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EURATOM - HOCHTEMPERATUR REAKTORBAU GmbH (HRB)

COSTANZA HRB
A TWO DIMENSIONAL DYNAMIC PROGRAMME FOR HIGH TEMPERATURE GAS COOLED REACTORS AND ITS APPLICATION TO THE THTR 300 MWe POWER PLANT

by

K. FRIEDRICH, E. INFÜHR (HRB)
L. MASSIMO and E. VINCENTI (Euratom)

1973

THTR 107

Work performed at
HRB - Hochtemperatur Reaktorbau GmbH, Mannheim - Germany

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A first version of the code has been written for accident analysis and solves the dynamics equations assuming constant Xenon and Samerium concentration in the reactor during the transient. A second version has been written for the investigation of the normal reactor operation neglecting delayed neutrons but treating Xenon transients in detail.

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ABSTRACT

COSTANZA-HRB is a computer code for two dimensional reactor dynamic calculations in cylindrical RZ geometry and two energy groups, especially developed for the analysis of High Temperature Reactors with spherical or prismatic fuel.

A first version of the code has been written for accident analysis and solves the dynamics equations assuming constant Xenon and Samerium concentration in the reactor during the transient. A second version has been written for the investigation of the normal reactor operation neglecting delayed neutrons but treating Xenon transients in detail.

KEYWORDS

THTR-300 REACTOR
C CODES
TRANSIENTS
REACTOR KINETICS
REACTOR OPERATION
REACTOR ACCIDENTS
POISONING
XENON
SAMARIUM
TWO-DIMENSIONAL CALCULATIONS

Contents

1. Introduction

All reactor dynamic calculations can be classified in accident analysis and investigations of the normal reactor operation.
While various zero and one dimensional codes exist for both types of calculations, investigations performed on high temperature gas cooled reactors have demonstrated the need of more detailed two dimensional calculations in order to reach sufficient accuracy in the space dependent treatment of temperature transients and of Xenon distribution. The cylindrical RZ geometry has been chosen. As for the one dimensional case /1/ two versions of the code have been written and adapted to high temperature reactor calculations for the above mentioned two types of calculations.

2. Code for fast transient analysis

Theory and subdivision of the reactor

The first type of code solves the actual dynamics equations in two energy groups considering up to 10 groups of delayed neutrons, but assuming constant Xenon and Samarium concentration in the reactor during the transient.
The equations are the same as already described for the one dimensional case /1/.

$$\frac{1}{v_1}\frac{\partial \phi_1}{\partial t} = D_1 \nabla^2 \phi_1 - (\Sigma_{rem1} + N\sigma_{c1})\phi_1 + (1-\beta)(\nu\Sigma_{f1}\phi_1 + \nu\Sigma_{f2}) + \sum_{i=1}^{k} \lambda_i C_i \qquad (1)$$

$$\frac{1}{v_2}\frac{\partial \phi_2}{\partial t} = D_2 \nabla^2 \phi_2 - (\Sigma_{a2} + N\sigma_{c2})\phi_2 + p\Sigma_{rem1}\phi_1 \qquad (2)$$

$$\frac{\partial C_i}{\partial t} = \beta_i(\nu\Sigma_{f1}\phi_1 + \nu\Sigma_{f2}\phi_2) - \lambda_i C_i \qquad (3)$$

These equations are solved numerically subdividing the two space coordinates in an appropriate number of mesh points and the time in constant time steps (finite difference approximation). The heat transfer equations from the heating element to the coolant in the channel are also solved numerically.

To that end the fuel and graphite elements are subdivided into a specified number of zones. This number which may be independently chosen for each of the two element classes is limited to 9. Since each zone is characterized by a thermal capacity and the thermal resistances between itself and the two neighbouring zones (one instead of two for the first and the last zone), no restriction to spherical elements is made.
The spatial distribution of the physical quantities of the reactor is described by means of a mesh point lattice (400 points at maximum), as i.g. that of fig. 2. The outer points are located at the extrapolated boundaries of the reactor. The first two vertical arrays are located symmetrically to the axis to obtain zero radial derivative at the axis. Within the core the axial point lattice is the same for neutronic and thermal calculations.
The equations (1), (2) and (3) are integrated over the volume corresponding to each mesh point (i,j) in the RZ plane, as in fig. 1, and each of the 4 subvolumes surrounding the mesh point corresponds to different coefficients of the equations. This takes into account regional differences in composition, or simply variations of the coefficients due to spatial temperature variation. Details of the numerical method are given in /2/.
The core may be subdivided into a maximum number of 30 regions having different core compositions and up to 10 vertical zones. The vertical zones have the same height as the reactor, including top and bottom reflectors if existing. Each zone is characterized by the same depth of rod insertion and by the same typical channel (if any). If a zone is specified as a channel the temperature at each mesh point of the zone is calculated at every time step from the equation for heat conduction considering the actual power distribution.

Temperature feed back on reactivity is determined by the temperature effect on the coefficients of equations (1) and (2), similiarly as in the one dimensional version /1/.
Control action can be simulated either by changing the control poison concentration or by rod movement (as to the latter cf. 4.).
Flow rates and inlet temperatures of the coolant are externally imposed as input functions of time

Criticality search

Criticality may be obtained by varying the poison concentration in any wanted composition region or by varying the depth of rod insertion in any wanted vertical control zone.
The calculation is repeated until the reciprocal of the period of the average thermal flux differs from zero by less than a fixed amount. During this process only prompt neutrons are considered.

Dynamic calculation

Starting from the initial equilibrium conditions the code calculates the dynamic behaviour of the reactor in time. The calculations of the flux distributions and delayed neutron precursor concentrations will be repeated at every time step. The thermohydraulic calculations and the corresponding temperature reactions are calculated at every n time steps, n to be specified in input. During the transient the power level and flux distributions evolve freely according to the reactivity introduced by any perturbation and to the temperature feed-back. The perturbations may be given by varying the depth of rod insertion, or the mass flow, or the inlet temperature in any wanted zone independently.

3. Code for slow transient analysis

Theory

The following description contains only the changes with respect to the code for fast transient analysis, described in section 2.

Whereas in the code for fast transient analysis the power is calculated from a given control poison concentration (or rod position) in time, in the code for slow transient analysis the control poison concentration (or rod position) is calculated from the given total power in such a way as to compensate the reactivity caused by changes in temperature and Xenon concentration (see below).
An exception is made in the case of a shut down (see below).
The temperature at each mesh point of a channel is calculated at every time step as the stationary temperature corresponding to the power distribution at the time step.
As for the one dimensional version the calculation of the slow transients is made simpler by neglecting the delayed neutrons.
The Iodine and Xenon differential equations are introduced in the code in the form:

$$\frac{\partial I}{\partial t} = \gamma_I (\Sigma_{f1}\phi_1 + \Sigma_{f2}\phi_2) - \lambda_I I \qquad (4)$$

$$\frac{\partial Xe}{\partial t} = \gamma_{Xe}(\Sigma_{f1}\phi_1 + \Sigma_{f2}\phi_2) + \lambda_I I - \lambda_{Xe} Xe - \sigma_{Xe}\phi_2 Xe \qquad (5)$$

and then normalized to the Xe saturation value for infinite neutron flux X_o^∞ introducing the variables

$$i = \frac{I}{X_o^\infty} \qquad x = \frac{Xe}{X_o^\infty}$$

Equations (1) and (2) are still used in their time dependent form. Actually the static diffusion calculation could be used for these slow transients but it was more convenient to make use of the time dependent diffusion equations for criticality search. Starting from a first guess on the control rod (or equivalent poison) insertion a dynamic calculation is performed for some time steps and an iteration on this insertion is performed until the asymptotic reactor period is greater than a specified value (the time step length used for this procedure is of the order of 0.001 sec and differs from the time step used for the solution of Xe equations which is of the order of 10 min.).
At the beginning of the calculation the flux level is normalized to the initial power and criticality is achieved by dividing the initial production term by the resulting k_{eff}. This calculation takes also into account the temperature feedback and the Xe poisoning at its asymptotic concentration in each point of the core

$$\chi_e = \frac{(\gamma_I + \gamma_{Xe})(\Sigma_{f1}\phi_1 + \Sigma_{f2}\phi_2)}{\lambda_{Xe} + \sigma_{Xe}\phi_2}$$

As temperature and Xenon concentrations are flux dependent in each point, the equilibrium concentrations are obtained by means of an iterative process.

Shut down

It is possible to consider that the reactor is shut down after having been operated for a very long time at the nominal power. The reactor remains shut down for any wanted time t. The corresponding concentrations of Iodine and Xenon are then calculated by:

$$I = I_o e^{-\lambda_I t}$$

$$\chi_e = e^{-\lambda_{Xe} t}\left\{\frac{\gamma_I\left[e^{(\lambda_{Xe}-\lambda_I)t}-1\right]}{\lambda_{Xe}-\lambda_I}(\Sigma_{f1}\phi_1+\Sigma_{f2}\phi_2) + \chi_o\right\}$$

I_o and X_o = initial values

The reactor is then restarted at the nominal power. It is supposed that there is sufficient built-in reactivity to attain this power.
If the built-in excess reactivity is not sufficient the code calculates automatically the maximum power which can be reached.

This of course is only possible if the temperature coefficient is sufficiently negative, so that an appreciable reactivity gain can be obtained by running the reactor at lower power, with constant gas outlet temperature and hence lower fuel temperature.

Perturbed asymptotic Xe and I distribution

There is the possibility of altering the initial asymptotic distribution of Xe and I in any specified way, according to distribution factors given in input. This provision is made to check if an instable oscillation may be induced.

Power following

After the initial equilibrium calculation, the power may vary in time in any specified way. The power as function of time is given in input in tabulated form.
At every time step the code interpolates linearly. The fluxes are normalized to the value of the total power at every instant, their radial distribution determines how the total power is subdivided among the cooling channels. A thermal calculation is made for each channel according to the local power and gives the fuel, coolant and moderator temperature. The temperature feed back is calculated regionwise as function of these temperatures in each channel.

Restart an interrupted calculation

It is possible to give in input the values of fast and thermal fluxes and the concentrations of Xenon and Iodine for each point of the core, and to by-pass the initialzation. By this means it is possible to restart an interrupted calculation.

4. Control rod representation in both versions

In each control zone the rods move as a bank all together. They are represented by a diffused equivalent poison. The fast and thermal macroscopic cross-section of this equivalent poison are given in input. The poisoned part of the zone is limited by a movable boundary, A-B (see Fig. 3). When the movable boundary lies between two points of the vertival array, a linearly interpolated value of poison is assigned to the space between the two points.
The initial insertion of the rods in each zone is given in input. The criticality search is made by moving the rods in any wanted zone.
The movable boundaries, in the zones chosen for criticality search, move with the same speed and maintain the relative distances as given in input. If the criticality is not reached when a bank of rods in one zone is completely inserted or completely extracted, its position does not change any more and the other banks continue to move in the same direction until criticality is reached.
In all other zones, not chosen for criticality search, the rods maintain their initial position.

5. Programme size and time for calculation

The two COSTANZA codes described in this publication were made by adapting the COSTANZA versions /2/ and /3/ to comuptations of the dynamic behaviour of high temperature gas cooled reactors. So they were originally written for an IBM/360 Model 65. The number of mesh points was limited to 40 in either direction but their total number could not excede 400. At first only the code for slow transient analysis should be used by HRB on a Model 50 (256 K). Since its size was too big for this machine, the overlay structure which had been essentially the same as that of the code for fast transient analysis (fig. 5) was replaced by the overlay structure shown in fig. 4. In addition the maximum total number of mesh points was reduced from 400 to 350. Furthermore variable dimensions

were introduced for the sake of a greater flexibility in the case of programme changes (though this showed to be of little advantage). Meanwhile it has become possible to use a "virtual memory" so that there is no immediate need for such changes for the HRB version of the code for fast transient analysis.
The code for slow transient analysis on the IBM/360 Model 50, when using the geometrical model of fig. 2 (THTR) but no channels, with a burn-up time step of 10 minutes and adequate error barriers, needs about one minute computation time for 3 time steps. With temperature calculations (i.e. introducing channels) the computation time would not be appreciably higher.

6. Programme composition of the slow transient analysis code

The programme has the overlay structure as shown in fig. 4.

Segment 1 (root segment):
MAIN calls the first routine of each segment of level α.

Level α :

Segment 2:

ADRES — reads the size parameters of all the arrays for which variable dimensioning is provided and defines the first address of each of these arrays.

Segment 3 and 4:

The routines contained in these two segments are called only once for a case. They calculate all the coefficients which will not be changed during the case and transfer them into the COMMON blocks of the root segment.

INP — reads all the other input data from cards or tape. It calls AZER1 and DCAN.

AZER1 — called from INP before reading the data, sets to zero all COMMON blocks of the root segment and of the segment containing INP.

DCAN — calculates all the thermohydraulic coefficients which will remain unchanged during the transient.

PRIC — takes the data which have been read region wise and transforms them into point wise data. It calls GEØM.

GEØM — calculates all the coefficients depending on the geometry of the core and the point lattice.

Segment 5:

PRINC2 — In its first part this routine determines the initial conditions. It calls AZER2 to put equal to zero all the commons of segment 5, puts the control rods into the initial position, calls INIZIØ, to give a first approximate distribution of the fluxes, calls CRIT to calculate the initial equilibrium distributions of fluxes, temperatures and Xenon concentrations. Optionally it calls SPENTØ, to shut down the reactor and calculate the Xenon concentration after a given time. Optionally it perturbs the Xenon and Iodine equilibrium concentrations according to a given perturbation factor. In the second part it determines the transient behaviour, calculates at every time step the Iodine and Xenon concentration in each point of the lattice. It calls PØTENZ which determines the power at every time step according to a tabulation given in input, calls CRITVE or CRIT-BA to determine the criticality conditions at every time step, either with variable poison concentration or with rod movement. When the

reactor remains undercritical even with zero poison or with all the rods totally extracted, it reduces the power to a level at which the criticality can again be reached. It calls STAMPA to print according to the orders given in input.
It controls the restart operations to store on tape the results at the end of a calculation and to start from tape an interrupted calculation (see Restart Instructions).

MAT — calculates the coefficients of the system of linear equations to be solved by FLUSSI. This calculation is made using the invariant coefficients and variable physical magnitudes depending on the temperature reaction and the rod position. This routine will be called at every thermal calculation, and from CRIT when the reactivity search is made by varying the $\nu\Sigma_f$.

FLUSSI — solves directly along each radius the two-group system of linear equations (see method). It scans axially the point lattice, in alternate directions, until the residuals of each group

$$\frac{\sum_{i=1}^{N}|\Delta\psi_i|}{\sum_{i=1}^{N}\psi_i} < EP1 \quad \text{and} \quad \frac{\sum_{i=1}^{N}|\Delta\varphi_i|}{\sum_{i=1}^{N}\varphi_i} < EP2$$

are smaller than the quantities EP1 and EP2 given in input.
It calculates the fast and thermal flux average values and the reciprocal of the period.

RENØRM — normalizes the fast and thermal fluxes for a given value of power.

CANALE — calculates for each channel the temperature distribution in the fuel and in the coolant at every time step at all axial levels (see Thermal Calculation).

CØVAR — calculates the new values of the physical constants corresponding to the average temperatures given by INTEGR (see temperature reaction).

INTEGR — calculates for each channel independently at every axial level the fuel, moderator and coolant average temperatures.

VINIZ — determines for each channel the coolant inlet temperatures and mass flow at every time step, interpolating the values given in input as function of time in tabualted form.

Level β

Segments 6 and 7:

If there is no restart after a shut down the routines of these two segments are called only once.

AZER2 — called from PRINC2 sets to zero all the commons of segment 5.

INIZIØ — calls FLUSSI a number of times specified in input. Starting from an initial flat distribution it determines a first approximate distribution of the fluxes. In these calculations the delayed neutrons are not considered. It normalizes the fluxes at a given initial power level, using a neutronic time step DELTI which may be different from DELT used in CRIT.

CRIT — determines the criticality at the initial conditions by varying the ν in $\nu\Sigma_f$ with a given rod disposition and given poison concentration. At every iteration $\nu\Sigma_f$ is multiplied by $(1+\delta\rho)$ where $\delta\rho$ will be varied in order to render zero the reciprocal of the period. In each iteration the thermal calculation and temperature reaction will be repeated as will be the calculation of the Xenon equilibrium concentrations at every point.

(See Flow Chart.)

Segment 8:

RESTAR — stores on tape the results of a given time. It restarts an interrupted calculation reading the results stored on tape (see restart instructions).

Segment 9:

BACØ — calculates the ratio between the maximum and the average value of the thermal flux. If this ratio is greater than a value given in input, it determines its location in the core and proceeds to insert the compensation rod to flatten the flux.

BARRE — calculates the new coefficients of the system of linear equations only where a new condition of poison was determined by the displacement of the rods. As example see M and N of fig. 6.
The recursive coefficients of the forward elimination and backword substitution method however are calculated by BARRE in all the points of the region A B C D of fig. 6 determined by the rods displacement and the outer boundary.

PØTENZ determines the power at every time step interpolating the values of power given in input as function of time in tabulated form.

SPENTØ calculates at each mesh point the Xenon concentration after a given time of shut-down.

STAMPA prints the output. Any wanted result may be printed in several optional types of print (see input instructions).

Level 8

Segments 10 and 11

According to specification in input either CRITVE or CRITBA operates at every Xenon time step DT.

CRITVE varies the poison concentration in order to decrease the reciprocal of the period.
The temperature reaction is calculated only once before the iterations according to the normalized power distribution of the first iteration. The Xenon concentrations are calculated in the routine PRINC2 considering the flux distributions as at the preceding time step. As first poison guess CRITVE uses a value given in input at the first time step and the poison calculated at the preceding time step afterwards.

CRITBA As for CRITVE the temperature reaction and Xenon concentrations are calculated outside of the iterative cycle. At the first time step the first guess rod insertions are given in input, afterwards as first guess will be used the insertion calculated at the preceding time step.

7. Programme composition of the fast transient analysis code

The code consists of a Main and 19 Subroutines of which 5 belong to segment 2 (first Overlay) and the remaining 14 belong to segment 3 (second Overlay) of the overlay structure, both segments being arranged on the same level α, which is the only one annexed to the root segment (segment one).
The 5 routines of the first group are called only once. They calculate all the coefficients which will not be changed anymore and will be transfered to the second overlay in order to make available the rest of the memory.

Segment 1 (root segment)

MAIN — calls the first routines of the first overlay and PRINC2, control routine of the second overlay

Segment 2

INPUT — Reads the vector DATA from cards or tape.

PRINC — it takes the data which are read region-wise in INPUT and transforms them into point-wise data. Calls GEØM and DCAN.

DCAN — calculates all the thermohydraulic coefficients which will remain unchanged during the transient.

GEØM — calculates all the coefficients depending from the geometry of the core and the point lattice.

AZER1 — called from INPUT, before reading the data. Puts equal zero all the commons of the first Overlay.

Segment 3

PRINC2 — in its first part, before label 1000, this routine determines the initial conditions. It calls AZER2 to put equal zero all the commons belonging only to the second Overlay. Puts the control rods in the initial position. Calls INIZ to give a first approximate distribution of the fluxes. Calls CRITIC to calculate the initial equilibrium distributions of fluxes and temperatures.
In the second part after the label 1000 it determines the transient behaviour.
At every time step it calls BARRE to determine the rod position; it calls FLUSSI to calculate the flux distribution; optionally it calculates the accumulated energy per cm^3 at every point; it calculates the delayed neutrons precursors concentrations at every point.
At every KPC (see input key) time steps it calls the thermal routines CANPAL and CØVAR to determine the temperature reactions.
Calls STAMPA to print according to the orders given in input.
Controls the restart operations to store on tape the results at the end of a calculation and to start form tape an interrupted calculation (see Restart Instructions).

AZER2 — puts equal zero all the commons belonging only to the second Overlay.

INIZ — it calls FLUSSI a number of times specified in input. Starting from an initial flat distribution determines a first approximate distribution of the fluxes. In these calculations the delayed neutrons are not considered. It normalizes the fluxes at a given initial power level. Uses a neutronic time

step DELTI which may be different from DELTC used in CRITIC, and from DELT used for the transient calculation.

FLUSSI — it solves directly along each radius the two-group system of linear equations. (see Method). It scans axially the point lattice, in alternate directions, until the residuals of each group

$$\frac{\sum_{i=1}^{N} |\Delta\psi_i|}{\sum_{i=1}^{N} \psi_i} < EP1 \quad \text{and} \quad \frac{\sum_{i=1}^{N} |\Delta\varphi_i|}{\sum_{i=1}^{N} \varphi_i} < EP2$$

are smaller than the quantities EP1 and EP2 given in input.
It calculates the fast and thermal flux average values and the reciprocal of the period.

MAT 1 — it calculates the coefficients of the system of linear eq. to be solved by FLUSSI. This calculation is made using the invariant coefficients transferred from the first overlay and variable physical magnitudes depending from the temperature reaction and the rod position.
This routine will be called at every thermal calculation, from PRINC2 and from CRITIC.
When only thepoison concentration is varied it is enough to call MAT 2, because, as the routine contains the Entry Mat 2, the first part of it will be bypassed.

CRITIC — searches the criticality by varying iteratively either the concentration of poison in any wanted region, or the insertion of the rods in any wanted zone. In the first part of this iterative method, from two values of poison and the corresponding values of reciprocal period, it determines, by extrapolation, the next value of poison and so on.

When the reciprocal period is below a given value it variates the poison at every iteration by one thousandth of the last concentration, until the convergency criterium is satisfied or the reciprocal of period changes its sign.
The same proceeding is followed when the criticality is searched with rod movement. After a first part with the extrapolation method, the rods, are displaced by 1 millimeter at every iteration.
In both cases at every iteration the thermohydraulic routines are called to determine the temperature reaction.
The calculation is made without considering the delayed neutrons.

BARRE — see description in code for slow transients. It is called from CRITIC and PRINC2. When called from PRINC2 it determines the rod position by interpolation of the tabulation given in input.

TEST — this is a dummy routine which contains all the commons and may be used to introduce any new statement in the programme. It is called at every time step from PRINC2.

CANPAL — this routine calculates from each channel the temperature distribution in the fuel elements and in the coolant at all axial levels (see thermal calculation). It is called during the transient from PRINC2 at every KPC time steps, and from CRITIC to determine the equilibrium initial condition.
The descriptions of the subroutines FLUSSI; STAMPA; VINIZ; INTEGR; CØVAR; RESTAR are the same as in the code for slow transient analysis.

8. Input

Code for the slow transient analysis

First card

The first card of every problem contains the size parameters of all the quantities for which variable dimensioning is provided, in the following order (format 5I4):

IMAX, JMAX, NMP1, NZB, NREG

Explanation:

IMAX — number of axial mesh points ≤ 40

JMAX — number of radial " ≤ 40
IMAX*JMAX ≤ 350

NMP1 — 1 + maximum number of shells in any fuel element. NMP1 ≤ 10

NZB — number of vertical zones ≤ 10.
The vertical zones have the same height as the reactor. Each zone is characterized by the same depth of rod insertion and by the same typical channel.

NREG — number of regions with different composition.
NREG ≤ 30.

Title card (second card)

Columns 1, 2, 3 if left blank, the data are read from cards and the results will be stored on a tape. It is possible to store results on tape and restart interrupted calculation when positive or negative integers are put in cloumns 1, 2, 3. A positive integer in column 6 means that the problem is the last of the run. Any alphanumerical information may appear in columns 7-70 and will be printed in output.

Following cards

All the other data are read according to the following procedure:
A vector of 10000 memory positions (4-byte words) DATA(1)... DATA (10000) contains all the data. Since entire groups of memory positions are zero, it is possible to read separate sets of significant data; each set of data must be preceded by a card containing the integers Ki3, Ki1, Ki2, written in format (2I6, I12) where Ki3 is normally zero. Ki1 and Ki2 are the indexes of the first and last datum of the set. Only in the last set of a problem Ki3 must be any positive integer number. The data are in floating form, six per card (Format 6E12.8).
Any number of problems may be run in sequence; for all the subsequent problems only the data different from the corresponding data of the first problem need to be given.
The vector DATA will be memorized on an auxiliary tape. Do not forget to instruct the operator.

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
1	TEMAC	computer time (see restart p.2) (min)		only if first three columns of title card contain a number
2	DELT	neutronic time step for transient calculation (sec)		In case of restart from tape it must be DELT=DT
3	DT	burn-up time step (sec)		
4-7		blank		
8	INGR	maximum allowable number of iterations between the two energy groups	s.v.=30	
9	IDST	number of initial iterations before criticality search	s.v.=20	
10	IT1M	number of inner iterations for the fast energy group	s.v.=20	
11	IT2M	same for the thermal group	s.v.=20	
12	DELTI	neutronic time step for INIZIØ routine (sec)		
13		blank		
14	EP1	convergence criterium for the fast group	s.v.=0.01	
15	EP2	same for the thermal group	s.v.=0.01	
16	SI	initial reactor power (watts)		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
17	TEMPØ	time of shut down (sec)		only if IXE=DATA (41)=1
18	NCAN	number of radial zones containing channels		
19		blank		
20		blank		
21		blank		
22	ICA	axial index of the points lying on the upper core boundary (reflector excluded)		
23	ICB	same for the lower boundary		
24	JCI	radial index of the points lying on the inner core boundary		usually the control part of the reactor belongs to the core then JCI=2
25	JCE	radial index of the points lying on the outer boundary of the core (radial reflector excluded)		
26	W	fast group neutron velocity (cm/sec)		
27	V	thermal group neutron velocity (cm/sec)		
28	SPRG	first guess of control poison concentration		blank if criticality search is made with rod movement

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
29	DAPF	convergence criterion for reciprocal of period in criticality search (sec^{-1})	s.v.=0.1	
30	LF	maximum allowable number of criticality iterations	s.v.=30	
31	IDIR	=1 if the control rods enter into the core at the same side as the coolant =2 if they enter at the opposite side		
32	IBCR	=0 criticality search made with diffused poison =1 criticality search made with rod movement		
33-35		blank		
36	GAI	γ_I Iodine yield		
37	GAXE	γ_{Xe} Xenon yield		
38	DLI	λ_I Decay constant for Iodine (sec^{-1})		
39	DLXE	λ_{xe} Decay constant for Xenon (sec^{-1})		
40	SAXE	Microscopic Xenon absorption cross section (cm^2) (only thermal group)		
41	IXE	10 SPENTØ 0 Power transient -10 Perturbation of equilibrium distribution of I and Xe		
42	RAMAX	100 $\frac{\text{Ø}_{max}}{\text{Ø}_{average}}$, nominal ratio		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
43	IBARC	1 Compensation Rod Total length 2 Compensation Rod per length		
44	DERØG	$\Delta\varphi$, guess		
45	LPARC	Number of points of the vertical lattice corresponding to half length of the part length rod.		
301	I1	Index of the upper boundary of the first region		This group of data for each region is included in one card. For the region bounded by the axis of cylinder J1=1
302	I2	Index of the lower boundary of the first region		
303	J1	Index of the left (inner) boundary of the first region		
304	J2	Index of the right (outer) boundary of the first region		
305		blank		
306		blank		
307-312		For the second region		
475-480		For the 30th region		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
1001	D1	Diffusion coefficient fast group (cm)		
1002	SR	Removal cross section (cm^{-1})		
1003	SF1	$\nu\Sigma_{f1}$, Production cross section (cm^{-1}) (fast group)		This group of fast constants for each region is contained in one card
1004	P	Fast absorption probability		
1005	SPB1	Microscopic poison cross section (cm^2) (fast group)		
1006	ASN1	Σ_{f1}, Macroscopic fission cross section (cm^{-1}) (fast group)		
1007-1012		Second region		
1175-1180		30th region		
1601	D2	Diffusion coefficient thermal group (cm)		
1602	SA	Σ_{a2}, thermal absorption cross-section (cm^{-1})		If IBCR=0 SPR will be varied to obtain criticality in the control regions
1603	SF2	$\nu\Sigma_{f2}$, Production cross section (cm^{-1}) (thermal group)		
1604	SPB2	Microscopic poison X -section (cm^{-2}) (thermal group)		
1605	SPR	Poison concentration (cm^{-3}); is multiplied by SPB1=DATA(1005) and SPB2= DATA (1604)		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
1606	ASN2	Σ_{f2}, Macroscopic fission cross section (cm^{-1}) (thermal group)		
1607-1612		Second region		
1775-1780		30th region		
2201	EQUI1	Thermal equivalent of fission (fast) (Watt-sec)		
2202	EQUI2	" " " (thermal) (Watt-sec)		
2203	FNU	ν, neutron yield per fission		
2204	KV	= order number of the region, then in that region SPR will be varied for criticality search = zero, SPR will not change		only if IBCR=0
2205	TRU	The initial values of the physical constants given in input were calculated according to a fuel temperature = TRU and a moderator temperature = TRM for each composition region (°C)		
2206	TRM			
2207-2212		For the second region		
2375-2380		For the 30th region.		
2801	KB	if = order number of the zone, this zone contains control rods. if = 0, no rods		see note for NZB

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
2802	KBC	if = order number of the zone, the rods of the zone are used for criticality search if = zero, no movement of rod for criticality search	only if IBCR =1	see note of NZB
2803	J1B	Index of the left (inner) boundary of the zone		the order number of the zone must increase from left to right. For the region bounded by the axis of cylinder J1B=0
2804	J2B	Index of the right (outer) boundary of the zone		
2805	KCA	if = order number of zone, the zone contains channels if = 0 no channel		
2806		blank		
2807-2812		second zone		
2855-2860		10th zone		
2861	VEBA1	Macroscopic cross section of the rod equivalent poison (fast)		
2862	VEBA2	" (thermal)		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
2863	VECØ1	Compensation rod equivalent poison (fast macroscopic X-section)		
2864	VECØ2	" " " (thermal macroscopic X-section)		
2865	-	blank		
2866	-	blank		
2867-2872		Second zone		
2915-2920		10th zone		
3031	PRIN	Depth of rod insertion for the first zone (cm)		
3091		Same for the second zone etc.		
3571		10th zone		
4001-4040	X(J)	Distance of mesh points from the axis (cm)		
4101-4140	Y(I)	Distance of mesh points from the upper boundary (cm)		The upper boundary is for definition the side from which the coolant enters. The first distance is Y(1) = 0.0
4141-4490	FRI(I)	Perturbation factor for Iodine and Xenon concentrations in each point of the lattice		
4541-4890	FRXE(I)			

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
		First Channel Data		
5001-5002		blank		
5003	SC	Gas Specific heat		
5004		blank		
5005		blank		
5006		blank		
5007	N1	Number of shells in the fuel element type 1	$N1 \leq 9$	
5008	PALN1	Number of fuel elements of type 1 per axial zone corresponding to the cross section of the channel in the height Δz		
5009	RAVI	Power of the elements of type 1 / total power		
5010	ØSE1	Outer surface of the element (cm^2)		
5011		blank		
5012		blank		
5013-5018		These six data contained in one card correspond to the first shell of the type 1 element as follows:		
5013	RES1	Thermal resistance between the shell and the next one		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
5014		blank		
5015	VØS1	Shell volume (cm^3)		
5016	PZØ1	Power fraction corresponding to the shell		Relative values are significant. Normalization is performed by the code.
5017	FF1	Quantity of fuel contained in the shell of the fuel elements type 1 (g)		
5018	FM1	Quantity of moderator contained in the shell of the fuel element type 1 (g)		
5019-5024		Same data for the second shell etc.		
5061-5066		For the 9th shell		
5107-5160		These data concerning the type 2 element correspond exactly to the Data 5007-5066 concerning the type 1 element.		
5190	VITE	Inlet temperature of coolant on equilibrium initial conditions (put zero if inlet temperature is tabulated as function function of time) (^oC)		
5191	STEPT	Step of coolant inlet temperature (^oC)		only if VITE≠0
5192	RAMPT	Value of dT/dt for ramp in coolant inlet temperature		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
5193	VIPØ	Initial value of coolant mass-flow (put zero if tabulated) (g/sec)		
5194	STEPPØ	Step of coolant mass flow (g/sec)		only if VIPØ≠0
5195	RAMPØ	Value of dm/dt for ramp in mass flow (g/sec^2)		
5198-5199		blank		
5201-5399		SECOND CHANNEL DATA		
6801-6999		TENTH CHANNEL DATA		

NOTE: All the cards must be repeated for each channel. The order number of the existent channel must be the same as the order number of the radial zone in which the channel is contained.

(Ex. Suppose that zones one and three contain channels and zone two do not contain any channel, then the channel of zone three must be considered as the third and its data are in the group DATA (5401 ... 5599).)

7001-7060		Tabulation of inlet temperature and mass flow for the <u>first channel</u>. Each point of the tabulation for both magnitudes is contained in one card, (4 data), as follows:		
7001	TØTE	Time of the temperature tabulation (sec) (Zero in the first card)		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
7002	TENT	Value of the corresponding temperature (°C)		
7003	TØPØ	Time of the mass flow tabulation (sec) (Zero in the first card)		
7004	PENT	Value of the corresponding mass flow (g/sec)		
7005	-	blank		
7006	-	blank		
7007-7012		Second card of the tabulation etc.		
7061-7120		Same for the second channel etc.		
7541-7600		Same for the 10th channel		
7800-7900		Tabulation for variable power (PØTENZ)		
8001-9200		TEMPERATURE COEFFICIENTS		

NOTE:

The temperature dependence of the physical constants is expressed in a Taylor expansion:

$$C = C_0 + \alpha_1 \cdot (T_f - T_{fo}) + \alpha_2 \cdot (T_m - T_{mo}) + \alpha_3 \cdot (T_f - T_{fo})^2 + \alpha_4 \cdot (T_m - T_{mo})^2 + \alpha_5 (T_f - T_{fo}) \cdot (T_m - T_{mo})$$

DATA Number	Variable Name	Description	Allowable or suggested values	Notes

The variable physical constants are 8 in the following order:

1	D1	$= D_1$
2	SR	$= \Sigma_{rem}$
3	SF1	$= \nu\Sigma_{f1}$
4	P	$= p$
5	D2	$= D_2$
6	SA	$= \Sigma_{a2}$
7	SF2	$= \nu\Sigma_{f2}$
8	SPR	$= \Sigma_{poison}$

The algoritm giving the position of the temperature coefficient in the vector DATA is as follows:

CTN (K, L, N) = DATA [8000 + 40* (N-1) + 8* (L-1) + K]

where K (1, 8) = order number of the physical constant
L (1, 5) = order number of α_i in the taylor series
N (1,NREG) = order number of the composition region

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
9901-9960		PRINTING ORDERS It is possible to give in input up to 5 different printing orders. Each order is contained in two cards as follows:		
9901		Number of the time step up to which the print is made according to order given in this card.		
9902		Print type 1 will be made at every DATA (9902) time steps.		
9903		Same for type 2		
9904		" " " 3		
9905		" " " 4		
9906		"" " " 5		
9907		" " " 6		
9908		" " " 7		
9909		" " " 8		
9910		" " " 9		
9911		blank		
9912		The results are stored on tape at every DATA (9912) time steps.		
9913-9924		Next printing order		
		The calculation stops at the time step indicated by the last printing order.		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes

List of printing orders

print type 1 = Flux core average, reciprocal period and total power.

2 = Flux map

3 = Map of rod insertions

4 = Map of power density

5 = Map of Iodine and Xenon Concentrations.

6 = Max. fuel temperature, max. cladding temp., max. heat flow, inlet and outlet temp., mass flow.

7 = Map of temperatures

8 = criticality print

9 = nothing

9. Input

Code for fast transient analysis

Title card (first card)

Columns 1-2-3 if left blank the data are read from cards and the results will not be stored on tape. Numbers in these columns correspond to store and restart (see Restart Instructions). Columns 4-5-6. If only one problem is treated they must contain any positive integer. If a series of problems are to be treated in the same run, only the title card of the last problem must have any positive integer, in the preceding title cards these columns must be blank. Columns 7-70 may contain any alphanumerical information which will be printed in output.

Following cards

A vector of 10000 memory positions: DATA (1) .....
DATA (10000) contains all the data.
Since entire groups of memory positions are zero, it is possible to read separate sets of significant data; each set of data must be preceded by a card containing the integers Ki_1, Ki_2, Ki_3, written in Format (2I6, I12) where Ki_1 is normally zero, Ki_2 and Ki_3 are the indexes of the first and last datum of the set.
Only in the last set of a problem Ki_1 must be any postive integer number. The data are in floating form, six per card (Format 6 E 12.8).
Any number of problems may be run in sequence; for all the subsequent problems only the data different from the corresponding data of the first problem need to be given. The vector DATA of the first problem must be memorized on an auxiliary tape. (see Restart Instructions).

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
1	TEMAC	Computer time (min.)		only if the first three columns of the title card contain a number; see Restart Instructions
2	DELT	Neutronic time step Δt for transient calculation (sec)		
3	DELTC	Neutronic time step Δt for criticality search (sec)		
4	IMAX	Number of axial mesh points	≤ 40	(IMAX * JMAX) ≤ 400
5	JMAX	" " radial " "	≤ 40	
6	NREG	Number of regions with different composition	≤ 30	
7	NRIT	Number of delayed neutron groups	≤ 6	
8	ITMAX	Maximum allowable number of axial iterations	suggested value = 30	
9	IDST	Number of initial iterations before criticality search	suggested value = 20	
10		blank		
11		blank		
12	DELTI	Neutronic time step Δt for the initial iterations before criticality search	s.v.DELTI= DELTC	
13		blank		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
14	EP1	Convergence criterium for the fast group	s.v. = 0,01	
15	EP2	Same for the thermal group	s.v. = 0,01	
16	SI	Initial reactor power (Watts)		
17	KPC	The thermal calculation is done every KPC neutronic steps		
18	NCAN	Number of radial zones containing channels		
19		blank		
20		blank		
21	KTE	If KTE > 0 Subroutine TEST will be called.		
22	ICA	Axial index of the points lying on the upper core boundary. (Reflector excluded)		
23	ICB	Same for the lower boundary		
24	JCI	Radial index of the points lying on the inner core boundary		Usually the central part of the reactor belongs to the core, then JCI=2
25	JCE	Radial index of the points lying on the outer boundary of the core. (Radial reflector excluded)		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
26	W	Fast group neutron velocity ($\frac{cm}{sec}$)		
27	V	Thermal " " " "		
28	SPRG	First guess of control poison concentration		blank if criticality search is made with rod movement
29	DAPF	Convergence criterion for reciprocal of period in criticality search (sec^{-1})	s.v.=0.1	
30	LF	Maximum allowable number of criticality iterations	s.v.=30	
31	IDIR	= 1 if the control rods enter into the core at the same side as the coolant. = 2 if they enter at the opposite side		
32	IBCR	= 0 criticality search made with diffused poison = 1 criticality search made with rod movement		
33	NZB	Number of the vertical zones	≤ 10	The vertical zones have the same height as the reactor. Each zone is characterized by the same rod depth of insertion and by the same typical channel.

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
34	SPB1	Microscopic control poison (barn) cross section for the fast group		they are multiplied by SPR in each region to obtain the corresponding macroscopic cross section
35	SPB2	Same for the thermal group		
201-206	BETA	β_i, delayed neutrons yield per fission		
211-216	DL	λ_i, delayed neutrons precursors decay constants (sec^{-1})		
231	INTG	= 1 The power will be integrated in the time at each mesh point = 0 No integration will be effectuated		
232	NUSO	Number of thresholds of integrated energies	$\leqslant 10$	only if INTG = 1
233-242	SØLEN	Thresholds of the integrated energies in increasing order from the lower to the higher (Joule/cm^3)		see printing orders No 8 and 9
301	I1	Index of the upper boundary of the first region		This group of data for each region is included in one card. For the region bounded by the axis of cylinder J1=1
302	I2	Index of the lower boundary of the first region		
303	J1	Index of the left (inner) boundary of the first region		
304	J2	Index of the right (outer) boundary of the first region		
305-306		blank		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
307-312		for the second region		
375-480		for the 30th region		
1001	D1	Diffusion coefficient fast group (cm)		
1002	SR	$\Sigma_{R1} = \Sigma_{a1} + \Sigma_{s1}$ Removal cross section (cm^{-1})		
1003	SF1	$\nu\Sigma_{f1}$ (cm^{-1})		
1004	P	Resonance escape probability		
1005		blank		
1006		blank		
1007-1012		second region		
1175-1180		30th region		
1601	D2	Diffusion coefficient thermal group (cm)		
1602	SA	Σ_{a2} thermal absorption cross-section (cm^{-1})		
1603	SF2	$\nu\Sigma_{f2}$ (cm^{-1})		
1604	SPR	Poison concentration ; it is multiplied by SPB1=Data (34) and SPB2=Data (35)		
1605-1606	-	blank		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
1607-1612		Second region 30th region		
2201	EQUI1	Thermal equivalent of fission (fast) (Watt-sec)		
2202	EQUI2	Thermal equivlanet of fission (thermal) (Watt-sec)		
2203	FNU	ν Neutron yield per fission		
2204	KV	KV = order number of the region, then in that region SPR will be varied for criticality search KV = Zero, SPR will not change		only if IBCR=0
2205 2206	TRU TMU	The initial values of the physical constants given in input were calculated according to a fuel temperature = TRU and a moderator temperature = TMU for each composition region.		
2207-2212		for the second region		
2375-2380		for the 30th region		
2801	KB	KB = order number of the zone , this zone contains control rods KB = 0, no rods		see note of DATA (33)

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
2802	KBC	KBC = order number of the zone, the rods of the zone are used for criticality search KBC = zero, no movement of rod for criticality search	only if IBCR=1	The order number of the zone must increase from left to right
2803	J1B	Index of the left (inner) boundary		For the region bounded by the axis of cylinder J1B = 1
2804	J2B	Index of the right (outer) boundary of the zone		
2805	KCA	KCA = order number of zone, the zone contains channels KCA = zero, no channel		
2806		blank		
2807-2812		Second zone		
2855-2860		10th zone		
2861	VEBA1	Macroscopic cross section of the rod equivalent poison (fast) (cm^{-1})		
2862	VEBA2	Macroscopic cross section of the rod equivalent poison (thermal) (cm^{-1})		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
2863		blank		
2864		blank		
2865		blank		
2866		blank		
2867-2872		second zone		
2915-2920		10th zone		
3001-303	TØBA	Times of the rod movement tabulation for the first zone (sec)	DATA(3001) must always be zero	
3031-3060	PRIN	Corresponding depth of rod insertion in the tabulation for the first zone (cm)		
3061-3090		Same for the second zone	DATA(3061) = 0	
3091-3120		etc.	DATA(3541) = 0	
4001-4040	X(J)	Distance of mesh points from the axis		
4101-4140	Y(I)	Distance of mesh points from the upper boundary		The upper boundary is for definition the side from which the coolant enters. The first distance is Y(1) = 0.0

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
5001	DZ	Constant axial mesh distance (cm)		
5002	SEZ	Section of channel (cm^2)		
5003	SC	Gas specific heat (Joule/(g^oC))		
5004	RO	Gas density (g/cm^2)		
5005	POR	Porosity ≤ 1 = $\frac{\text{empty volume}}{\text{total volume}}$		
5006	-	blank		
5007	N1	Number of shells in the fuel element type 1	N1 $\leq$ 9	
5008	PALN1	Number of fuel elements of type 1 per axial zone corresponding to a section of channel = SEZ in the height ΔZ		
5009	RAVI	Power of the elements of type 1/total power		
5010	Ø SE 1	Outer surface of the element (cm^2)		
5011	-	blank		
5012	-	blank		
5013-5018		These six data contained in one card correspond to the first shell of the type 1 element as follows:		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
5013	RES1	Thermal resistance between the shell and the next one (^{o}C/Watt)		
5014	CPT1	Thermal capacity of the shell (Joule/^{o}C)		
5015	-	blank		
5016	PZØ1	Power fraction corresponding to the shell		Relative values are significant. Normalization is performed by the code.
5017	FF1	Quantity of fuel contained in the shell of the fuel element type 1	(g)	
5018	PM1	Quantity of moderator contained in the shell of the fuel element type 1	(g)	
5019-50 24		Same data for the second shell etc.		
5061-5066		For the nineth shell		
5107-5160		These data concerning the type 2 element correspond exactly to the data 5007-5066 concerning the type 1 element		
5190	VITE	Inlet temperature of coolant at equilibrium initial conditions (put zero if inlet temperature is tabulated as function of time) (^{o}C)		
5191	STEPT	Step of coolant inlet temperature		Only if VITE $\neq$ 0

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
5192	RAMPT	Value of $\frac{dT}{dt}$ for ramp in coolant inlet temperature (^{o}C/sec)		
5193	VIPØ	Initial value of coolant mass-flow (put zero if tabulated) (g/sec)		
5194	STEPPØ	Step of coolant mass flow		only if VIPØ $\neq$ 0
5195	RAMPØ	Value of $\frac{dW}{dt}$ for ramp in mass flow (g/sec)		"
5201-5395		SECOND CHANNEL DATA		
6801-6999		TENTH CHANNEL DATA		

NOTE: All the cards must be repeated for each channel. The order number of the existent channel must be the same as the number of the radial zone in which the channel is contained. (e.g. Suppose that zones one and three contain channels and zone two does not contain any channel, then the channel of zone three must be considered as the third one and its data are in the group - Data (5401) (5599)

7001-7060		Tabulation of inlet temperatures and mass flow for the first channel. Each point of the tabulation for both magnitudes is contained in one card (4 data) as follows:		
7001	TØTE	Time of the temperature tabulation (sec) (zero in the first card)		
7002	TENT	Value of the corresponding temperature (^{o}C)		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
7003	TØPØ	Time of the mass flow tabulation (sec) (zero in the first card)		
7004	PENT	Value of the corresponding mass flow (g/sec)		
7005	-	blank		
7006	-	blank		
7007-7012		Second card of the tabulation etc.		
7061-7120		Same for the second channel		
7541-7600		Same for the 10th channel		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes

8001-8960 TEMPERATURE COEFFICIENTS

NOTE

The temperature dependence of the physical constants is expressed in the form of a Taylor expansion

$$C = C_o + \alpha_1 \cdot (T_f - T_{fo}) + \alpha_2 \cdot (T_m - T_{mo}) + \alpha_3 \cdot (T_f - T_{fo})^2 + \alpha_4 \cdot (T_m - T_{mo})^2$$

The variable physical constants are 8 in the following order:

1	D1	$= D_1$
2	SR	$= \Sigma_{rem1}$
3	SF1	$= \nu\Sigma_{f1}$
4	P	$= \rho$
5	D2	$= D_2$
6	SA	$= \Sigma_{a2}$
7	SF2	$= \nu\Sigma_{f2}$
8	SPR	$= \Sigma_{poison}$

The algoritm giving the position of the temperature coefficient in the vector DATA is as follows:

CTN (K,L,N) = DATA [8000 + 32* (N-1) + 8* (L-1) + K]

DATA Number	Variable Name	Description	Allowable or suggested values	Notes

where K (1,...8) = order number of the physical constant

L (1,...4) = order number of α_i in the Taylor series

N (1,...30)= order number of the composition region

9901-9960 PRINTING ORDERS

It is possible to give in input up to 5 different printing orders. Each order is contained in two cards (12 data)

9901-9912 First order

9913-9924 Second "

9949-9960 Fifth "

In each group of 12 data (two cards) corresponding to an order the first datum = n1 indicates that the printing order is valid up to the $n1^{th}$ time-step.

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
		The other data of the group $n_i \leq n1$ (i=2,3,...12) indicate that the corresponding type of printing will be made at every n_i time-steps. If some of the data $= n_i$ are left blank the corresponding type of printing will not be made.		
		List of printing orders		
		The number in the column "DATA No" indicates the position of n_i in the first printing order.		
9901	n1	The first printing order will be performed up to the $n1^{th}$ time step.		First card
9902	n2	Flux core average, reciprocal period and total power		
9903	n3	Flux map		
9904	n4	Map of rod insertions		
9905	n5			
9906	n6	Map of the concentration of the delayed neutron precursors		

DATA Number	Variable Name	Description	Allowable or suggested values	Notes
9907	n7	Maximal fuel temperature, max. cladding temperature, max. heat flux, inlet and outlet temperature, mass flow.		
9908	n8	Map of temperatures		
9909	n9	Percent of core (in volume) below a given integrated energy threshold		
9910	n10	Map of integrated energies		
9911		nothing		
9912				

Second card

The calculation stops at the time-step indicated by the first datum = n1 of the last printing order.

Restart an interrupted calculation

Two dimensional calculations require long computer time. It may be interesting to have the possibility of restarting an interrupted calculation, without repeating it from the beginning. In particular it may be interesting to have the possibility to initiate again a calculation from the equilibrium condition, without repeating the criticality search. For this purpose it is necessary to store on tape the results already obtained.
It is possible after a restart to change the printing orders. The first card of the new printing orders must contain in the first twelve columns the number IT of the time step at which the calculation was interrupted; this card is blank in all other columns. A second blank card must follow, then groups of two cards must follow containing the new printing orders.
It is also possible to change the tabulations given in input for the rod movements, inlet temperatures, and mass flow.
Of course only changements after the instant t of restart have a meaning.
The new tabulations must contain a first point at time zero, with any value of the variable, the second point will be at the instant t and the value of the variable (insertion of rod, inlet temperature, mass flow) must be that indicated in the output of the results which were stored on tape. From t on any new point may be introduced in the tabulation.

At any subsequent restart after having changed the original tabulation, it is necessary to use the cards of the new tabulation, otherwise the programme will calculate according to the original one which remains stored on tape.

It is also possible in a restarted calculation to introduce a new value of the time step DATA (2). In this case a new printing order must be given, as described in the preceding page. The original vector DATA is stored on tape, only the new changed values must be given by cards.
The orders of restart are given in the first three columns of the title card:

Title Card:

Blank = Input data read from card, no storing of results on tape

001 = Input data read from cards, three files are stored on tape

file 1	input data
file 2	results of criticality search
file 3	results of instant t.

002 = Only if more than one problem is treated. Input data corresponding to the first problem are read from tape, file 1. Only those input data of the new problem which differ from those of the first problem are read from cards. At every new restart of the problem the cards corresponding to changement of the input data must be introduced, because on tape will always remain stored the input of the first problem.

003 = Restart from equilibrium conditions after criticality search, and store results at the end of calculation at time t.

004
005 = restart from results stored on file
006 (n-1) and store results on file n.
00n

-03
-04
-05
-On

Restart from the results stored in any file without destroying the subsequent files. This in case of temptative changements of rods, inlet temperature, mass flow tabulation and time step in any part of the transient.

First data card:

In addition to the title card the first data card, containing DATA (1) to (6) must always be present.
In DATA (1) = TEMAC is indicated the computer time (minutes). At every thermal calculation the programme will compare the remaining computer time with the computer time necessary to make a thermal time step. If it will not be possible to make the next thermal claculation, then the results will be stored on tape.

If no thermal calculations are made then the programme makes this check at every 100 steps.

10. Comparison between zero, one and two-dimensional calculations in the analysis of the power following requirements of the THTR reactor

A comparison between zero and one dimensional calculations of Xenon transients performed on the THTR 300 MWe reactor has shown discrepancies of the order of 20% in the excess reactivity required for Xenon override /3/. This result showed the necessity of a more accurate two dimensional calculation.

Before starting the comparison it was important to assess whether the limitations to 2 energy groups and 350 mesh points of COSTANZA did not have too much influence on the representation of flux and power distribution.
Comparison calculations where then performed with the CRAM /4/ diffusion code which was used as a standard tool for the two dimensional static THTR calculations.
The core is described in 20 regions taking into account the radial and axial variations of composition due to the loading scheme which was chosen and to the axial dependence of burn-up, typical of pebble bed reactors. The reflector was represented by 6 regions of different density and composition. The boundary between fast and thermal group was set at 1.9 eV.
The Xe override is performed with the movement of reflector control rods which are simulated with a poisoned region (gray curtain) of the reflector. The mesh net chosen includes 18 radial and 19 axial points. This is a rather coarse mesh, but a test calculation performed with CRAM with double number of points in both directions did not show any appreciable discrepancy.
In order to check the inaccuracy introduced in the power distribution by the limitation of COSTANZA to two energy groups the CRAM test was repeated in 2 and 6 groups, the last being the standard energy partition used for THTR calculations. The maximum discrepancy between the standard THTR calculation and the COSTANZA calculation is of the order of 5% in the relative power distribution, including the effects of group structure, mesh point number and some geometrical simplification.

Having performed this check the Xe override was analyzed for the THTR reactor in case of a power reduction from 750 MW_{th} to 300 MW_{th}, and a return to full power after having reached equilibrium condition at partial power.
The reactivity as function of time during this transient is given in Fig. 7 where it is compared with the results of zero and one dimensional calculations. One must notice here that the code COSTANZA does not give a reactivity, but the poison concentration needed in the control rod region to keep the reactor critical. This concentration was converted into reactivity with a separate calculation in order to be able to compare the results with those of a zero dimensional code. It results that in this case the curves of reactivity versus time have a similar form so that their relation can be nearly specified by a constant factor

$$\frac{\Delta k_{1\text{-dim.}}}{\Delta k_{0\text{-dim.}}} = 0.85$$

and

$$\frac{\Delta k_{2\text{-dim.}}}{\Delta k_{0\text{-dim.}}} = 0.96$$

The two dimensional calculation gives results nearer to the zero-dimensional than the one-dimensional calculation. This is largely due to the peculiarity of the THTR reactor where the increase in Xe concentration is relatively high in the outer region during the transient, the importance in the outer region is however relatively low.
This fact, which is already fully treated in the one dimensional calculations produces the strong reduction in Δk between the zero and the one-dimensional results. The consideration of the axial dependence produces an increase in Δk, as it is always the case when the relation between the power density and the thermal flux is nearly constant along the axis. Then the increase in Xe concentration takes mainly place in the region of high flux.

In the particular case of the THTR the effect of the reflector control rods compensates the increase due to the consideration of spatial effects. In reactors with constant macroscopic fission cross section an increase in Δk due to the treatment of spatial effects would always have to be expected.
The thermal flux and Xe distributions are shown in Fig. 8, 9 and 10 in the radial direction at 3 different times: 100% power before the transient, 40% power 5 h after the power reduction, 100% power 3 h after return to full power.

The two dimensional COSTANZA calculations allowed also the evaluation of the effect of the instationary Xe distribution on the maximum fuel temperatures. Comparing the results with previous calculations based on equilibrium Xe distribution one can see some slight temperature increase. The worst case is given by return to full power in the moment of maximum Xe concentration, 5 h after the power reduction, but even in this pessimistic case the increase in the maximum fuel temperatures is smaller than $10^{o}C$.
The above mentioned THTR results refer to the equilibrium core which is reached after a few years of operation. Similar calculations have been repeated for the first reactor loading: in this case because of the greater inhomogenety of the flux distribution the space dependent treatment of the Xe concentration is even more important especially in the axial direction.

11. Nomenclature

C	Delayed neutron precursor concentration or general physical quantity
D	Diffusion coefficient
I	Iodine concentration
$\dot{m}$	Mass flow
N	Control poison concentration or number of mesh points
p	Resonance escape probability
T	Temperature
t	time
v	Neutron velocity
Xe	Xe-135 concentration
β	Delayed neutron fraction
γ	Fission yield
$\delta\varrho$	Reactivity
λ	Decay constant
ν	Neutrons per fission
Σ	Macroscopic cross section
σ	Microscopic cross section
Φ	Neutron flux
φ	Thermal } neutron flux, when related to
ψ	Fast } a certain mesh point

Indexes

1	Fast neutron group
2	Thermal neutron group
c	Control poison
f	Fission
i	Delayed neutron precursor or mesh point
rem	Removal (=absorption + slowing down)

12. Literature

(1) K. Friedrich, L. Massimo, E. Vincenti
COSTANZA BBK: a one dimensional dynamic code
EUR 4410e, THTR 93, 1970

(2) E. Vincenti, A. Clusaz
COSTANZA (R,Z) EUR 4673e, 1971

(3) K. Friedrich, L. Massimo, E. Vincenti
Fast and slow transients in high temperature reactors
ATKE 15-6 (35-38) 1970

(4) A. Hassit
A computer programme to solve the multi-group diffusion equation
TRG-229

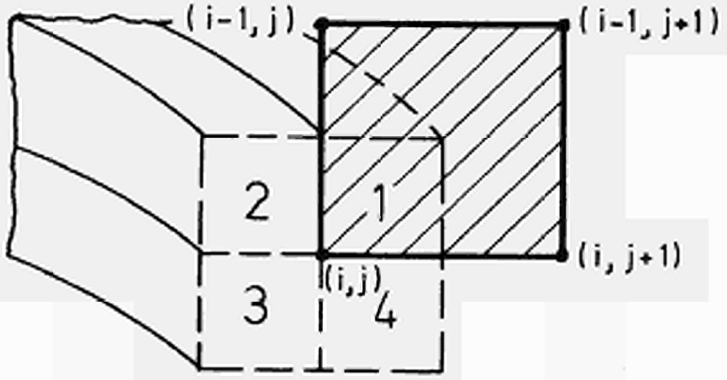
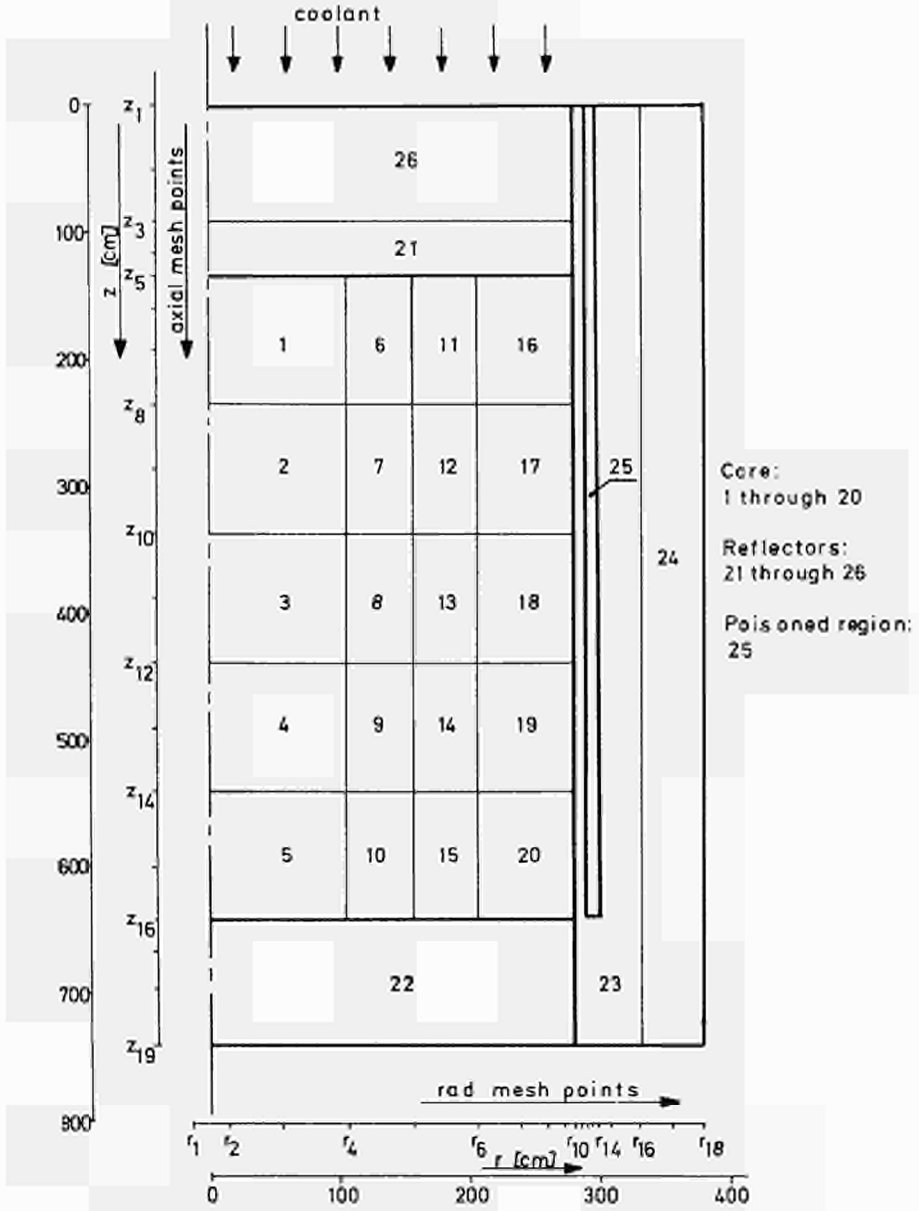
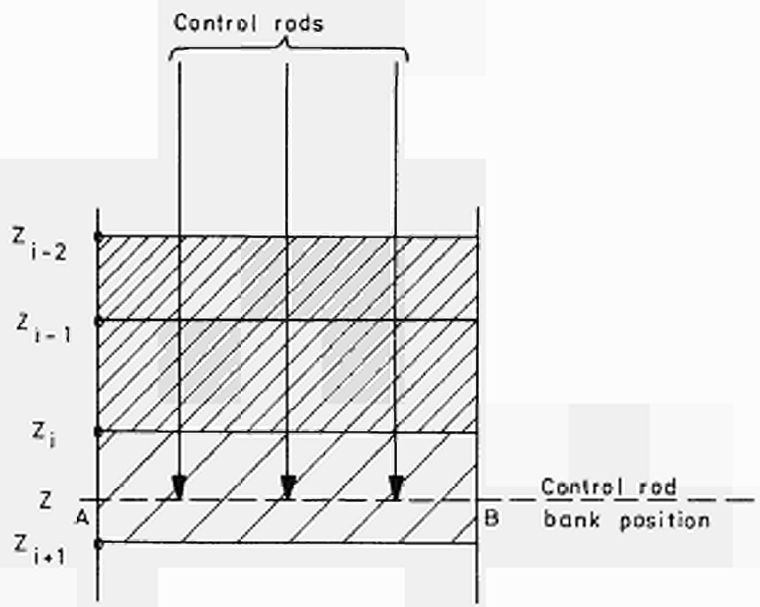


FIG. 1 MESH POINT TREATMENT



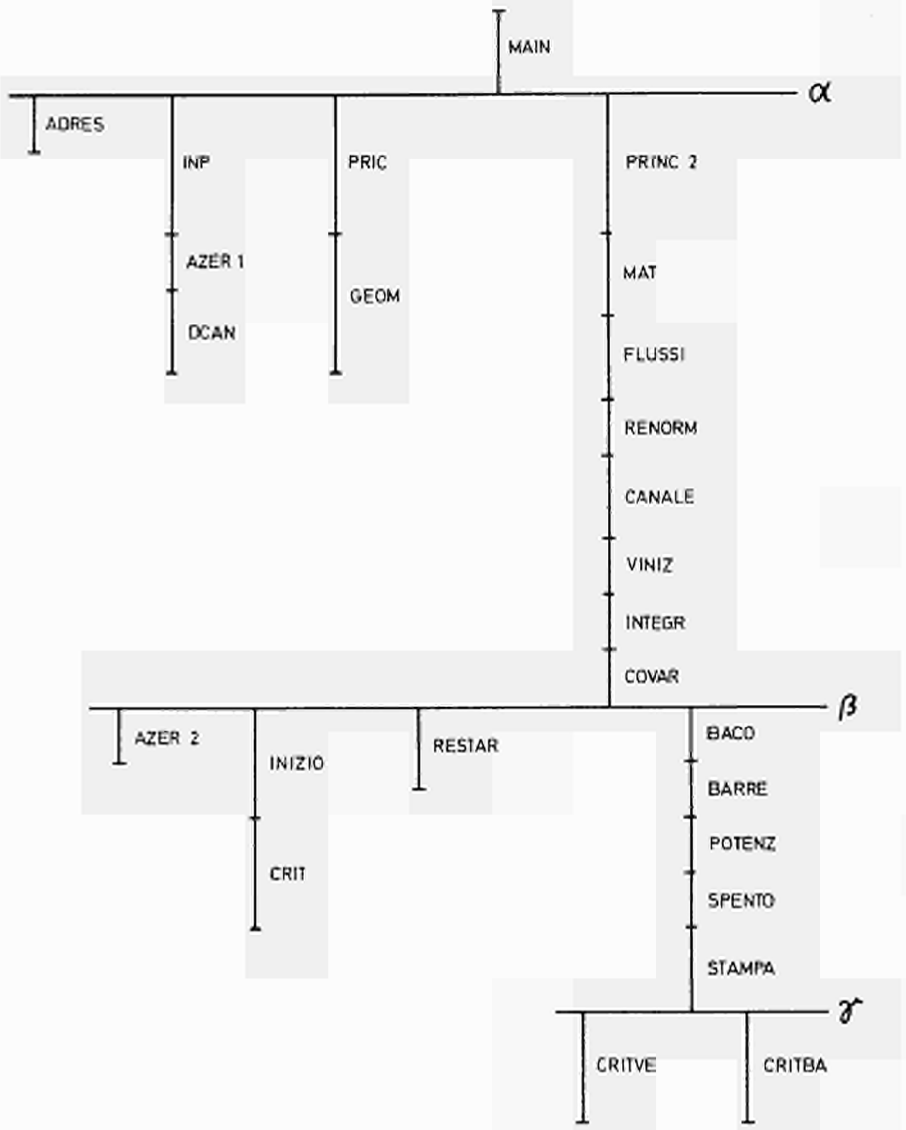
THTR - 300 MWe

FIG. 2 SUBDIVISION OF CORE AND REFLECTORS



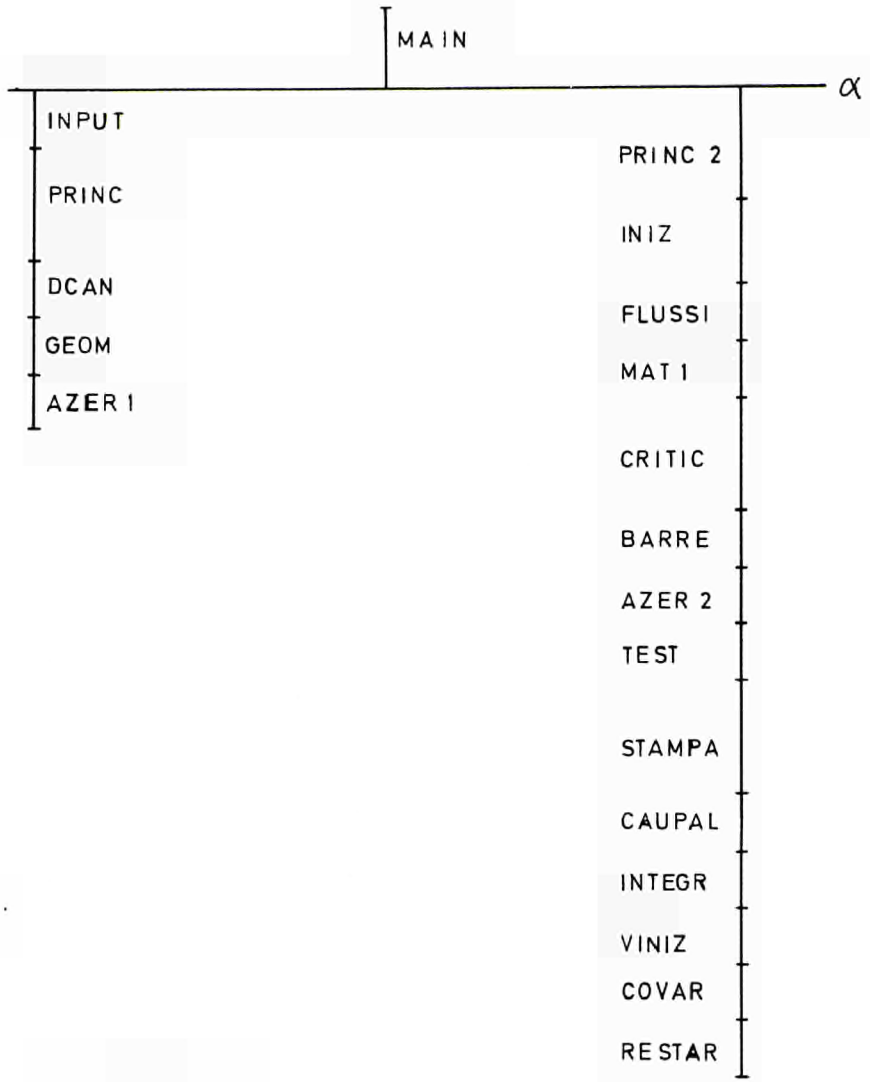
THTR-300MWe

FIG. 3 ROD MOVEMENT SIMULATION WITHIN A CONTROL ZONE



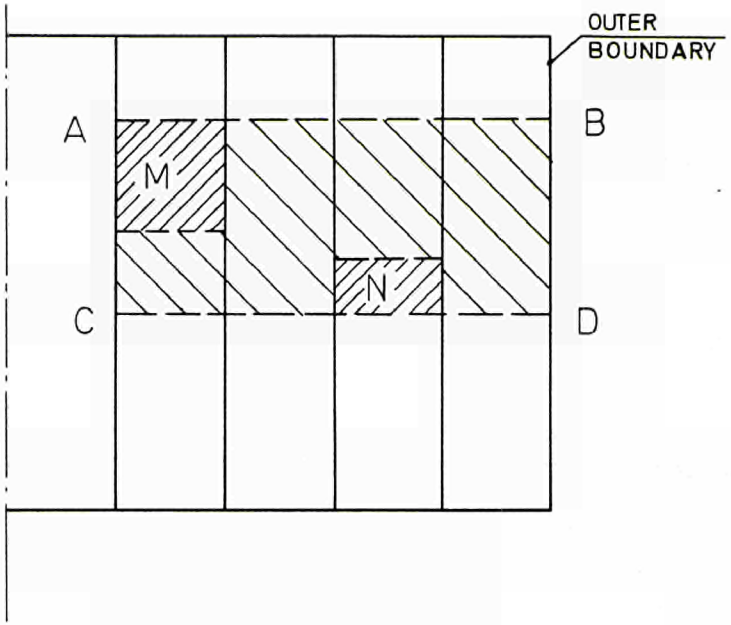
THTR - 300 MWe

FIG. 4 OVERLAY STRUCTURE OF THE CONSTANZA (RZ) CODE FOR SLOW TRANSIENT ANALYSIS



THTR - 300 MWe

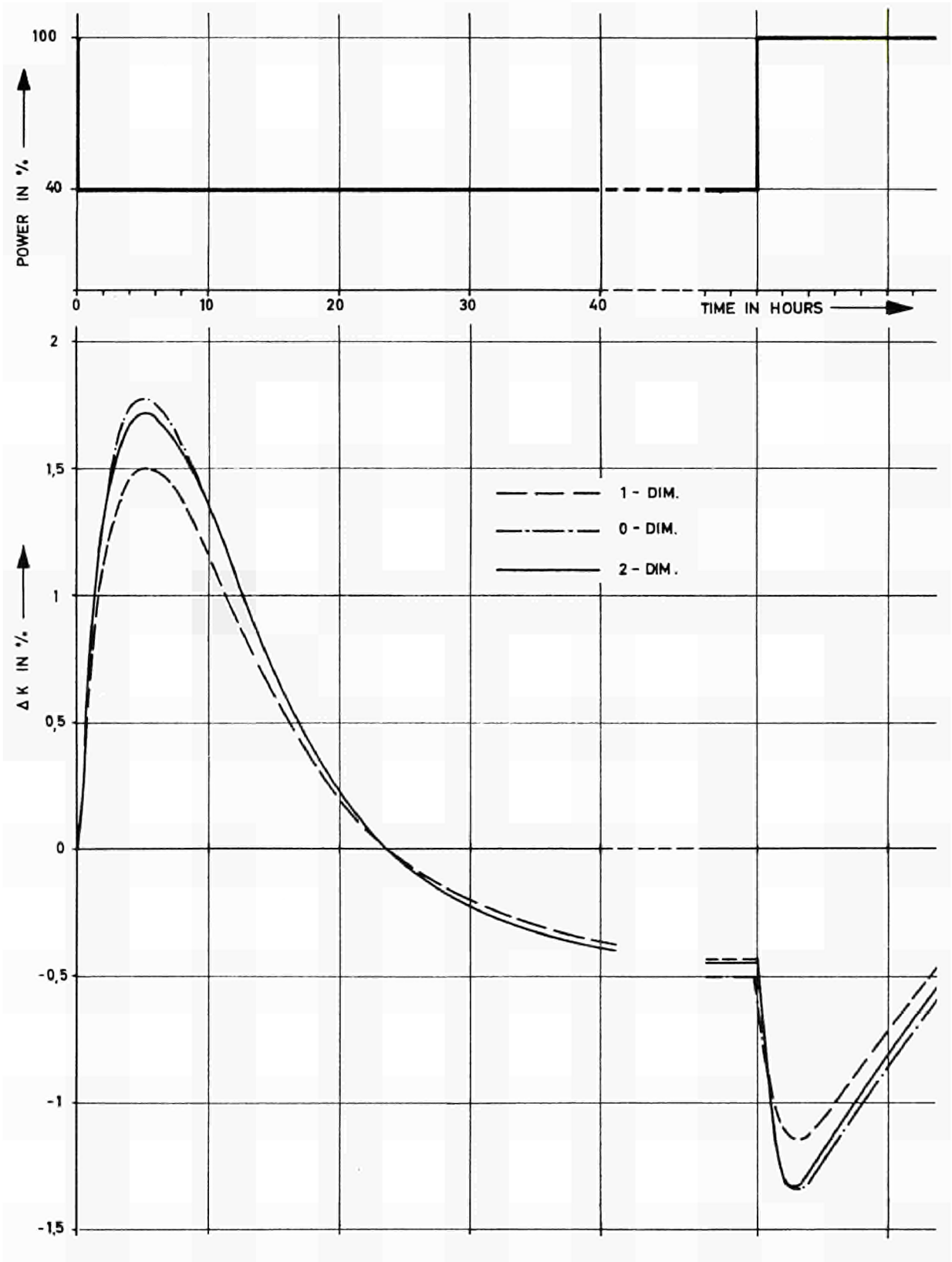
FIG. 5 OVERLAY STRUCTURE OF THE COSTANZA (RZ) CODE FOR FAST TRANSIENT ANALYSIS



ROD MOVEMENT IS RESTRICTED TO THE AREAS M AND N

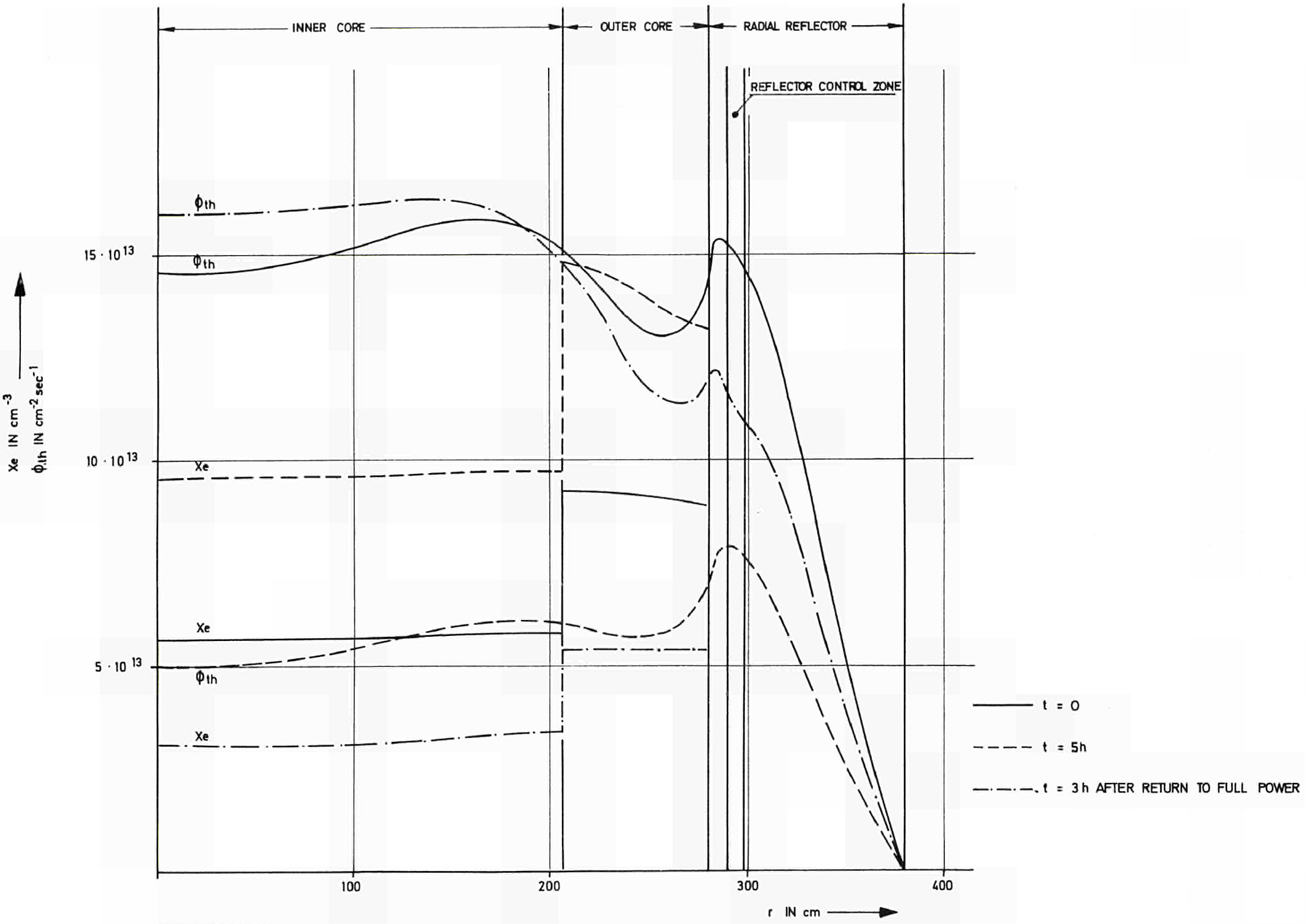
THTR-300 MWe

FIG. 6 READJUSTMENT OF THE COEFFICIENTS OF THE DIFFUSION EQUATION TO A NEW CONTROL ROD CONFIGURATION



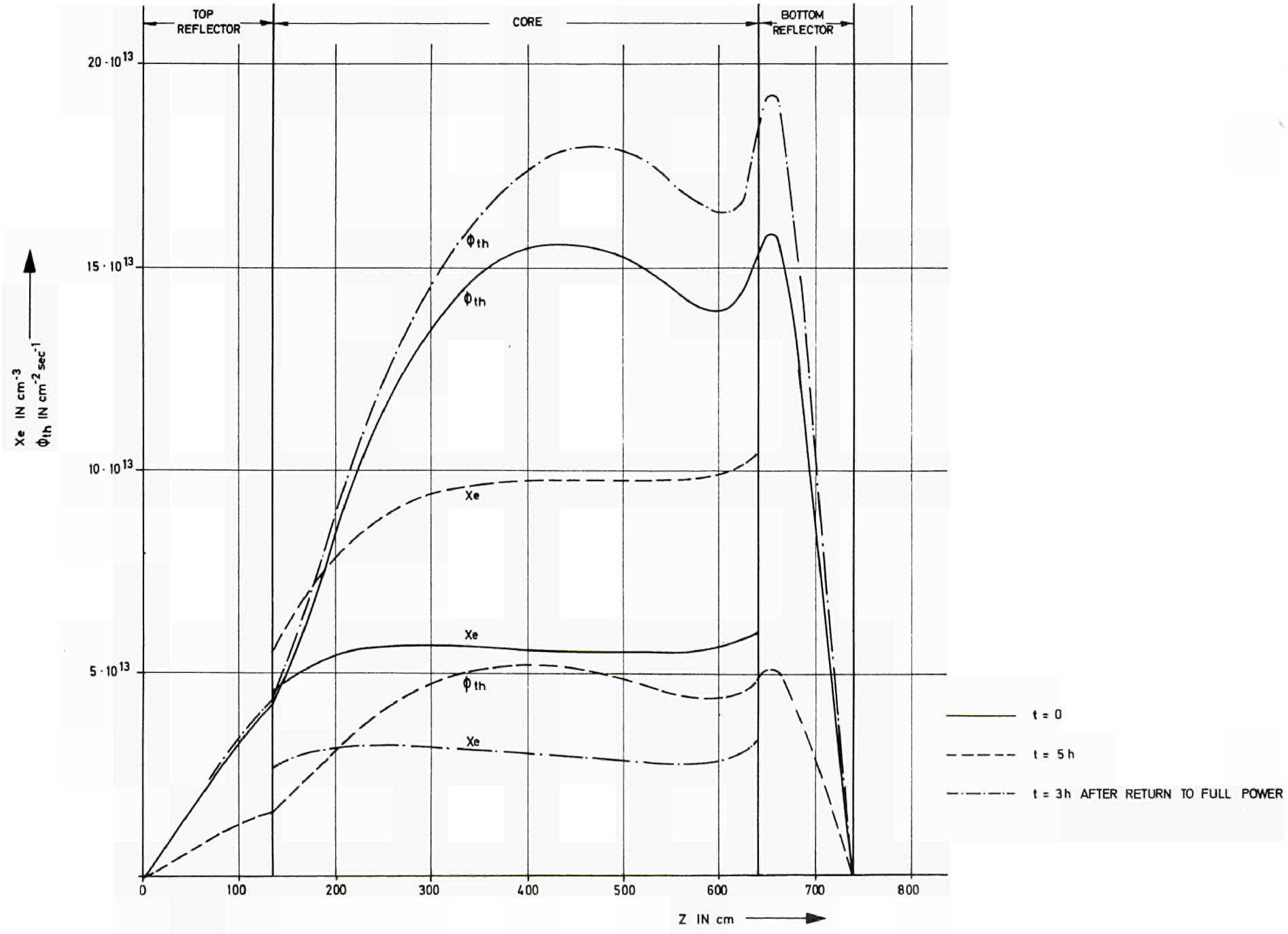
THTR - 300MWe

FIG. 7 COMPARISION OF REACTIVITY AS A FUNCTION OF TIME FOR A GIVEN POWER PROGRAMME



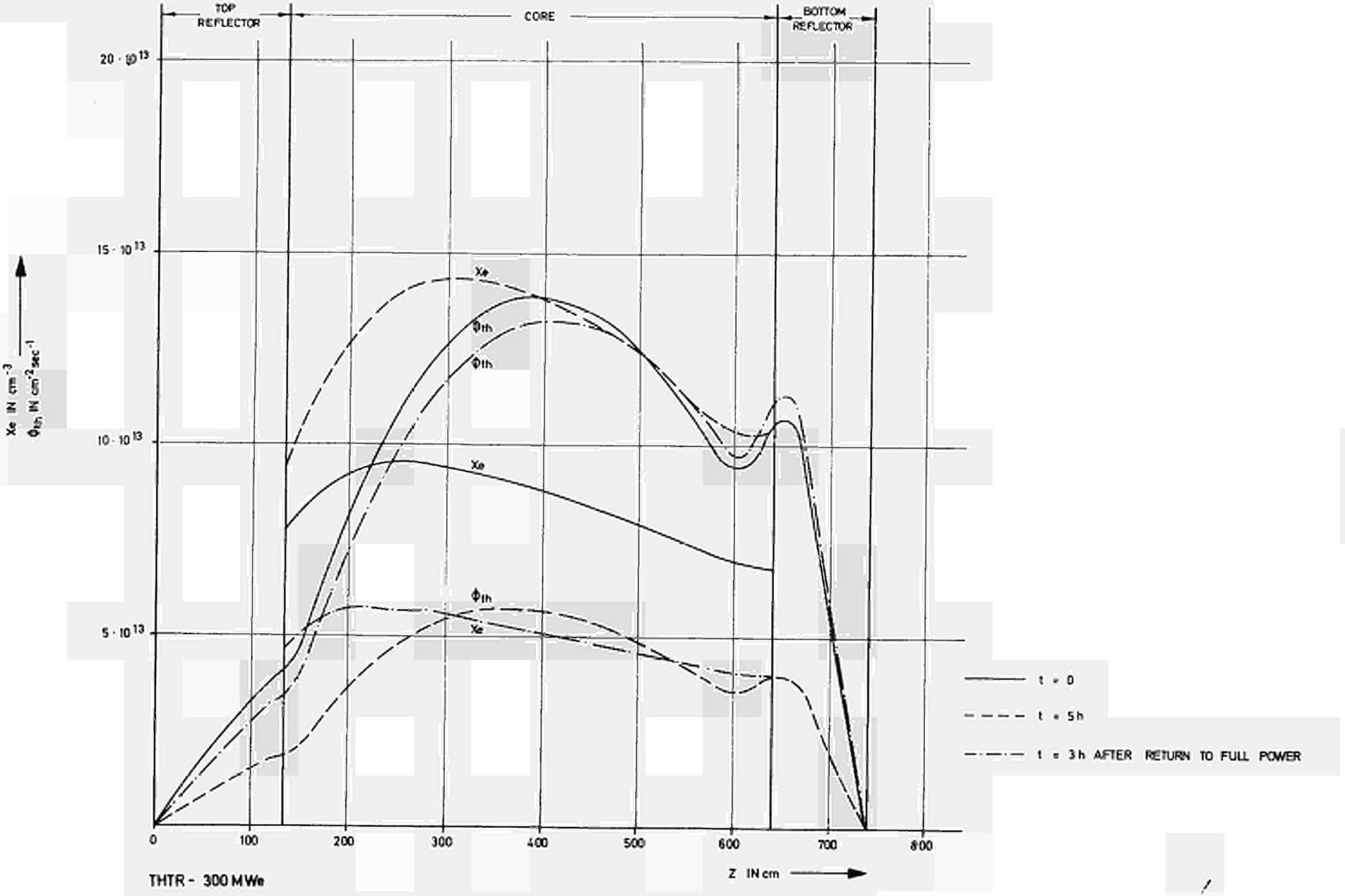
THTR - 300MWe

FIG. 8 THERMAL FLUX ϕ_{th} AND Xe NEAR THE CORE MID-PLANE IN THE RADIAL DIRECTION



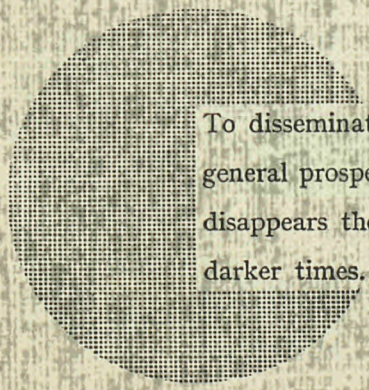
THTR - 300 MWe

FIG. 9 THERMAL FLUX Φ_{th} AND Xe ALONG THE CORE AXIS



THTR - 300 MWe

FIG. 10 THERMAL FLUX Φ_{1h} AND Xe AXIAL DISTRIBUTION IN THE OUTER CORE ZONE



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

Alfred Nobel

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