACE)

Reading routines : FR46 (called by SPACE)

FILE NUMBER 47

Name(s) : IPSD

L component(s) : 89

Routines of number definition : DATIN, SHAPIN

Type : sequential-temporary (permanent for RESTART procedure)

Object : identical to file IPSM, but for dynamic calculations

Writing routines : FW46 (called by CROSS)

Reading routines : FR46 (called by CROSS and RETRO)

FILE NUMBER 50

Name(s) : INF5

L component(s) : 92

Routine of number definition : INPUTD

Type : sequential-temporary

Object : copy of the input data cards on file INFS

Writing routines : INPUTD

Reading routines : DATIN, RW, TRERR

APPENDIX 3 : DESCRIPTION OF THE INTERFACE FILES

As mentioned in section 3, the various modules of CASSANDRE are interconnected by interface files and eventually by labeled common blocks.

In this appendix a detailed description of these interface files is given with an inventory of their contents followed in some cases by additional informations.

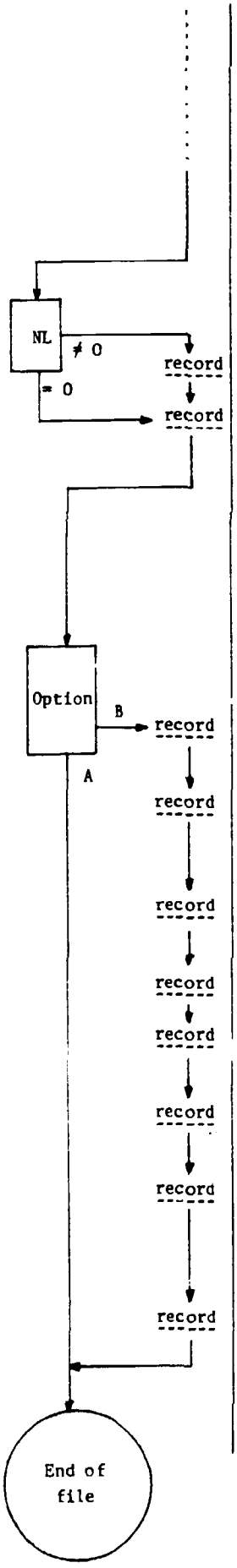
It has to be pointed out that :

- files IDP, IDS, IDD are formatted files
- files IPS, IPSM, NFT, NCPL are binary files.

File IDP

A) Case of preprocessing derived from MULCOS (NEXEC = 1)

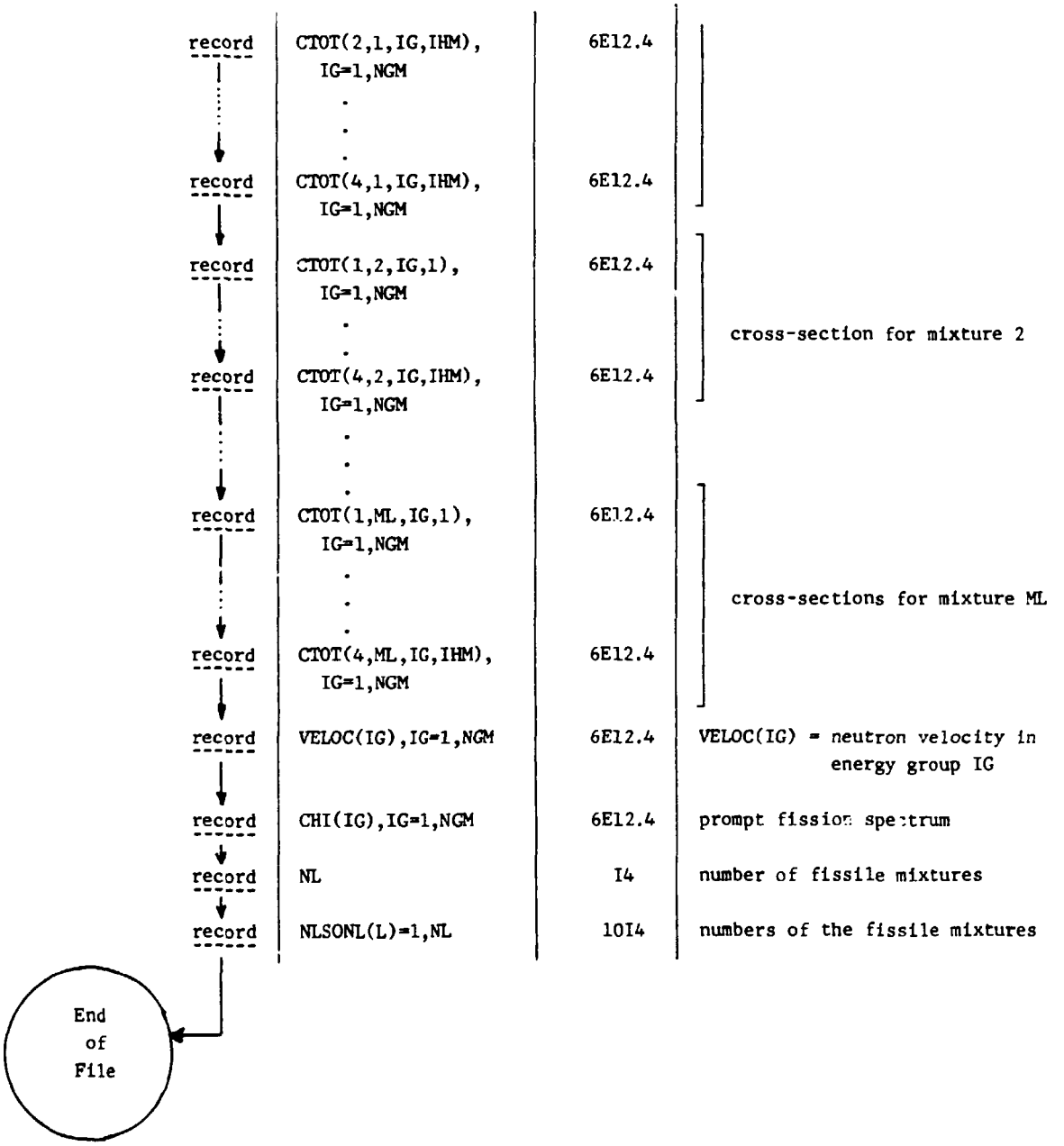
	Variable(s)	Format	Definition
record	ML,IPRO1,IPRO2	3I4	ML = number of mixtures IPRO1=0 : no printing of intermediate results for preprocessing =1 : printing of intermediate results for preprocessing IPRO2=0 : no printing of the cross-sections =1 : printing of the cross-sections
record	TIT,NMIX(1)	A8,I4	TIT = 'bMIXTURE' NMIX = number of the first mixture
record	ITK1,ITK2,ITK3, ITK4,TYPE,NIS	4I8,A4,I4	ITK1,ITK2,ITK3,ITK4 : 4 basis temperatures for the mixture (°K) TYPE = key word describing the mixture type (see input data) NIS = number of isotopes in the mixture
record	NAME,C	A8,4X,E12.4	NAME = name of the first isotope in the mixture (see input data) C = atomic density of this isotope in the mixture (10^{24} at/cm^3)
	this last record has to be repeated NIS times, i.e. for each isotope of the mixture the records for the first mixture have to be repeated ML times, i.e. for each mixture		
record	TIT	A8	TIT = 'bENDbbbb'
record	NMELA	I4	number of mixtures in the first composition
record	NMEL,FRAC	I4,E12.4	NMEL = number of the first mixture in the composition FRAC = volume fraction of this mixture in the composition



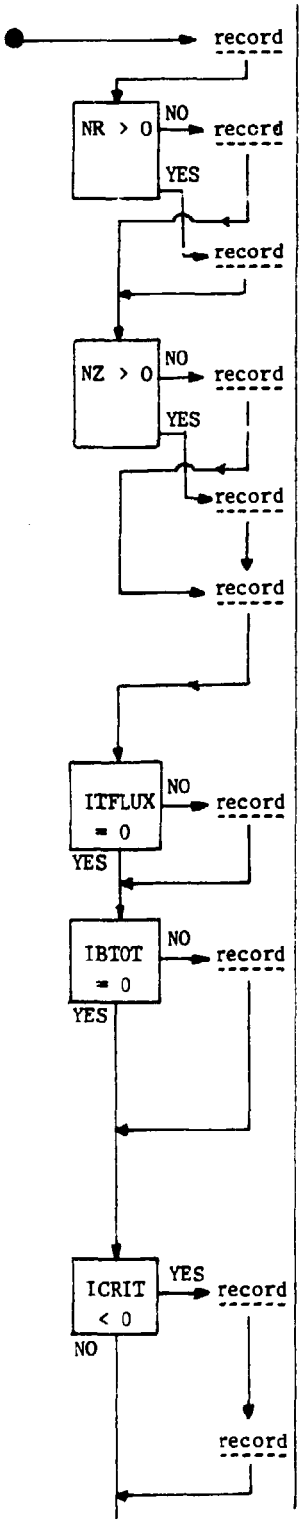
	this record has to be repeated NMELA times, i.e. for each mixture in the composition the records for the first composition have to be repeated MT times, i.e. for each composition		
record	NISONL(IL),IL=1,NL	10I4	numbers of the fuel mixtures
record	NLIB,NGM	3A8,I4	NLIB = 'bLIBRARYbKFK-NAP-26bGR.b' or 40 option A or NLIB = 'bFEWGRbbbbbbbbbbbbSCHEMEb' option B NGM = number of energy groups
record	NUMGR(1,IG),IG=1,NGM	20I4	numbers of the first groups for the collapsing
record	NUMGR(2,IG),IG=1,NGM	20I4	numbers of the last fine groups for the collapsing (see input data)
record	TITLIB,IDLIB	2A8,I4	TITLIB = 'bKFK-NAP-26bGR.b' IDLIB = 26
record	NISL	I4	total of isotopes
record	NAML(I),I=1,NISL	8(A8,2X)	list of the isotopes (see input data for code names)
record	NSPEC	I4	number of spectra to be associated to the compositions for the collapsing
record	NUMSP(I),I=1,MT	20I4	numbers of the spectra to be associated to the MT compositions (see input data)
record	FLUX(IG),IG=1,26	6E12.4	first spectrum
	this record has to be repeated NSPEC times,i.e. for each spectrum		

B) Case of equivalent preprocessing

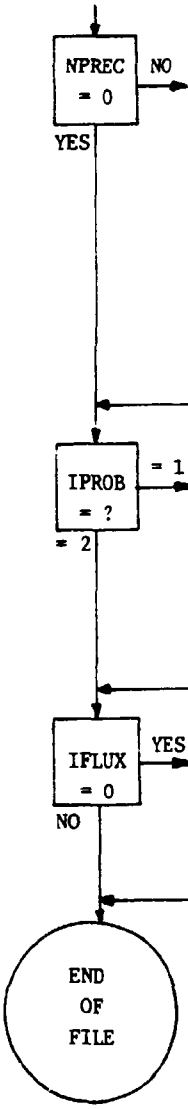
	Variable(s)	Format	Definition
record	ML,NGM,IHM,MT	4I4	ML = number of mixtures NGM = number of energy groups IHM = number of cross-section types MT = number of compositions
record	TYPE(I),I=1,ML	20A4	key words for the ML mixtures = 'bCOM' for fuel = 'bCLD' for cladding = 'bSOD' for coolant = 'bSTR' for structure material
record	NMELA(1), NMEL(1,J),j=1,NMELA(1) . . . this record is repeated MT times,i.e. for each composition	26I3	NMELA(1) = number of mixtures in the first composition NMEL(1,J) =number of the J^{th} mixture in the first composition
record	FRAC(1,J),J=1,NMELA(1) . . . this record is repeated MT times,i.e. for each composition	6E12.4	FRAC(1,J) = initial volume fraction of the J^{th} mixture in the first composition
record	ITK(I),I=1,ML	16I5	base temperatures at which the cross-sections are determined for each mixture (°K)
record	CTOT(1,1,IG,1), IG=1,NGM . . .	6E12.4	cross-sections for mixture 1
record	CTOT(1,1,IG,IHM), IG=1,NGM . . .	6E12.4	
record	CTOT(2,1,IG,1), IG=1,NGM . . .	6E12.4	(see input data for equivalent preprocessing : CTOT is defined likewise)


record
CTOT(2,1,IG,IHM),
IG=1,NGM
6E12.4
record
CTOT(4,1,IG,IHM),
IG=1,NGM
6E12.4
record
CTOT(1,2,IG,1),
IG=1,NGM
6E12.4
record
CTOT(4,2,IG,IHM),
IG=1,NGM
6E12.4
cross-section for mixture 2
record
CTOT(1,ML,IG,1),
IG=1,NGM
6E12.4
record
CTOT(4,ML,IG,IHM),
IG=1,NGM
6E12.4
cross-sections for mixture ML
record
VELOC(IG),IG=1,NGM
6E12.4
VELOC(IG) = neutron velocity in energy group IG
record
CHI(IG),IG=1,NGM
6E12.4
prompt fission spectrum
record
NL
I4
number of fissile mixtures
record
NLSONL(L)=1,NL
10I4
numbers of the fissile mixtures
End of File

File IDS

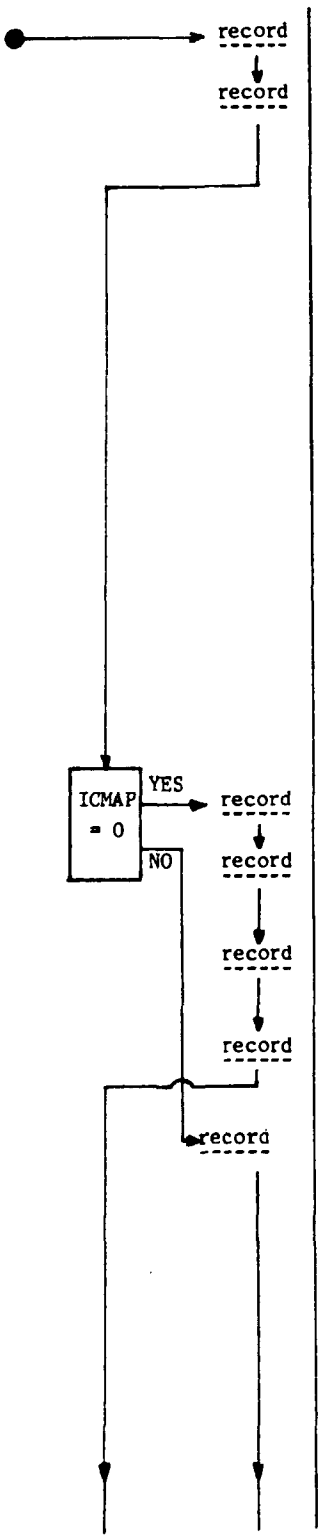


Variable(s)	Format	Definition
TITLE	10A8	title for steady state
R(I),I=1, |NR|	6E12.4	abscissa of the mesh nodes along the x(r) axis
RMIN,RMAX	2E12.4	minimum and maximum abscissa of the uniform mesh grid along the x(r) axis
Z(J),J=1, |NZ|	6E12.4	abscissa of the mesh nodes along the y(z) axis
ZMIN,ZMAX	2E12.4	minimum and maximum abscissa of the uniform mesh grid along the y(z) axis
NCOMP,IR1,IR2, IZ1,IZ2 . . . NMAX records	5I3	see input data for reactor lay-out
IMTH(I) I=1,ITFLUX	26I3	number of the compositions to be coupled with thermohydraulics
MTABS,IRC1,IRC2, IZC1,IZC2,IRZ8 . . . IBTOT records	6I3	MTABS = number of the absorbing composition in the control rod IRC1,IRC2,IZC1,IZC2 : respectively left, right columns and bottom, top rows of the mesh grid enclosing the control rod region IRZ8 = 0 control rod not used for criticality search = 1 control rod used for criticality search
MTFRA,FRAMAX	I3,E12.4	MTFRA = number of poisoned compositions FRAMAX = maximum permitted volume fraction of poison in the coolant
NCOPO(I),I= 1,MTFRA	24I3	numbers of the poisoned compositions

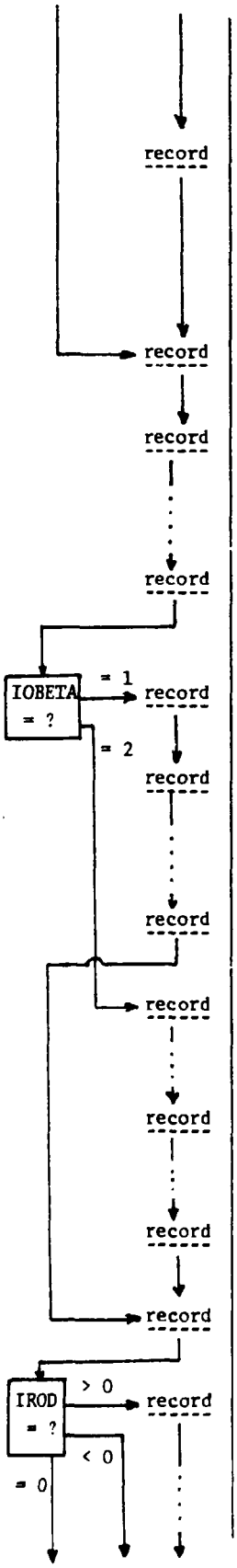


record	BETA(1,I) I = 1,NI . . .	6E12.4	delayed neutron fractions of the NI precursor families for the NL fuel isotopes
record	BETA(NL,I) I = 1,NL	6E12.4	(β_i^{ℓ})
record	CHID(IG) IG = 1,NGM	6E12.4	delayed neutron fission spectrum χ_g^d
record	Q(1,IG) IG = 1,NGM . . .	6E12.4	independent multigroup source in the MT compositions
record	Q(MT,IG) IG = 1,NGM	6E12.4	
record	RR(I),I=1,NRF	6E12.4	abscissa along the x(r) axis where the fluxes are to be edited
record	ZZ(J),J=1,NZF	6E12.4	abscissa along the y(z) axis where the fluxes are to be edited

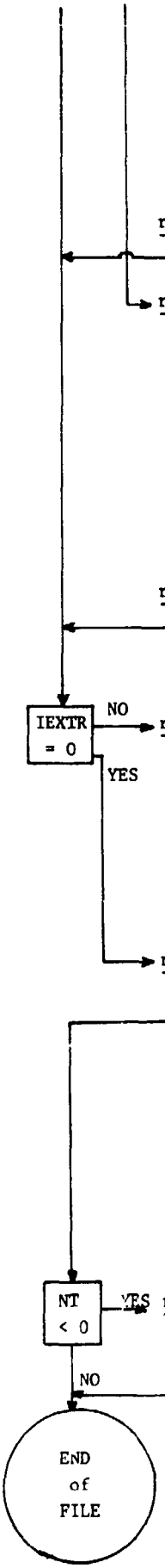
File IDD



Variable(s)	Format	Definition
TITLE	10A8	title for transient
IEXTR,ICER,ICMP, ICMAP	4I3	IEXTR = 0 no Burlish-Stoer extrapolation for amplitude functions calculation = 1 Burlish-Stoer extrapolation for amplitude functions calculation ICER = 0 no error control for amplitude functions calculation = 1 error control for amplitude functions calculation ICMP = 0 no automatical control of microtimestep ≠ 0 automatical control of microtimestep (= maximum number of microsteps) ICMAP = 0 no automatical control of macrotimestep = 1 automatical control of macrotimestep
MACMAX	I3	number of macrotimesteps
PMA(K),K=1, MACMAX	6E12.4	macrotimestep lengths
NMIC(K),K=1, MACMAX	24I3	number of microtimesteps in each macrotimestep at the first Newton-SOR iteration
NEWT(K),K=1, MACMAX	24I3	maximum numbers of Newton-SOR iterations for each macrotimestep
PMAC1,PMAX,PMIN, FRMIN,DPLIM,RPOM	6E12.4	PMAC1 = first macrotimestep length PMAX = maximum permitted macrotimestep length PMIN = minimum permitted microtimestep length FRMIN = minimum value of the macrotimestep reduction factor DPLIM = maximum permitted relative variation of the shape functions over a macrotimestep



		RPOM = maximum permitted value of the power ratio between beginning and end of a macrotimestep
record	NEWMAX,NMIC	2I3	NEWMAX = maximum number of Newton-SOR iterations in each macrotimestep NMIC = number of microtimesteps in each macrotimestep at the first Newton-SOR iteration
record	XLAMDA(I,1), I=1,NI	6E12.4	decay constants of the NI precursor families for the NL fuel isotopes (λ_i^{ℓ})
record	XLAMDA(I,2), I=1,NI	6E12.4	
record	XLAMDA(I,NL) I=1,NI	6E12.4	
record	BETA(I,1), I=1,NI	6E12.4	delayed neutron fractions of the NI precursor families for the NL fuel isotopes (β_i^{ℓ})
record	BETA(I,2), I=1,NI	6E12.4	
record	BETA(I,NL), I=1,NI	6E12.4	
record	XNBET(I,1,1), I=1,NI	6E12.4	values of the $(\nu_{\ell}\beta_i^{\ell})_g$
record	XNBET(I,1,NGM), I=1,NI	6E12.4	
record	XNBET(I,NL,NGM), I=1,NI	6E12.4	
record	CHID(IG),IG=1,NGM	6E12.4	delayed neutron fission spectrum χ_g^d
record	NROD,FO,F1,F2, TS,TF	I3, 5E12.4	NROD = number of the first moving control rod FO,F1,F2,TS,TF = coefficients of the driving function for control rod NROD:



		F = F0+F1*(T-TS)+F2*(T-TS)^2 for TS $\leq$ T $\leq$ TF = 1 for 0 $\leq$ T < TS (F is the ratio of the rod insertion at time T by the initial rod insertion)
NROD,F0,F1,F2,TS,TF	I3,5E12.4	idem but for the last moving rod
NCOM,IMDF,F0,F1,F2,TS,TF	2I3,5E12.4	NCOM = number of the composition to be modified IMDF = number of the variable mixture F0,F1,F2,TS,TF = coefficients of the driving function for mixture IMDF F = F0+F1*(T-TS)+F2*(T-TS)^2 for TS $\leq$ T $\leq$ TF = 1 for 0 $\leq$ T < TS
NCOM,IMDF,F0,F1,F2,TS,TF	2I3,5E12.4	idem but for the last composition to be modified (F is the ratio of the volume fraction of mixture IMDF at time T by its initial volume fraction)
EPSA	E12.4	if ICER = 0, EPSA is the maximum permitted relative error on the amplitude functions at the first microtimestep in each macrotimestep if ICER ≠ 0, EPSA is the maximum permitted relative error on the amplitude functions at the end of the transient
EPSF,EPSP,EPSR	3E12.4	EPSF = convergence criterion on the shape functions at each Newton-SOR iteration in each macrotimestep EPSP = convergence criterion on the total reactor power at the end of each macrotimestep EPSR = convergence criterion on the reactor reactivity at the end of each macrotimestep
TPR(I),I=1,|NT|	6E12.4	times at which the power, fluxes and power densities are to be edited

File IPS

Record	Variable(s)	Definition
1	XNAM	XNAM = 'CROSSECT'
2	ML,NGM,IHM,MT	ML = number of mixtures NGM = number of energy groups IHM = number of rows in the cross-section matrices CTOT MT = number of compositions
3	TYPE(I),I=1,ML	mixture types = 'bCOM' for fuel mixtures = 'bCLD' for clad mixtures = 'bSOD' for coolant mixtures = 'bSTR' for structure mixtures
4 . . .	NMELA(1), NMEL(1,J),J=1,NMELA(1), FRAC(1,J),J=1,NMELA(1)	NMELA(1) = number of mixtures in composition 1 NMELA(1,J) = number of the J^{th} mixture in composition 1 FRAC(1,J) = initial volume fraction of the J^{th} mixture in composition 1
3+MT	NMELA(MT) NMEL(MT,J),J=1,NMELA(MT), FRAC(MT,J),J=1,NMELA(MT)	NMELA(MT) = number of mixtures in composition MT NMELA(MT,J) = number of the J^{th} mixture in composition MT FRAC(MT,J) = initial volume fraction in the J^{th} mixture in composition MT
4+MT	ITK(I),I=1,ML	ITK(I) = reference temperature of mixture I at which the cross-sections are determined (°K)
4+MT+1	CTOT(1,1,IG,1), IG=1,NGM	cross-sections for mixture 1 (see input data for equivalent preprocessing : CTOT is defined likewise)
4+MT+IHM	CTOT(1,1,IG,IHM), IG=1,NGM	
4+MT+IHM +1	CTOT(2,1,IG,1), IG=1,NGM	
4+MT+2*IHM	CTOT(2,1,IG,IHM), IG=1,NGM	
4+MT+4*IHM	CTOT(4,1,IG,IHM), IG=1,NGM	
4+MT+4*IHM +1	CTOT(1,2,IG,1), IG=1,NGM	cross-sections for mixture 2
4+MT+8*IHM	CTOT(4,2,IG,IHM), IG=1,NGM	

4+MT+4*(ML-1)*IHM +1	CTOT(1,ML,IG,1), IG=1,NGM	cross-sections for mixture ML
4+MT+4*ML*IHM	CTOT(4,ML,IG,IHM), IG=1,NGM	
5+MT+4*ML*IHM	VELOC(IG), IG=1,NGM	VELOC(IG) = neutron velocity in energy group IG
6+MT+4*ML*IHM	CHI(IG), IG=1,NGM	prompt fission spectrum
7+MT+4*ML*IHM	NL	number of fuel isotopes (mixtures)
8+MT+4*ML*IHM	NISONL(L), L=1,NL	NISONL(L) = number of the L^{th} fuel isotope (mixture)

File IPS is created at the end of the preprocessing and before starting the steady state calculations.

File IPSM

File IPSM is identical to file IPS, but after steady state (file IPS is created before steady state).

Criticality search can introduce new compositions in the control rod zones and this modification justifies the creation of a file IPSM different from IPS.

File NFT

Record	Variable(s)	Definition
1	L,NDG,NPT, NFR,NFZ	L = vector of dimension 100 collecting the most important integers NDG = degree of the finite element polynomials NPT = NDG + 1 NFR = number of abscissa along the x(r) axis where the fluxes are to be edited NFZ = number of abscissa along the y(z) axis where the fluxes are to be edited
2	POWNOM,XKEFF, EFISS	POWNOM = nominal power of the reactor in steady state XKEFF = value of the k_{eff} of the reactor EFISS = energy delivered per fission
3	ABBC,BBBC,ATBC, BTBC,ALBC,BLBC, ARBC,BRBC	values of the coefficients for the boundary conditions (see input data)
4	R(I),I=1,NR	abscissa of the mesh nodes along the x(or r) axis
5	Z(I),I=1,NZ	abscissa of the mesh nodes along the y(or z) axis
6	NC(I,J), I=1,NR+1 J=1,NZ+1	matrix of the "material" lay-out of the reactor
7	NCT(I,J), I=1,NR+1 J=1,NZ+1	matrix of the "thermal" lay-out of the reactor
8	Q(NCOM,IG) NCOM=1,MT IG=1,NGM	Q(NCOM,IG) is the independent source in composition NCOM for energy group IG
9	RR(I),I=1,NFR	abscissa along the x(r) axis where the fluxes are to be edited
10	ZZ(I),I=1,NFZ	abscissa along the y(z) axis where the fluxes are to be edited
11	ITYP(I),I=1,MT	if ITYP(I) = 0, composition I is not coupled with thermo-hydraulics if ITYP(I) = 1, composition I is coupled with thermo-hydraulics

12	IRZ(IROD,K), IROD = 1,5 K=1,8	characteristics of the control rods
	HIG(IROD), IROD=1,5	control rod insertions
13	TMP(NCOT,NN), NCOT=1,MTT NN=1,ML	TMP(NCOT,NN) is the average temperature of mixture NN in thermal composition NCOT in steady state (°C)
14	RO(NCOT,NN), NCOT=1,MTT NN=1,ML	RO(NCOT,NN) is the average density ratio of mixture NN in thermal composition NCOT in steady state
15	DPOW(K,L,I,J) K=1,NPT L=1,NPT I=1,NR-1 J=1,NZ-1	power density distribution in the reactor in steady state
16	TTHE(I,J,K) I=1,NR-1 J=1,NZ-1 K=1,4	average temperature distribution in steady state (°C) K=1 → fuel material; K=2 → clad material K=3 → coolant material; K=4 → structure material
17	RTHE(I,J,K) I=1,NR-1 J=1,NZ-1 K=1,4	average density ratio distribution in steady state K=1 → fuel material; K=2 → clad material K=3 → coolant material; K=4 → structure material
18	X(I),I=1,NPAR	neutron flux distribution for energy group 1
19	X(I),I=1,NPAR	neutron flux distribution for energy group 2
.		
.		
.		
17+NGM	X(I),I=1,NPAR	neutron flux distribution for energy group NGM
17+NGM+1	X(I),I=1,NPAR	adjoint flux distribution for energy group 1
17+NGM+2	X(I),I=1,NPAR	adjoint flux distribution for energy group 2
.		
.		
.		
17+2NGM	X(I),I=1,NPAR	adjoint flux distribution for energy group NGM

NR is the number of mesh nodes along the x(r) axis.

NZ is the number of mesh nodes along the y(z) axis.

NGM is the number of energy groups.

MT is the number of isotopical compositions.

MTT is the number of "thermal" compositions.

ML is the number of mixtures.

NPAR is the number of finite element nodal parameters.

Additional informations

* In addition to its geometrical dimensions, each finite element is characterized by its isotopical composition within , but also by the mean temperatures of the mixtures of this composition; for that reason, we have introduced the notion of 'thermal' compositions as opposed to 'material' or 'isotopical' compositions. A material composition is defined by its mixtures, whereas the thermal composition is determined moreover by the mixture temperatures; two compositions of same mixtures are considered as distinct thermal compositions if they differ from the temperatures. Obviously, if neutronics is not coupled with thermohydraulics the material and thermal compositions are identical.

  In the same view, we have introduced two kinds of lay-out : the material lay-out and the thermal lay-out of the reactor. The material lay-out NC provides for each finite element the material composition number, whereas the thermal lay-out NCT gives the thermal composition numbers. NC and NCT bring also a few more informations, as we shall see with the following example.

0	0	0	0	0	0	0
0	-2	-2	-2	-2	-2	0
0	1	-3	1	1	-2	0
0	1	-3	1	1	-2	0
0	1	-4	1	1	-2	0
0	-2	-2	-2	-2	-2	0
0	0	0	0	0	0	0

NC

-1	-1	-1	-1	-1	-1	-1
-1	2	2	2	2	2	-1
-1	10	3	11	12	2	-1
-1	7	3	8	9	2	-1
-1	1	4	5	6	2	-1
-1	2	2	2	2	2	-1
-1	-1	-1	-1	-1	-1	-1

NCT

NR = 6

NZ = 6

First it has to be noted that NC and NCT contain every one (NR+1)*(NZ+1) elements, the boundary elements being added to the finite element mesh grid at the top, bottom, left side and right side of the reactor. The corresponding values of NC, NCT for these boundary elements are respectively put to 0 and -1; this particularity is especially used for the set up of the finite element matrices.

The inner elements of NC are put to the values of the corresponding material composition numbers with the positive sign if the compositions are coupled with thermohydraulics and with the negative sign if not; in the example hereabove only composition number 1 is coupled with thermohydraulics. Thus

if NCOM = NC(I+1,J+1) > 0, it means that composition NCOM in element I,J is coupled with thermohydraulics

if NCOM < 0, it means that composition |NCOM| in element I,J is not coupled with thermohydraulics

The inner elements of NCT differentiate the thermal compositions and they are all positive

- if composition NCOM in element I,J is not coupled with thermohydraulics, NCT(I+1,J+1) is put equal to NCOM
- if composition NCOM in element I,J is coupled with thermohydraulics, NCT(I+1,J+1) is put to a value NCOT = NCOM or >MT not yet assigned to another element.

In the example hereabove 12 different thermal compositions are so numbered.

* Variables IRZ and HIG are variables characterizing the control rods.

We consider a maximum number of 5 control rods.

HIG(IROD) = insertion of rod number IROD

$= z_{max} - z_{bot}$

where : z_{bot} is the level of the bottom of the rod in the reactor

z_{max} is the maximum possible value of z_{bot}.

IRZ(IROD,1)
IRZ(IROD,2)
IRZ(IROD,3)
IRZ(IROD,4)
= respectively the left, right columns and bottom, top rows of the mesh grid enclosing the control rod number IROD

IRZ(IROD,5) = number of the row immediately below the bottom of control rod IROD

IRZ(IROD,7) = composition number of control rod IROD

IRZ(IROD,8) = 0 → control rod IROD is not used for criticality search

= 1 → control rod IROD is used for criticality search

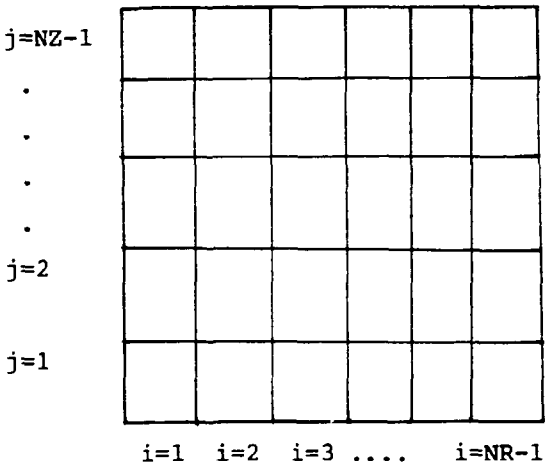
* for variables DPOW, TTHE, RTHE, see explanations for file NCPL.

File NCPL

Record	Variable(s)	Definition
1	NR,NZ,NPT	NR = number of mesh nodes along the x(or r) axis NZ = number of mesh nodes along the y(or z) axis NPT = degree of the finite element polynomials + 1
2	R(I),I=1,NR	abscissa of the mesh nodes along the x(or r) axis
3	Z(I),I=1,NZ	abscissa of the mesh nodes along the y(or z) axis
4	NT,TO,T1	NT = number of times at which the power density distribution is given TO = value of the first time at which the power densities are given T1 = value of the last time at which the power densities are given
5	DPOW(K,L,I,J) K=1,NPT L=1,NPT I=1,NR-1 J=1,NZ-1	power density distribution at time TO
6	DPOW(K,L,I,J) K=1,NPT L=1,NPT I=1,NR-1 J=1,NZ-1	power density distribution at the second time
4+NT	DPOW(K,L,I,J) K=1,NPT L=1,NPT I=1,NR-1 J=1,NZ-1	-ower density distribution at time T1
4+NT+1	TTHE(I,J,K) I=1,NR-1 J=1,NZ-1 K=1,4	average temperature distribution at time T1 (°C) K=1 → fuel material; K=2 → clad material K=3 → coolant material; K=4 → structure material
6+NT	RTHE(I,J,K) I=1,NR-1 J=1,NZ-1 K=1,4	average density ratio distribution at time T1 (°C) K=1 → fuel material; K=2 → clad material K=3 → coolant material; K=4 → structure material

Additional informations

* The reactor is represented by a rectangular domain subdivided in rectangular finite elements as shown on the figure hereunder



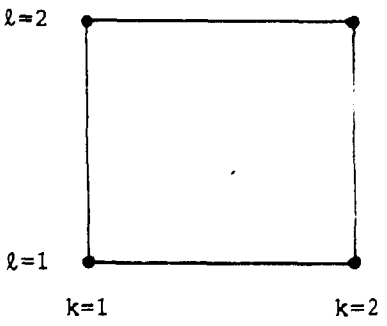
Each element is marked by its indices i,j and the power density $p^{(i,j)}$ within is approximated by :

$$p^{(i,j)}(x,y) \text{ (or } p^{(i,j)}(r,z)) = \sum_{k=1}^{NPT} \sum_{\ell=1}^{NPT} p_{k\ell}^{(i,j)} \pi_k(\rho)\pi_\ell(\zeta)$$

where $\rho = \dfrac{x-x_i}{x_{i+1}-x_i}$ (or $= \dfrac{r-r_i}{r_{i+1}-r_i}$)

$$\zeta = \frac{y-y_j}{y_{j+1}-y_j} \quad (\text{or } = \frac{z-z_j}{z_{j+1}-z_j})$$

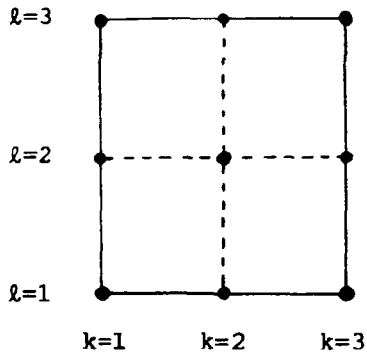
According to the degree NDG chosen for the approximating polynomials (NDG = 1,2 or 3), we have :



<u>for NDG = 1</u> (NPT = 2)

$\pi_1(x) = 1-x$

$\pi_2(x) = x$

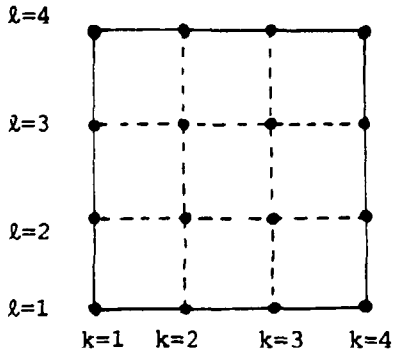


for NDG = 2 (NPT = 3)

$\pi_1(x) = 2(x-\frac{1}{2})(x-1)$

$\pi_2(x) = -4x(x-1)$

$\pi_3(x) = 2x(x-\frac{1}{2})$



for NDG = 3 (NPT = 4)

$\pi_1(x) = -\frac{9}{2}(x-\frac{1}{3})(x-\frac{2}{3})(x-1)$

$\pi_2(x) = \frac{27}{2}x(x-\frac{2}{3})(x-1)$

$\pi_3(x) = -\frac{27}{2}x(x-\frac{1}{3})(x-1)$

$\pi_4(x) = \frac{9}{2}x(x-\frac{1}{3})(x-\frac{2}{3})$

$p_{k\ell}^{(i,j)}$ is the value of the power density at the point marked by the indices k, ℓ on the figures hereabove

We have the correspondance DPOW (K,L,I,J) $\leftrightarrow p_{k\ell}^{(i,j)}$

* The power density distribution is provided at each micro time step over a whole macro time step, i.e. NT times where NT-1 is the number of microsteps in a macrostep. In steady state NT=1, T0=T1=0.0.

* The temperature and density distributions determined by the thermo-hydraulics module are provided on file NCPL only at the end T1 of the macro time step.

  From the neutronics point of view the materials are assumed homogeneously reparted and the cross-sections are supposed uniform in each finite element; therefore the temperature and density distributions are averaged over each element and furnished for each type of material, i.e. for the fuel type (K=1), the clad type (K=2), the coolant type (K=3) and the structure material type (K=4).

* Instead of storing the density distribution on file NCPL, one stores the density ratio distribution; the density ratio is defined as the ratio of the density by the reference density, i.e. the density at the reference temperature used for the corresponding material.

APPENDIX 4 : DESCRIPTION OF THE LABELED COMMON BLOCKS

The code CASSANDRE contains a certain number of labeled common blocks. In this appendix, a detailed description is given for each of these common blocks with a list of the arguments and their significances.

Label	Variables	Definition
ADDR	IL,IDX,LAWA	IL = dimension of the dynamic allocation vector A IDX = number of arrays stored in vector A LAWA = number of allocated components of vector A
BOUND	ABBC,BBBC,ATBC,BTBC,ALBC,BLBC, ARBC,BRBC	coefficients for the boundary conditions The boundary conditions are the Neumann-Dirichlet conditions : $a\phi + b\bar{D}\bar{n}\cdot\bar{\nabla}\phi = 0$ ABBC, BBBC } coefficients a, b at the bottom of the reactor ATBC, BTBC } coefficients a, b at the top of the reactor ALBC, BLBC } coefficients a, b at the left side of the reactor ARBC, BRBC } coefficients a, b at the right side of the reactor
CVERG	EPSK,EPSF,EPSKT,EPSKC	EPSK = convergence criterion on the k_{eff} value in the power method in steady state EPSF = convergence criterion on the fluxes in case of source problem in steady state EPSKT = convergence criterion on the k_{eff} value in the neutronics-thermohydraulics coupling iterations EPSKC = convergence criterion on the k_{eff} value for criticality search
CSCOMP	DR,DZ,S	DR, DZ] values of the diffusion coefficients respectively in the x(r) and y(z) directions in the considered finite element S value of the absorption coefficient in the considered finite element
CSGEOM	DRZ,RDZ,RZ	geometrical factors used for the calculation of the total contribution of a current point to the finite element matrices
CVERG	EPSF,EPSP,EPSR,EPSA	EPSF = convergence criterion on the shape functions at each Newton-SOR iteration in each macro time step EPSP = convergence criterion on the total reactor power at the end of each macro time step

		EPSR = convergence criterion on the reactor reactivity at the end of each macro time step
		EPSA = maximum permitted relative error on the amplitude functions (see input data)
DEGREE	NDG,NPT	NDG = degree of the interpolation functions for the fluxes in each direction (= 1,2 or 3)
		NPT = NDG+1
DIM	L(100),TITLE(10)	L : array containing the most important integers (see appendix 5)
		TITLE : general title
DIVERS	RAU1,BETA1,XLA1,RAUM1,RAU0,BETAO, XLAO,RAUFO,RAUIN	RAU1 : reactor reactivity at the end of the macro time step
		BETA1 : delayed neutron fraction at the end of the macro time step
		XLA1 : neutron generation time at the end of the macro time step
		RAUM1 : reactor reactivity at the end of the macro time step and at the previous Newton-SOR iteration
		RAU0 : reactor reactivity at the beginning of the macro time step
		BETAO : delayed neutron fraction at the beginning of the macro time step
		XLAO : neutron generation time at the beginning of the macro time step
		RAUFO : feedback reactivity at the initial time
		RAUIN : inserted reactivity
DRVF	F0(10) F1(10) F2(10) TS(10) TF(10)	coefficients characterizing the driving functions (see input data)
	NROD(10)	number of the moving control rods (if IROD > 0) or numbers of the compositions for which a mixture is submitted to a driving function (if IROD < 0)
	IMDF(10)	numbers of the mixtures submitted to a driving function

FLUDY	NFR,NFZ	NFR : number of abscissa along the x(r) axis where the fluxes are to be edited NFZ : number of abscissa along the y(z) axis where the fluxes are to be edited
IBBS	N1D,LD,LU,NJV(15)	N1D = first value of the Burlish-Stoer's sequence LD+1 = number of columns of the extrapolation table at the previous Newton-SOR iteration LU+1 = number of columns of the extrapolation table at the last Newton-SOR iteration NJV : values of the Burlish-Stoer's sequence
INTABL	ZZ(4,4),DZDZ(4,4),RR(4,4,2), DRDR(4,4,2),ZF(4),RF(4,2), SPR(4,4),SPZ(4,4)	Table of constant values used for the set-up of the finite element matrices in function of the degree of the interpolation polynomials.
IPO	IPOINT	Value of the virtual record number on direct-access file NFS
LAYN	HIG(5),RBC(5),XK1,XK2,CMQ1, CMQ2,DILMAX,DIL,MTFRA, IRZ(5,8),IMTCR(3,30)	HIG : values of the control rod insertions RBC : values of the ratios of the initial rod insertions to the initial insertion of the first control rod XK1 : value of k_{eff} obtained at the first and second poisonings of the reactor for criticality search XK2 : value of k_{eff} obtained at the third poisoning of the reactor for criticality search CMQ1 : value of the control parameter (rod insertion or coolant poisoning) at the first and second poisonings of the reactor for criticality search CMQ2 : value of the control parameter at the third poisoning of the reactor for criticality search DILMAX : maximum permitted dilution of poison in the coolant DIL : value of the dilution of poison in the coolant MTFRA : number of poisoned compositions for criticality search IRZ(K,1) } numbers of the radial mesh nodes enclosing IRZ(K,2) } control rod number K respectively at the left and right sides

		IRZ(K,3) } numbers of the axial mesh nodes enclosing IRZ(K,4) } the zone related to control rod number K respectively at the bottom and at the top IRZ(K,5) : number of the axial mesh node immediately below control rod number K IRZ(K,6) : number of the composition below control rod K IRZ(K,7) : number of the composition in the control rod K IRZ(K,8) = 0 control rod K not used for criticality search = 1 control rod K used for criticality search IMTCR(1,I), I=1,MTFRA : numbers of the compositions poisoned for criticality search by poisoning of the coolant IMTCR(2,I) = NMP is the NMPth mixture of composition I corresponding to the poison mixture IMTCR(3,I) = NMC is the NMCth mixture of composition I corresponding to the coolant mixture
MICMAC	FRMIN,PMAX,PMIN,DPLIM, RPOM,PMAC1,NMICI	FRMIN = minimum value of the macro time step reduction factor PMAX = maximum permitted value for the macro time step PMIN = minimum permitted value for the macro time step DPLIM = maximum permitted relative variation of the shape functions over a macro time step RPOM = maximum permitted value of the ratio of the power at the end of the macro time step to the power at the beginning of the macro time step PMAC1 = length of the first macro time step NMICI = number of micro time steps in each macro time step at the first Newton-SOR iterations
PARAM	INTERP	INTERP = 1 : interpolation of the fundamental mode and another mode for the amplitude functions INTERP = 2 : interpolation of the fundamental mode and the mode $e^{\sigma.t}$ for the amplitude functions

		INTERP = 3 : double interpolation of the mode $e^{o.t}$ for the amplitude functions
PCROS	ECROS	if ECROS = .TRUE. printing of the cross-sections if ECROS = .FALSE. no printing of the cross-sections
PKREAL	PMIC,PMAC,FR,DPSIM	PMIC = micro time step PMAC = macro time step FR = reduction factor for the macro time step DPSIM = maximum relative variation of the shape functions over the macro time step
PKTSHP	VP,OM1,OM2,OM11,OM22	-VP = value of the time constant of the second interpolated mode when INTERP = 1 OM1 = OM11 when INTERP = 1 or 2, 0.0 otherwise OM2 = OM22 when INTERP = 1 or 2, = 0.0 otherwise OM11 = value of the time constant of the fundamental mode at the beginning of the macro time step OM22 = value of the time constant of the fundamental mode at the end of the macro time step
PO	POWNOM,XKEFF,EFISS	POWNOM = nominal power of the reactor in steady state XKEFF = value of the reactor k_{eff} EFISS = energy released by fission
POINTD	NADR	number of the record on the direct-access file NFO
POPR	T1,T2,RA1,RA2,RAI1,RAI2, RAF1,RAF2,DQ1,DQ2	T1,T2 : times at the end of the 2 last macro time steps RA1,RA2 : total reactivities at the 2 last macro time steps RAI1,RAI2 : inserted reactivities at times T1, T2 RAF1,RAF2 : feedback reactivities at times T1, T2 DQ1,DQ2 : energies accumulated in the reactor core during the 2 last macro time steps
PRIWA	K1,K2	T(K1), T(K1+1),...,T(K2) are the printing times for the fluxes and power densities included in the considered macro time step
QINT	Q	Q is the energy released in the reactor during the considered macro time step

RBBS	FRP,FRPMAX	FRP = reduction factor of the micro time step FRPMAX = maximum value of the micro time step reduction factor over a macro time step
TEMPS	TIME,TMAX	TIME = time at the end of the considered macro time step TMAX = transient duration
XLOF	TLOF	$e^{-t/TLOF}$ is the law of mass flow rate decrease in case of loss of flow
XPO	POWER1,POWM1,POWER0	POWER1 = reactor power at the end of the considered macro time step POWM1 = reactor power at the end of the considered macro time step and at the previous Newton-SOR iteration POWER0 = reactor power at the beginning of the considered macro time step
XPT	KPMIN,KPMAX	represent the minimum and maximum record numbers for a set of records on file NFX1 in unsteady state
XRES	NREST	if NREST = 0, the RESTART procedure is not used if NREST = -1, the code begins a transient problem from the steady state with possibility of RESTART afterwards if NREST = 1, the code restarts a transient problem stopped in a previous run
XRGEOM	C1,C2	C1 = 1.0 in x-y geometry C2 = 0.0 C1 = r_{min} in r-z geometry C2 = $\Delta r = r_{max} - r_{min}$ r_{min}, r_{max} are the minimum and maximum radii respectively in the considered finite element
ZMAC	ICMAP2	if ICMAP2 = -1, the macro time step length is constant if ICMAP2 = 0, the macro time step length can vary and is specified for each macro step if ICMAP2 = 1, automatical control of macro time step
	NEWM2	maximum number of Newton-SOR iterations when ICMAP2 ≠ 0

APPENDIX 5 : DESCRIPTION OF VECTOR L

As mentioned in section 3, the most important integers are put in equivalence each one with a component of an array L(100) (sometimes called LL or LX).

In this appendix, a detailed description of this vector is given with all the equivalences and the significances for each component.

	STEADY STATE		TRANSIENT	
Component number	Equivalent variable name(s)	Definition	Equivalent variable name(s)	Definition
1	ITEMAX	maximum number of iterations for the power method (IPROB = 2) (with or without Chebyshev acceleration) or for the rebalancing method (IPROB = 1)	not used	
2	IPROB	IPROB=1 → source problem IPROB=2 → eigenvalue problem	not used	
3	IADIR	IADIR=1 : only direct problem IADIR=2 : direct + adjoint problems		
4	not used		ICMAP	ICMAP = 0 : no automatical control or = -1 of macro time step size ICMAP = 1 : automatical control of macro time step size
5	not used		MACMAX	maximum number of macro time steps
6	not used		not used	
7	not used		not used	
8	NG	NG=0 : x-y geometry NG=1 : r-z geometry	NG	idem
9	NR	number of mesh nodes along the x(r) axis	NR	idem
10	NZ	number of mesh nodes along the y(z) axis	NZ	idem
11	IFLUX	IFLUX=0 : the fluxes are to be edited at given points IFLUX≠0 : the fluxes are to be edited at IFLUX points per mesh in each direction	IFLUX	idem

12	not used		IROD	IROD > 0 : IROD control rods are moving IROD < 0 : |IROD| mixtures are changing with t
13	NIL	dimension of the dynamic allocation vector A	NIL	idem
14	NGM	number of energy groups	NGM	idem
15	IHM	number of cross-section types	IHM	idem
16	IHS	= 7 + maximum number of group jumps by upscattering	IHS	idem
17	IHT	= 6	IHT	idem
18	MT	number of material compositions	MT	idem
19	not used		NEWMAX	maximum number of Newton SOR iterations at each macro time step
20	LR	number of nodal parameters in the x(r) direction	LR	idem
21	LZ	number of nodal parameters in the y(z) direction	LZ	idem
22	NPAR	total number of nodal parameters	NPAR	idem
23	LBAND	half band width of the FEM matrices	LBAND	idem
24	NFA	= LBAND*LBAND	not used	
25	not used		not used	
26	NFB1	number of a file on which the normalized or non-normalized direct or adjoint fluxes (group after group) are stored at a given power iteration	not used	
27	NFB2	number of a file containing the fission source finite element vectors (group after group)	not used	

28	NFX1	number of the file containing the direct or adjoint fluxes (group after group) at the last but one power iteration	NFX1	number of the direct-access file containing the flux shape functions (group after group)
29	NFX2,NFX	number of the file containing the direct or adjoint fluxes (group after group) at the last power iteration	not used	
30	NFEMAT	number of the file containing the 'absorption' finite element matrices	NFEMAT	idem
31	NFS	number of the file containing the 'source' finite element matrices	NFS	number of the direct access file containing the 'source' finite elements matrices
32	NSAVE	number of the file on which the neutronics data and results are stored before entring in the thermohydraulics module	NSAVE	idem
33	NFSF	number of the file containing the independent source finite element vectors	not used	
34	NFWORK	number of a work file used in routine CHSKYB	NF2	idem
35	NFTRIA	number of the file on which the factorized coefficient matrices in routine CHSKYB are stored	NF3	idem
36	NFR	number of abscissa along the x(r) axis where the fluxes are to be edited	NFO	number of the direct-access file containing informations and values related to the shape functions at the beginning of each macro time step
37	NFZ	number of abscissa along the y(z) axis where the fluxes are to be edited	NADJNT	number of the direct-access files containing the adjoint fluxes
38	not used		not used	
39	not used		not used	
40	not used		NFKM	number of the file containing the right members of the linear algebraic systems for the calculation of the shape functions

41	NFT	number of the file containing the steady state data and results	NFT	idem
42	ISTEAD	ISTEAD=0, static calculations are not followed by dynamic calculations ISTEAD=0, static calculations are followed by dynamic calculations	not used	
43	not used		NEWTON	Newton-SOR iteration number
46	ML	number of mixtures	ML	idem
47	not used		IOBETA	IOBETA=1, the β_i^ℓ values are given IOBETA=2, the $(\nu_\ell \beta_i^\ell)_g$ values are given
48	ICHEB	ICHEB=0, no Chebychev acceleration ICHEB=1, Chebychev acceleration	not used	
49	NFB3	number of a file containing the direct or adjoint fluxes at a given power iteration	not used	
50	not used		not used	
51	NPREC	NPREC=0, data are not given for delayed neutrons in steady state NPREC≠0, data are given for delayed neutrons in steady state	not used	
52	NI	number of precursor families	NI	idem
53	NL	number of fuel mixtures (isotopes)	NL	idem
54	not used		LCOMP	size of the virtual blocks in file NFS
55	not used		not used	
56	not used		not used	

57	not used		not used	
58	not used		MACRO	macro time step number
59	not used		not used	
60	NCPL	number of the interface file between neutronics and thermohydraulics	NCPL	idem
61	not used		not used	
62	not used		not used	
63	not used		NT	|NT| = number of times at which printing of power and fluxes is asked
64	not used		not used	
65	not used		NTM	number of the file containing informations and values concerning the calculation of the amplitude functions
66	not used		NTM1	number of the file containing the amplitude functions values at the last Newton-SOR iteration
67	not used		not used	
68	not used		NTM2	number of the file containing the amplitude functions values at the last but one Newton-SOR iteration
69	IDP	number of the interface file between the input module and the preprocessing module	not used	
70	IDS	number of the interface file between the input module and the static module	not used	
71	not used		ILD	number of the interface file between the input module and the dynamic module
72	NEXEC	index giving the level of execution	NEXEC	idem
73	not used		not used	
74	not used		not used	

75	NMAX	number of data cards to define the reactor lay-out	not used	
76	ITFLUX	ITFLUX=0, neutronics is not coupled with thermo-hydraulics ITFLUX=0, ITFLUX composi-tions are coupled with thermohydraulics	ITFLUX	idem
77	IBTOT	number of control rods to be considered	IBTOT	idem
78	ICRIT	ICRIT = 0, no criticality search ICRIT > 0, criticality search by control rod in-sertion ICRIT < 0, criticality search by homogeneous poisoning of the coolant	not used	
79	IPRINT	IPRINT = 0, no printing of fluxes and power den-sities IPRINT ≠ 0, printing of fluxes and power densi-ties	IPRINT	idem
81	MTT	number of thermal compo-sitions	MTT	idem
82	ITMAX	maximum number of itera-tions on criticality search and/or thermohy-draulics coupling	not used	
83	not used		IEXTR	IEXTR = 0, Burlish-Stoer's extrapolation is not used IEXTR = 1, Burlish-Stoer's extrapolation is used
84	not used		ICER	ICER = 0, no error control for the amplitude functions calculation ICER = 1, error control for the amplitude functions calculation

85	not used		ICMP	ICMP = 0, no automatical micro time step control ICMP ≠ 0, automatical micro time step control
86	not used		not used	
87	IPS	number of the file containing the output of the preprocessing corresponding to the initial configuration of the reactor	not used	
88	IPSM	number of the file containing the output of the preprocessing corresponding to the final steady state configuration of the reactor	IPSM	idem
89	not used		IPSD	number of the file containing the output of the preprocessing corresponding to the configuration of the reactor during the transient
90	not used		not used	
91	not used		not used	
92	INF5	number of the file where a copy of the input data cards is made	INF5	idem
93	INF3	= IDP,IDS,IDD according to the case	INF3	idem
94	not used		not used	
95	not used		N,NN	number of micro time steps in each macro time step
96	not used		KK	micro time step number
97	not used		not used	
98	not used		not used	
99	not used		not used	
100	not used		not used	

APPENDIX 6 : DYNAMIC ALLOCATION

The aim of the dynamic allocation is to store the major part of the dimensioned variables in one common vector A. Each variable takes exactly the necessary core memory during an execution and it may be deleted when it is no more necessary; it means that the corresponding space becomes available for other variables. The several possibilities are described hereafter.

The dynamic allocation program is constituted by the FUNCTION IDINIT with several entries. It is written for double precision so that an array of N components takes 8*N bytes in core memory.
Function IDINIT is called at the beginning of the execution for the dynamic allocation initializations :

IDX = 0 (IDX = number of vectors located in A)

LAWA = 0 (LAWA = index of the last used word in A)

A(I) = 0.0, I = 1,IL (IL = dimension of vector A)

W(I) = blank, I = 1,NIDX
IW(I) = 0, I=1,NIDX

Initialization of 2 working vectors (W and IW), containing respectively the variable names and the corresponding first addresses of these variables in A.

(NIDX is the maximum permitted number of arrays in vector A; practically NIDX = 200, but it can be put to a higher value).

The function assumes that IL (maximum number of 8-bytes words in the common vector A), IDX and LAWA are located in the common block COMMON/ADDR/IL,IDX,LAWA.
IL is defined in the MAIN of the code.

The entries of IDINIT are :

1) IB = IDLOC (N,XNAM)

XNAM = '......' : vector name (6 characters)
N = vector length in 8-bytes words

IDLOC allocates N words in A for the vector named XNAM.
IB gives the address of the first component of vector XNAM in vector A

2) IB = IDKILL (XNAM)

XNAM = '......' : vector name (6 characters)

IDKILL deletes the vector named XNAM in vector A; a compressed vector takes place.

3) IB = ID(XNAM)

XNAM = '......' : vector name (6 characters)

ID provides the address of the first component of vector named XNAM in vector A.

4) IB = IDIDX (LL,J,K)

IDIDX gives in return IB = IDX (number of vectors located in A)
LL = 1
J = LAWA (index of the last used word in A)
K = 1

5) IB = IDSHOR(M)

IDSHOR deletes the M last vectors in vector A

6) CALL STAT

Prints out the status of vector A

7) CALL IBYTE

Prints out the maxi um core storage (in bytes) used in vector A

8) IB = IDWRIT (NSAVE)

The following variables are written on file NSAVE without format.

1^{st} record : IL,IDX,LAWA,LENGTH,NIDX
2^{nd} record : (W(I),I=1,IDX), (IW(I),I=1,IDX)
3^{rd} and next records : (A(I), I=1,LAWA)

IL = dimension of vector A
IDX = number of vectors located in A
LAWA = index (address) of the last used word in A
LENGTH = maximum number of words used in A
NIDX = maximum permitted number of vectors in A
W(I) = name (6 characters) of the I^{th} vector in A
IW(I) = first address of the I^{th} vector in A

The third and the next records contain a maximum of 500 words, i.e. vector A is stored in NREC records, where NREC is the smallest integer $\geq$ LAWA/500.
A REWIND operation has to be done before any calling to this entry.

9) IB = IDREAD (NSAVE)

Idem as for IDWRIT, but the writting operation has to be replaced by the reading operation.

Conclusions

The main advantages of the dynamic allocation technique can be summarized as follows :

1) The dynamic allocation allows to use the variable dimensioning without necessitating the definition of the variable dimensions in the MAIN. Only the dimension of A has to be provided.
   Since the dimension of vector A depends on the problem size (through the number of spatial nodes for example), it becomes then very easy to define this dimension without recompiling any routine of the code.
   Moreover the smallest the dimension of vector A, the smallest the region size to execute the problem.

2) The dynamic allocation allows to compress periodically vector A in the program and it avoids thus to keep in store unnecessary core memory. It has to be noted that this compress can be normally realized by means of EQUIVALENCE statements, but the dynamic allocation does it with much more flexibility.

APPENDIX 7 : SIMPLIFIED THERMOHYDRAULICS MODULE

This module is based on the concept of single fuel rod channel.

The main assumptions of the model are :

- the coolant flow is forced (no natural convection) and established;
- the coolant flow is one-dimensional in the axial direction;
- only one-phase flow is considered (no boiling);
- the viscous energy dissipation is neglected;
- the axial heat conduction is neglected as well in the coolant as in the rod;
- the geometry is axisymmetric;
- the thermophysical properties are constant; in particular the fluid is incompressible;
- the thermal inertia of the clad and the fuel-clad gap are neglected;
- the radial temperature profile is represented by a quadratic function in the fuel and by a linear function in the cladding;
- the heat source is radially homogeneous in the fuel and equal to zero in the clad and in the coolant;
- the heat transfer mechanisms through the fuel-clad gap and at the clad-coolant interface are represented by means of heat transfer coefficients.

The resulting equations are :

$$\rho_f \, c_f \, \frac{\partial T_f}{\partial t} = \text{div} \, (k_f \, \text{grad} \, T_f) + q_f = \frac{k_f}{r} \frac{\partial}{\partial r} \left(r \, \frac{\partial T_f}{\partial r} \right) + q_f \qquad \text{in the fuel}$$

$$\phi_{rod} = \phi_{fe} = \phi_{ci} = \phi_{ce} \qquad \text{in the cladding}$$

$$\rho_s \, c_s \, \frac{\partial T_s}{\partial t} + \rho_s \, c_s \, v \, \frac{\partial T_s}{\partial z} = \frac{P}{S} \, \phi_{rod} = \frac{1}{S} \, \phi_{rod} \qquad \text{in the coolant}$$

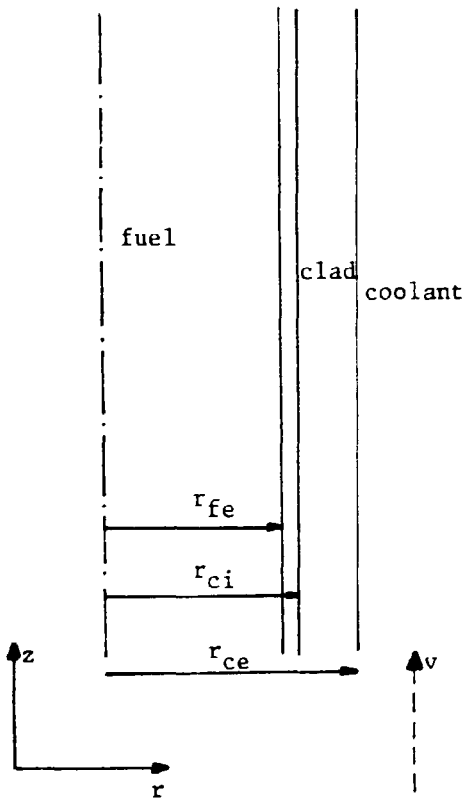
$$\phi = 0 \qquad \text{at } r = 0$$

$$\phi = h_g \, (T_{fe} - T_{ci}) \qquad \text{in the fuel-clad gap}$$

$$\phi = h_s \, (T_{ce} - T_s) \qquad \text{at the clad-coolant interface}$$

The initial conditions are : $T_s\ (z = 0,t) = T_{s0}(t)$ in the coolant, where $T_{s0}(t)$ is a given function

$T(z, t = 0)$ = solution of the steady state problem everywhere



c_f, c_s are the specific heats of the fuel and coolant respectively

ρ_f, ρ_s are the densities of the fuel and coolant respectively

k_f is the thermal conductivity of the fuel

q_f is the heat source in the fuel (function of z)

v is the flow velocity

S is the cross-sectional area of the fluid in the channel

T denotes the temperature and Φ denotes the linear power

T_f, T_s are the local temperatures in the fuel and the coolant respectively

ϕ_{rod} is the heat flux released by the rod and Φ_{rod} is the linear power of the fuel rod

h_g is the heat transfer coefficient in the fuel-clad gap

h_s is the transfer coefficient at the clad-coolant interface

Subscript fe refers to the outer surface of the fuel.
Subscripts ci, ce refer to the inner and outer surfaces of the cladding respectively.

Integrating the fuel equation, we obtain :

$$\rho_f \, c_f \frac{\partial \bar{T}_f}{\partial f} = - \frac{\dot{\varphi}_f}{\Pi r_{fe}^2} + q_c$$

$$\text{with } \bar{T}_f = \frac{\int_o^{r_{fe}} T_f \, dS}{\Pi r_{fe}^2} \text{ : mean fuel temperature}$$

$$\Phi_f = - 2\Pi \, r_{fe} \, k_f \left. \frac{\partial T}{\partial z} \right|_{r_{fe}} \text{ : linear power of the fuel rod}$$

$$= \Phi_{rod}$$

The linearity of the temperature profile in the cladding leads to :

$$T_{ci} - T_{ce} = \frac{e_c}{2\Pi \, r_c \, k_c} \Phi_{rod} \qquad \text{with } e_c = r_{ce} - r_{ci}$$

$$r_c = \frac{1}{2} (r_{ci} + r_{ce})$$

k_c = thermal conductivity of the clad

With the assumption of quadratic shape function for the fuel, it can be easily shown that :

$$\bar{T}_f - T_{fe} = \frac{1}{8\Pi \, k_f} \Phi_{rod}$$

Moreover we have :

$$T_{fe} - T_{ci} = \frac{1}{2\Pi \, r_g \, h_g} \Phi_{rod} \qquad \text{with } r_g = \frac{1}{2} (r_{fe} + r_{ci})$$

$$T_{ce} - T_s = \frac{1}{2\Pi\ r_{ce}\ h_s}\ \Phi_{rod}$$

Consequently we yield :

$$\bar{T}_f - T_s = \lambda\ \Phi_{rod}$$

with

$$\lambda = \frac{e_c}{2\Pi\ r_c\ k_c} + \frac{1}{8\Pi\ k_f} + \frac{1}{2\Pi\ r_g\ h_g} + \frac{1}{2\Pi\ r_{ce}\ h_s}$$

To summarize, we have finally to solve :

$$\rho_f\ c_f \frac{\partial \bar{T}_f}{\partial t} + \frac{1}{\Pi\ r_{fe}^2\ \lambda}\ (\bar{T}_f - T_s) = q_f \qquad \text{(A7.1)}$$

$$\rho_s\ c_s \frac{\partial T_s}{\partial t} + \rho_s\ c_s\ v \frac{\partial T_s}{\partial z} = \frac{1}{S\lambda}\ (\bar{T}_f - T_s) \qquad \text{(A7.2)}$$

with

$$\lambda = \frac{e_c}{2\Pi\ r_c\ k_c} + \frac{1}{8\Pi\ k_f} + \frac{1}{2\Pi\ r_g\ h_g} + \frac{1}{2\Pi\ r_{ce}\ h_s}$$

$$e_c = r_{ce} - r_{ci}$$

$$r_c = \frac{1}{2}\ (r_{ci} + r_{ce})$$

$$r_g = \frac{1}{2}\ (r_{fe} + r_{ci})$$

$$T_s(z=0,t) = T_{s0}(t)$$

Equations (A7.1) and (A7.2) are integrated by means of a classical implicit finite difference scheme.

In steady state, we obtain :

$$T_s^{j+1} = {}_sT^j + \frac{\Pi\ r_{fe}^2}{\rho_s\ c_s\ v\ S}\ \Delta z_f q^{j+1}$$

$$j = 1,2,...$$

$$\bar{T}_f^{j+1} = T_s^{j+1} + \Pi\, r_{fe}^2\, \lambda\, q_f^{j+1}$$

with

$$T_s^j \equiv T_s\,(z_j)$$

$$\bar{T}_f^j \equiv T_f\,(z_j)$$

$$q_f^j \equiv q_f\,(z_j)$$

$$\Delta z = z_{j+1} - z_j$$

In transient :

$$\left[1 + \frac{v\Delta t}{\Delta z} + \frac{\Delta t}{\rho_s c_s S\lambda}\right] T_s^{j+1}(n+1) - \frac{\Delta t}{\rho_s c_s S\lambda}\, \bar{T}_f^{j+1}(n+1) = T_s^{j+1}(n) + \frac{v\Delta t}{\Delta z}\, T_s^j(n+1)$$

$$\left[1 + \frac{\Delta t}{\Pi r_{fe}^2 \lambda \rho_f c_f}\right] T_f^{j+1}(n+1) - \frac{\Delta t}{\Pi r_{fe}^2 \lambda \rho_f c_f}\, T_s^{j+1}(n+1) = \bar{T}_f^{j+1}(n) + \frac{\Delta t}{\rho_f c_f} q_f^{j+1}(n+1)$$

$$j = 1,2,\ldots$$
$$n = 0,1,\ldots$$

with

$$T_s(n) \equiv T_s(t_n)$$

$$\bar{T}_f(n) \equiv \bar{T}_f(t_n)$$

$$q_f(n) \equiv q_f(t_n)$$

$$\Delta t = t_{n+1} - t_n$$

The values of T_{ci}, T_{ce} and $\bar{T}_c = \frac{1}{2}\,(T_{ci} + T_{ce})$ can be deduced from the values of $\bar{T}_f$ and T_s by means of the formulae hereabove.

These equations are solved in routine CALTEM, which provides in output the axial profiles of $\bar{T}_f$, $\bar{T}_c$ and T_s.

Routine CALTEM is called for each channel by routine SMPLTH, which moreover performs :

- the radial integration of the power densities (routine INPOW) in each 'neutronic' assembly (see section 10) in order to determine the axial profile of the average linear power in this assembly

- the axial averaging of $\bar{T}_f$, $\bar{T}_c$, T_s in each finite element in order to determine the temperature values required by neutronics.

Routine SMPLTH is called by THERMO which is the main routine of the thermohydraulics module.

Routine PLZ is called by CALTEM to determine the value of the linear power at any level.

This thermohydraulics module uses 2 sequential and temporary files NTHER1, NTHER2.
Each record of these files contains NZZ values, where NZZ is the number of axial nodes used for the axial integration of the coolant equation.

The input data are directly defined in routine CALTEM.

RFE = outer radius of the fuel [m]

RCI = inner radius of the cladding [m

RCE = outer radius of the cladding [m]

PITCHR = pitch to diameter ratio (= pitch of the lattice/outer clad diameter) [-]

NS = 3 for triangular lattices
= 4 for square lattices

H = channel height [m]

ROF = fuel density [kg/m^3]

ROS = coolant density [kg/m^3]

CPF = specific heat of the fuel [J/°C kg]

CPS = specific heat of the coolant [J/°C kg]

XKF = thermal conductivity of the fuel [W/m °C]

XKC = thermal conductivity of the cladding [W/m °C]

AG = heat transfer coefficient through the fuel-clad gap [W/m^2 °C]

AS = heat transfer coefficient at the clad-coolant interface [W/m^2 °C]

WO = initial velocity of the coolant [m/s]

TINO = initial temperature of the coolant at the entry of the channel [°C]

TLOF = time decrease constant for the coolant velocity ($w = w_o e^{-t/TLOF}$) [s]

NZZ = number of axial nodes in the coolant

NTT = number of time steps in the macrotimestep for the time integration of the thermohydraulic equations.