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Institut für Reaktorentwicklung
Projekt Schneller Brüter

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A Code for Thermal Design Reliability Analysis of a Reactor Core

A. Amendola

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Abstract

This report describes the Fortran-IV computer code THEDRA for thermal design reliability analysis of a reactor core. THEDRA allows the designer to get a complete reliability assessment of the core design against overtemperatures, since it evaluates:

- the expected number of hot spots in a core
- the expected number of pins in which hot spots occur
- the expected number of subassemblies containing hot pins

and the probability of no hot spot occurring in a core.

By means of this analysis it is possible to evaluate the pin failure expectation, if the distribution of pin failures vs operating temperature is known.

Zusammenfassung

Dieser Bericht beschreibt das Rechenprogramm THEDRA für die Zuverlässigkeitsanalyse der thermischen Auslegung eines Reaktorkerns.
Durch THEDRA ist es möglich, eine komplette Zuverlässigkeitsermittlung der thermischen Auslegung gegenüber Übertemperaturen zu bekommen, denn das Programm berechnet:

- die zu erwartende Anzahl von Heißstellen in einem Core
- die zu erwartende Anzahl von Brennstäben, welche von Heißstellen betroffen werden
- die zu erwartende Anzahl von Brennelementen, welche von "Heißstäben" betroffen werden

und die Wahrscheinlichkeit, daß keine Heißstelle in einem Core auftritt.

Nach dieser Analyse ist es möglich die Schadenserwartung zu berechnen, für den Fall, daß die Korrelation zwischen dem Versagen eines Brennstabes und dessen Temperatur bekannt ist.

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Introduction

The SHØSPA code [1] evaluated the probability of no clad (fuel) spot - with a preassigned geometrical size - exceeding a certain critical temperature. Moreover it offered the designer the possibility to obtain an approximate evaluation of the probability that a certain number of subassemblies are affected by hot spots.

At the Fast Reactor Fuel Conference in Karlsruhe, a new method [2] was presented for the calculation of the probability that the number of hot channels in a core is smaller than a preassigned one. This method was based on the same assumptions about the effects of local and global uncertainties as those performed by the author in Ref. [1, 3]. But a more complicated procedure was used in the computer code, which needs a Monte Carlo Routine. The hot spot probability was not yet included in the code.

Moreover, as already stated in Ref. [4], knowledge of the expected number of hot spots does not give a complete reliability assessment: it is necessary, in fact, to know how the hot spots are distributed among the different pins and subassemblies.

The THEDRA code answers this problem. It evaluates:

a) the expected number of hot spots in a core
b) the expected number of channels (or pins) in which hot spots occur
c) the expected number of subassemblies in which hot channels occur
d) the probability of no hot spot occurring in a core.

The quantities a) and b) are evaluated without approximation for a normal distribution of the uncertainties.

An approximation (better than that in Ref. 1) was used for calculation of the quantities c) and d).

THEDRA offers the designer the possibility to get a complete reliability assessment of overtemperature occurrences.

It is possible to design the core for a preassigned or accepted risk. If the correlation between operating temperature and clad (fuel) failure is known, the thermal design could be optimized for a minimum global cost, including the expected failures. However, THEDRA as SHØSPA can be used to obtain a global hot spot factor at a preassigned confidence level, (probability that no hot spot in a core is hot).

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Another advantage of THEDRA compared with SH0SPA is that the nominal temperature distribution is read from a data set (NTDS = nominal temperature data set) which contains the temperature fields of coolant, clad and fuel in a subassembly. Therefore no approximation is now required in order to take into account the nominal temperature and power distribution.

Moreover, if desired, THEDRA provides the factors by which the coolant flowrates in each subassembly should be multiplied in order to obtain a maximum in the outlet coolant temperature /¯5_7. The code is designed in such a way as to be easily integrable in a program system for core thermal design, according to the scheme in Fig. 1.

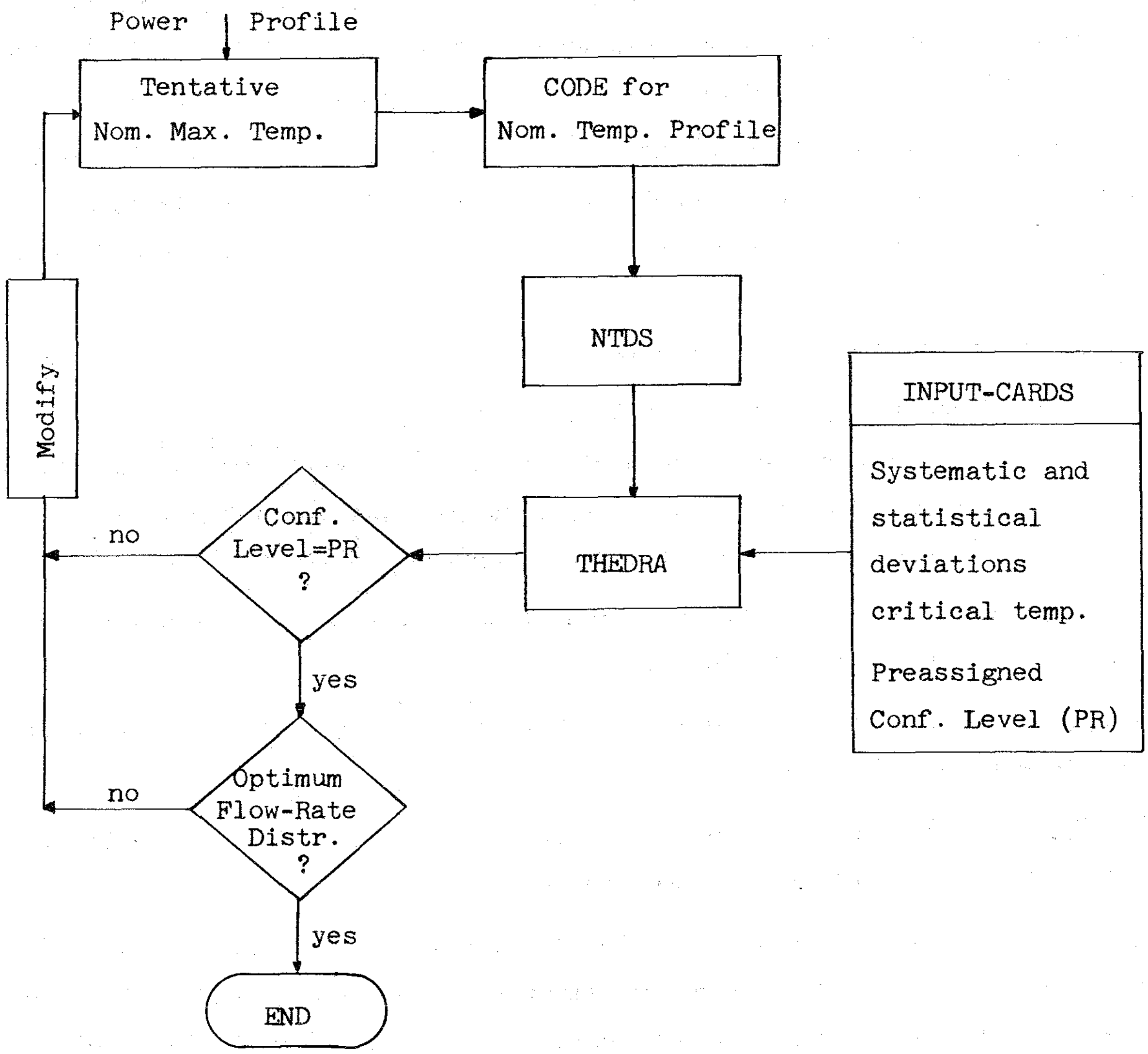

Fig. 1 Scheme for a thermal design program system

I. Theoretical Analysis

I.1 Premise

The theoretical bases were already given in the reports [1] and [3]. These reports are assumed as a necessary background for understanding the following analysis and code description. Only some new items will be discussed extensively in this paper.

I.2 Expected number of failed pins

To simplify the problem, let us assume that the principal failure cause is the creep process in the clad material, provoked by overtemperatures during the operation time of a pin. Moreover, we assume that pins operating at a temperature $\vartheta < \vartheta_{crit}$ cannot fail whereas pins operating at $\vartheta \geq \vartheta_{crit}$ fail with certainty. (This restriction will be removed at item V.2). Let us consider a flat power reactor core constituted of N_s subassemblies, each one containing N_p pins.

Let $p(\vartheta)\,d\vartheta$ be the probability that the maximum clad temperature falls within ϑ and $\vartheta + d\vartheta$.

If the uncertainties act on the individual pins in an independent way we expect on the average that the number of failed pins is

$$n_p = N_p N_s \int_{\vartheta_{crit}}^{+\infty} p(\vartheta)\,d\vartheta = N_p N_s \, P(\vartheta_{crit}) \qquad (1)$$

where $P(\vartheta_{crit})$ = probability that $\vartheta \geq \vartheta_{crit}$.

We now want to demonstrate that the same expression (1) holds true, even if the temperature uncertainties do not act on the individual pins in an independent way.

Let us assume for simplicity that the clad temperature is given by $\vartheta = x+y$, where, for instance, x is the coolant temperature and y the clad-coolant temperature drop.

Let f(x) and g(y) be the frequency distributions of x and y, respectively. If both f(x) and g(y) act on the pins within a subassembly in an independent way, we get: [3]

$$P(\vartheta_{crit}) = \int_{-\infty}^{+\infty} f(x) \int_{\vartheta_{crit}-x}^{+\infty} g(y)\,dy\,dx \qquad (2)$$

and the probability $P_o(\vartheta_{crit})$ that none of the N_pN_s pins in a core exceeds ϑ_{crit} is given by:

$$P_o(\vartheta_{crit}) = \left[1 - P(\vartheta_{crit})\right]^{N_pN_s} \tag{3}$$

If f(x) acts on all pins in a subassembly in the same way we get from Ref. [3]:

$$P'_o(\vartheta_{crit}) = \left[\int_{-\infty}^{+\infty} f(x)\left(1 - \int_{\vartheta_{crit}-x}^{+\infty} g(y)dy\right)^{N_p} dx\right]^{N_s} \tag{4}$$

and, by Eqs. (3) and (4), we get

$$P_o(\vartheta_{crit}) \neq P'_o(\vartheta_{crit}).$$

But the expected number of failed pins is the same in both cases. In fact,

$$n'_p = \int_{-\infty}^{+\infty} N_s\, f(x) \quad N_p \int_{\vartheta_{crit}-x}^{+\infty} g(y)dydx = N_sN_p\, P(\vartheta_{crit}) = n_p. \tag{5}$$

Eq. (5) was derived considering that we expect to find an average of $N_sf(x)dx$ subassemblies at a coolant temperature within x and $x+dx$ and at the same time $N_p\int_{\vartheta_{crit}-x}^{+\infty} g(y)dy$ pins with a temperature drop exceeding $\vartheta_{crit} - x$, so that: $\vartheta = x+y \geq \vartheta_{crit}$.

This result definitively explains the behaviour, investigated in papers [1, 4], of the probability distribution that a certain number of elements will fail. Furthermore it definitively explains the different influences of local and global uncertainties.

Consider for instance a core constituted of 100 equal pins and a normally distributed uncertainty with standard deviation σ in the clad temperature.

If we assume a distance of $2.4\ \sigma$ from the critical temperature, there is a probability of 1 °/o that ϑ_{crit} is exceeded in a pin.

If the uncertainty σ acts on the individual pins in an independent way, we expect to find 1 failed pin in every core, and therefore 100 failed pins in a population of 100 cores. Whereas, if the uncertainty σ acts on all pins in the same way, we expect to find 99 cores without failures and only one core with all 100 pins failed.

The number of failures is expected to be the same in both cases, but the failures are distributed in a very different way within the reactor core population.

It is possible now to predict in a simple manner the expected number of hot spots in a core, the number of pins affected by hot spots etc., since it is not necessary to take into account all the correlations, as will be shown in the following.

I.3 Calculation procedure in THEDRA

I.3.1 Hot spot expectation

In order to calculate the expected number of hot spots, it is not necessary now to take into account the correlation of the uncertainties according to their global or local action.

Therefore, if we calculate the total standard deviation $\sigma(r,z)$ as for uncorrelated uncertainties for a spot at coordinates r and z (radius and height) in a core, we obtain

$$n_{hs} = \sum_{i,j} n(r_i,z_j) \; P\left(\frac{\vartheta_{crit} - \bar{\vartheta}(r_i,z_j)}{\sigma(r_i,z_j)}\right) \Delta r \; \Delta z \qquad (6)$$

where n_{hs} = expected number of hot spots in the core

$n(r_i,z_j)\,\Delta r\;\Delta z$ = number of spots at coordinates r_i,z_j

$P\left(\frac{\vartheta_{crit}-\bar{\vartheta}(r,z)}{\sigma(r,z)}\right)$ = probability that a spot at nominal temperature $\bar{\vartheta}$ and standard deviation σ exceeds ϑ_{crit}.

In THEDRA n_{hs} is calculated as follows:

The core is subdivided into a number of subzones, each one containing identical subassemblies, i. e., subassemblies for which nominal temperatures, statistical and systematic deviations, critical temperatures and geometry are identical. Then the length of a channel is subdivided into an arbitrary number of segments according to the definition of the spot lenght (see Ref. /‾1_7). For each spot, $P\left[(\vartheta_{crit} - \bar{\vartheta})/\sigma\right]$ is evaluated. First, the sum in Eq. (6) is performed over the length of the channel. Then the same procedure is applied to all channels in a subassembly and the sum is extended over all channels of the subassembly. By extending the sum over all the subassemblies in the core, n_{hs} is evaluated. Intermediate quantities are printed by the program in order to identify the most critical channels and subassemblies. As seen above, no approximation is performed in the calculation of n_{hs}, neglecting the approximation introduced by the assumption of a normal distribution for the total uncertainty σ.

I.3.2 Hot channel expectation

To calculate the number of channels containing at least one hot spot the following procedure has been adopted: all global uncertainties, which act in the same way on all spots of a channel, are added statistically. (I. e. core, zone, subassembly and channel uncertainties [1]).
This standard deviation is indicated as G(i) in the program (H0TSPT). The local uncertainty on the clad (fuel) - coolant temperature drop is indicated as SX(i). The probability that at least one spot in a channel is hot is given by (see Eq. 4):

$$\mathrm{EXPCH} = \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \left(1 - \prod_i \left[1 - P\left(\frac{\vartheta_{crit} - x\, G(i) - \bar{\vartheta}_i}{SX(i)} \right) \right]^{Nap} \right) dx \qquad (7)$$

Where Nap is the number of spots at a given axial abscissa i , i. e., the number of pins surrounding the channel considered.
As for the hot spot expectation, EXPCH is summed over all channels in a subassembly and then over all subassemblies.
Therefore, the expected number of hot channels (i. e. channels with at least one hot spot) in the core is evaluated without approximation.

I.3.3 Hot subassembly expectation

In order to calculate the expected number of failed subassemblies (i. e., subassemblies containing at least one hot channel), it was necessary to introduce some approximation in the calculations. This approximation is of the same kind as in the SH0SPA code. An equivalent number of hot spots is evaluated as in Ref. 1 [item II.4.4], but now in such a way that the equivalent channel distribution (m_{ch}^{eq}, σ_{ch}^{eq}) gives the same EXPCH as the correct value in Eq. (7).
Then, the same procedure as under item I.3.2 is applied, starting from a global uncertainty (including core, zone and subassembly uncertainties) and the equivalent channel distribution calculated as above.
Then an equivalent number of channels and the equivalent subassembly distribution (m_s^{eq} , σ_s^{eq}) are evaluated as for the spots [see above and Ref. 1 (item II.5)].

I.3.4 Hot core expectation

With a procedure similar to that adopted in SH0SPA [1], an equivalent zone distribution is evaluated, and at least an equation similar to Eq. 7, evaluates the probability that at least one hot spot occurs in a core.

I.3.5 Hot pins expectation in a subassembly

Let us use the notation assumed in the main program.

ENHSCL(i) = ecpected number of hot spots in the channel i
ENCHCL(i) = probability of the channel i beeing hot
EXPSCL = probability of the subassembly considered being hot
NPIN(i) = number of pins surrounding the channel i
P1STAB(j) = probability that the pin j is hot if the subassembly contains at least one hot spot

$\frac{ENCHCL(i)}{EXPSCL}$ is the number of times that the channel i is hot, if the subassembly is affected by hot channels.

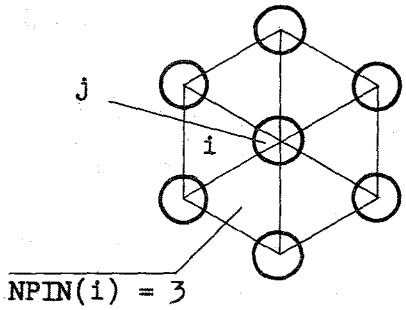

Fig. 2

Analogously,

$B_i = \frac{ENHSCL(i)}{NPIN(i) \quad ENCHCL(i)}$ is the number of times that the fraction (1/6 in Fig. 2) of the pin j contains hot spots if ENCHCL(i) has at least one hot spot.

Naturally, if $B_i > 1$, this means that more than one hot spot occurs in the same pin fraction. For our purposes it is not important whether 1 or more hot spots occur. Therefore, if $B_i > 1$ the program sets $B_i = 1$. This means that we have the certainty that the pin fraction j has hot spots, if the channel is hot.

Then $P1STAB(j) = \sum_j B_i \times \frac{ENCHCL(i)}{EXPSCL}$. Also in this case, if P1STAB(j) is larger than 1, the program sets P1STAB = 1.

The average number of hot spots per pin is obtained as the ratio of the total number of hot spots to the total number of hot pins in a subassembly.

I.4 Correlation between coolant flow-rate and clad-coolant heat transfer

This correlation was not considered in SHØSPA, but it is very important for a gas cooled reactor. Therefore, every time a deviation in the coolant flow-rate due to statistical or systematic causes is found in the calculations in THEDRA, the program multiplies the clad-coolant temperature drop by a factor F_{hcl} defined as follows:

$$F_{hcl} = A^{B} - B \times C \, (A-1) \, A^{B} \qquad (8)$$

Where B and C must be assigned as inputs to the program (EXP, CONST in block 5, see input card description).

A is the ratio nominal to the deviated flow-rate.

Eq. (8) was obtained as follows:

$$F_{hcl} = \frac{K1 + K2 \, \bar{m}^{B}}{K1 + K2 \, m_1^{B}} = \frac{K1 + K2 \, \bar{m}^{B}}{K1 + K2 \, \bar{m}^{B}/A^{B}} = A^{B} \, \frac{K1 + K2 \, \bar{m}^{B}}{K1 \, A^{B} + K2 \, \bar{m}^{B}} \, , \qquad (9)$$

Where $K1 = 0$ for gas coolant, and $\bar{m}$, m are the nominal and the deviated mass flow-rate, respectively.

Since A is not very different from 1, we get:

$$A^{B} \simeq 1 + B(A-1) \qquad (10)$$

and by Eqs (9) and (10) we get:

$$F_{hcl} = A^{B} \, \frac{K1 + K2 \, \bar{m}^{B}}{K1 + K2 \, \bar{m}^{B} + K1 \, B(A-1)} \approx A^{B} - B \, C \, (A-1) \, A^{B}$$

Where $C = K1/(K1+K2 \, \bar{m}^{B})$ can be calculated as an average value in the core for a sodium cooled reactor, and is equal 0 for gas.

II. THEDRA Program description

II.1 General requirements and specifications

THEDRA is a Fortran-IV code based upon the analytical method presented. It receives the nominal temperature distribution from a data set (NTDS) generated by THESYS /‾6_7, a code for subchannel thermal analysis. It can be quite well integrated in a program system for core thermal design as indicated in Fig. 1.

It is applicable to any reactor core constituted of hexagonal bundled fuel rods with single phase coolant.

The code takes into account both systematic and statistical deviations from nominal.

In order to apply the code, a reactor core must be divided into a number (NZ) of zones constituted of subassemblies for which the nominal temperatures are identical.

NZ cannot be larger than 30. But each zone can be subdivided into 5 subzones, in order to take into account different uncertainties or a burn-up configuration different from that for which the nominal temperatures were calculated. In this way, a total of 150 subzones constituted of identical subassemblies can be taken into account.

Other limitations of the code are in the nominal temperature axial distribution, in the number of channels per subassembly and in the number of spots considered: in the NTDS data set the number of axial points for which the temperatures are given cannot be larger than 30, and the number of subchannels per subassembly cannot be larger than 546; the length of a spot in the input cards cannot be assumed so small that the number of axial spots is larger than 300.

(These limitations were introduced in order not to exceed a 300 K memory capacity. They can easily be removed by acting on the DIMENSION statements).

Hot spot size is assumed to be the surface defined on the fuel or on the clad by a 60 ° arc (triangular channel arrangement) over a certain length (to be assigned in the input cards). Therefore, the "specific standard deviation" /‾1_7 for the local uncertainties must be calculated according to this definition.

It is possible (see input card description) to choose for the fuel either the inner or the outer surface, and for the clad the inner, mid or outer surface as a basis of the hot spot analysis.

In every subzone the following quantities can vary: (see input card description)

- clad (fuel) critical temperature and its standard deviation
- systematic factors
- statistical uncertainties.

The statistical uncertainties must be assigned as standard deviations and as relative (to nominal) value of their effects on the temperature drop considered.
(For instance, it is necessary to calculate the relative standard deviation in the nominal coolant temperature rise, provoked by an uncertainty in the pin pitch: such calculations were not included in THEDRA, in order not to specialize the code for a particular coolant or core design).

II.2 Code structure

The structure of the code is respresented in Fig. 3.

THEDRA = Main program. It receives the input data on critical temperatures, systematic and statistical deviations from the subroutine LEGGI. Then it reads the nominal temperature data set. The nominal temperatures are modified by the subroutine FACTØ in "reference temperatures", i. e., temperatures which already take into account the systematic factors.
The reference temperatures are interpolated by the subroutine INTERP, to get the temperatures in all the spots considered. Then the main program controls the execution of the probability calculations to get the expected number of hot spots and hot channels (subroutine HØTSPT) and the expected number of hot subassemblies (HØTSA).
At last the whole active zone (i. e. excluding the radial blanket) is analyzed by the subroutine HØTCR. If required, this analysis is repeated for the radial blanket.
The subroutine FLØPT delivers informations about the distribution of the coolant flow-rate which allows the maximum coolant temperature at core outlet at a fixed confidence level. A flow-chart of the main program is given in Fig. 8.

LEGGI = Subroutine. It controls the reading of the input cards, analyzes and elaborates the input data.

TRIHEX (I1, I2, I3, IR, IU) = Subroutine. It evaluates the normalized Hex-coordinates IR and IU from the given redundant tricoordinates I1, I2, I3. +) (see Fig. 5).

MESSER = Subroutine for error messages

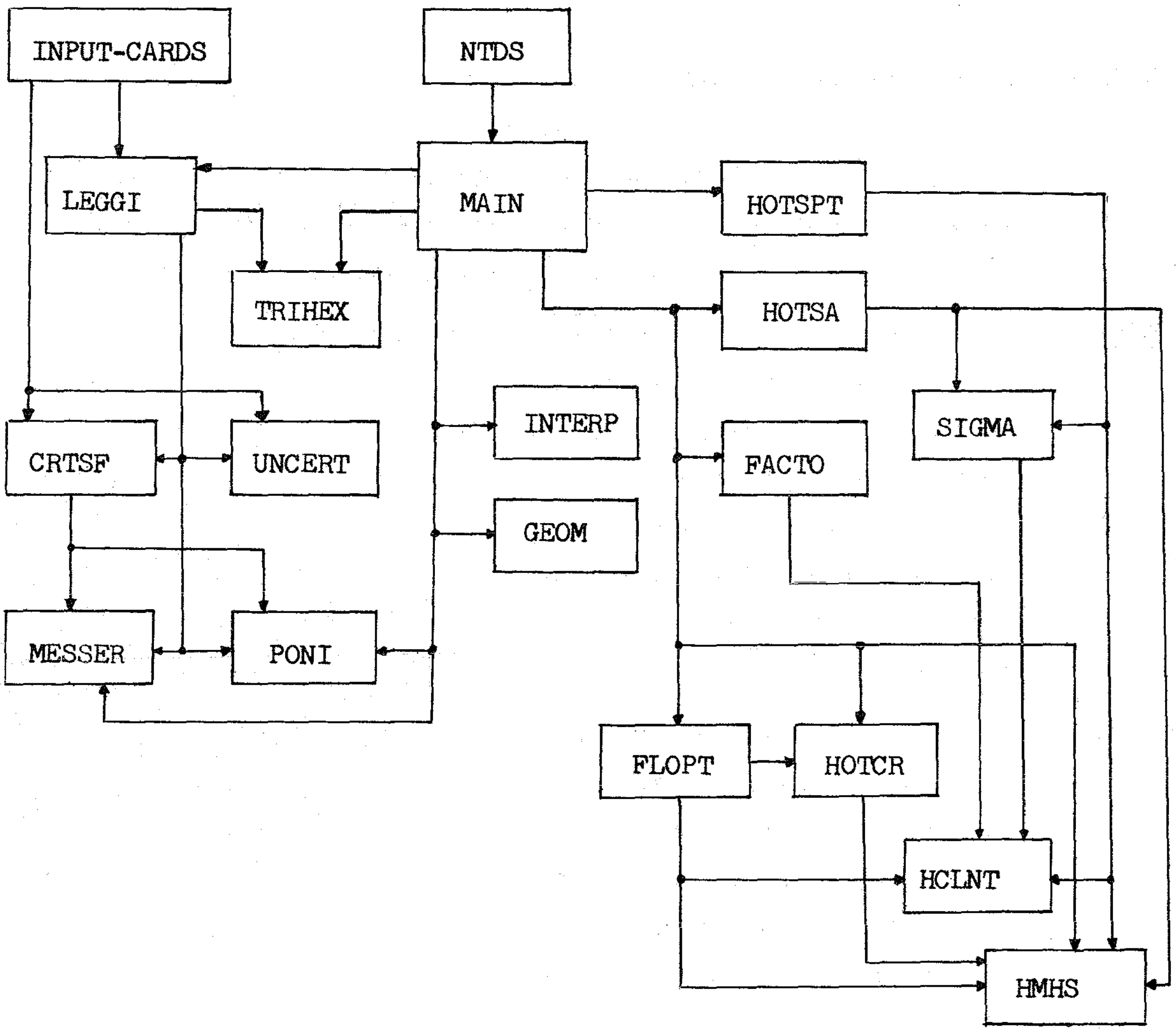

Fig. 3 Code Structure

+) For the purposes of this subroutine, see Ref. /7/. The author wishes to thank Dr. E. G. Schlechtendahl for his agreement to the publication of the TRIHEX subroutine list in this report.

PØNI (A, B, C, D, F, G, E, N) = Subroutine, it assign the value E(i) (with i within 1 and N) to the variables A, B, C, D, F, G, respectively.

UNCERT = Subroutine for reading an uncertainty card block (see input cards description). Moreover, it evaluates the total standard deviation of the uncertainties acting on the same temperature drop.

CRTSF = Subroutine for reading critical temperatures and systematic factors, if these are not a constant through the core.
Moreover, it verifies that these quantities have been assigned to all the subzones into which the core was divided, and that no different values have been assigned to the same subzone.

GEØM = Subroutine for identification of the pins surrounding the channel considered in the statistical analysis. The subscripts of the channels are read from NTDS GEOM evaluates the subscripts of the corresponding pins, according to the convention in Fig. 4.

FACTØ = Subroutine for taking into account systematic deviations from nominal. It evaluates the "reference temperatures" from the nominal temperatures modified by the systematic factors considered.

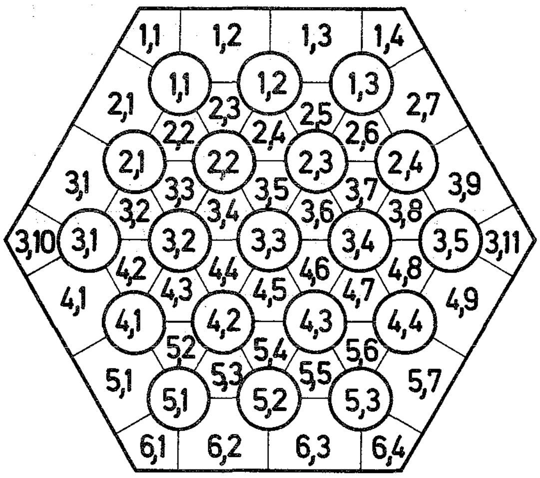

Fig. 4

Channel and pin identification

INTERP = Subroutine for interpolation. The reference temperatures are assigned for a number of axial points which is generally smaller than the number of spots considered. By means of a quadratic interpolation, INTERP furnishes the reference temperatures in all spots. Moreover, it evaluates the maximum axial clad (fuel) temperature and the abscissa at which it occurs.

SIGMA = Function for evaluation of the standard deviation (^{o} C) of coolant, clad and fuel temperature. Inputs are the reference temperatures and the relative standard deviations.

HCLNT = Function for the correlation between coolant flow-rate and clad-coolant temperature drop (see item I.4).

HMHS = Subroutine for evaluation of mean and standard deviation of the normal distribution approximating the distribution of the maximum value out of N samples drawn from the normal distribution (0,1) (see Ref. 1 item II.5).

HØTSPT = Subroutine (a flow chart is given in Fig. 9).
It analyzes a cooling channel and is called by the main program 3 times for each channel: for clad, fuel and coolant analysis, respectively.
It provides:
S = total standard deviation of the maximum temperature in the channel
SSPOT = standard deviation of the "local" uncertainty
SCH = standard deviation of the "channel" uncertainty
EXPNUM = expected number of hot spots in the channel
EXPCH = probability that a channel has at least one hot spot
XNSPOT = equivalent number of hot spot in the channel
XMCHEQ, SCHEQ = mean and standard deviation of the equivalent channel distribution.

HØTSA = Subroutine. It analyzes a subassembly and delivers:
SIGS, SIGZ, SIGC: standard deviation of the maximum temperature in the subassembly (REF) for "subassembly, zone and core" uncertainties, respectively.
EXPSUB: probability that the subassembly has at least one hot spot
EQCH: equivalent number of channels in the subassembly
TM, SEQCH = mean and standard deviation of the equivalent subassembly distribution.
The structure of the subroutine HØTSA is very similar to that of HØTSPT. Therefore, a flow-chart will not be given below. (The first segment of HØTSA arranges the channels by decreasing hot spot probability).

HØTCR = Subroutine. It analyzes the whole active core or the radial blanket. (A segment of HØTCR is used by FLØPT for its calculations).
It provides the final outputs of the code:
a) - Probability of at least one hot spot in the core.

- Expected number of cores containing hot spots, out of a population of 100 cores.
- Average number of subassembly in the core containing hot channels.
- Average number of hot channels per subassembly.
- Average number of hot spots per channel.

If all the channels were calculated individually in NTDS, HOTCR would provide the average number of hot pins per subassembly and the average number of hot spots per pin.

b) If required by the main program, HØTCR yields an approximate assessment of the maximum temperature in the core as a function of the confidence level. (In this calculation, the standard deviations of the critical temperatures are not taken into account).

c) If required by the main program, it supplies the factor by which the temperature drop (max. temp. - coolant inlet temp.) must be decreased (or could be decreased) in such a way that the design satisfies the condition imposed by a preassigned confidence level.

FLØPT = Subroutine. (A flow-chart is given in Fig. 10).
It operates on the basis of the analysis in Ref. [5] and supplies the factors by which the coolant flow-rate should be divided in order to get a maximum in the average coolant temperature at core outlet.

II.3 Input cards

The input cards can be divided into 7 blocks according to the following scheme:

1. Program control
2. Zone description
3. Critical temperatures
4. Systematic factors
5. Heat transfer clad-coolant
6. Core uncertainties
7. Other uncertainties

Block 1 - Program control

This block contains the three following cards:

The first card - Format (20A4) - is an identification card, containing a free comment (KOMM), which will be printed by the program as output headline.

The second card - Format (13I5) contains in the order:

NZ = number of zones into which the core has been divided for the nominal thermal calculations ($1 \leq NZ \leq 30$)

IB = subcript of the first radial blanket zone.
IB $\leq$ 0 if no blanket is considered

NBU = number of input card blocks for the statistical uncertainties

NBF = number of input card blocks for the systematic factors

NBT = number of input card blocks for the critical temperatures

ICB = if equal to 1 the hot channel is considered at axial blanket outlet, otherwise at active zone outlet

1 if the hot spot is considered on the clad outer surface
ICL = 2 " " " " " " at clad midpoint
3 " " " " " " on the clad inner surface

1 hot spot on the fuel outer surface
IFL =
2 hot spot on the surface of fuel inner channel

KCH = if > 0, the expected maximum coolant temperature vs confidence level must be calculated

KCL, KFL = the same as KCH, for clad and fuel respectively.
Moreover the flow-rate distribution will be optimized only if KCL = 2

NWRITE controls the printing. It must be equal to 1, if the printing of all the nominal temperatures is desired

NX controls the printing. If NWRITE is equal to 1, the reference temperatures are printed for the first NX channels.

The third card - Format (4F10.7) - contains in the order:

PRCH, PRCL, PRFL = preassigned confidence level for coolant, clad and fuel respectively. It must be assigned as ratio of deviation to standard deviation. For instance if a $2\ \sigma$ confidence level is assumed for the clad, PRCL must be equal to 2.
If they are $\leq$ 0, a hot spot factor for a successive iteration will not be calculated.

PRMIN = controls the printing. Intermediate quantities in the calculations of the overtemperature probabilities are printed only for the channels in which the total hot element expectation is greater than PRMIN.

Block 2 - Zone description

This block contains NZ cards (FORMAT I5). In each card the following integer quantities must be assigned in the order:

IZ = zone subscript, the zones must be ordered according to increasing IZ.

I1, I2, I3 = subscripts of the subassembly representative for the zone in the thermal calculation (see TRIHEX and Fig. 5).

ISZ = number of subzones in the zone IZ ($1 \leq$ ISZ ≤ 5).

NSASUZ(IZ,J) = with J indicating a subzone (J within 1 and ISZ) number of subassemblies in the subzone J of the zone IZ.

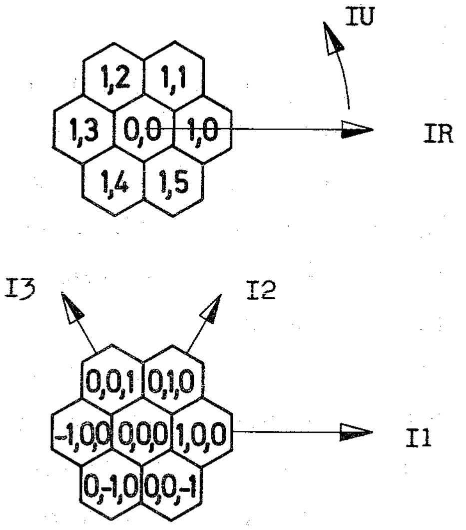

Fig. 5

Hex- and Tricoordinates

Block 3 - Critical temperatures

If NBT = 1, this block contains only one card (FORMAT (8F10.4)).
The following quantities must be assigned in the order:

XLF = length assumed for fuel hot spot (cm)
XLCL = length assumed for clad hot spot (cm)
TC = critical coolant temperature (° C)
STC = standard deviation of TC (° C)
CRTF = critical fuel temperature (° C)
CRSTF = standard deviation of CRTF (° C)
CRTCL = critical clad temperature (° C)
CRSTCL = standard deviation of CRTCL (° C)

If NBT > 1, this block contains:

A card (FORMAT 4F10.4) for the variables XLF, XLCL, TC, STC defined as above.

And, repeated NBT times, the following cards:

A) FORMAT (16I5) containing:

N = number of subzones for which the critical temperatures in the card B) hold true.

(NA1(J), NA2(J), J=1,N) zone and subzone subscripts

B) FORMAT (4F10.4) containing CRTF, CRSTF, CRTCL and CRSTCL

Block 4 - Systematic factors

If NBF = 1, this block contains only one and - FORMAT (5F10.4) -:

SFC = factor due to systematic deviations in the coolant flow-rate
SFA = systematic factor for uncertainty in the heat transfer clad-coolant (the deviations provoked by SFC are calculated by the
C) program itself, and therefore must not be given in SFA)
SFG = for the heat transfer in the fuel-clad gap
SFF = for the inner fuel temperature drop
SFP = for the power.

To explain the significance of these factors, it is necessary to note that the nominal coolant temperature rise will be multiplied by SFC, the temperature drop clad-coolant by SFA, the temperature drop fuel-clad by SFG, the inner fuel temperature drop by SFF and the total temperature drop /̲ inner fuel (clad) - inlet coolant /̲ will be multiplied by SFP.

If NBF > 1, this block contains - repeated NBF times - cards of type A) in block 3, followed by a card of type C), defined as above.

Block 5 - Heat transfer clad-coolant

It contains only a card - FORMAT (2F10.4) - with the quantities EXP, CONST defined at item I.4.

Block 6 - Core uncertainties

This block contains:

D) A card FORMAT (9I5) with the following variables

K = identification of the type of uncertainty
    K = 1 for core uncertainty
N = total number of (core) uncertainties, and therefore of following cards ($\Sigma N1(I)=N$)
N1(I) = number of uncertainties acting on the quantity I, with I within 1 and 7, according to the following scheme:

1 only on flow-rate (coolant temperature rise)
2 only on clad-coolant temperature drop
3 only on clad thickness temperature drop
4 only on fuel-clad temperature drop
5 only on inner fuel temperature drop
6 on the total fuel (clad) - inlet coolant temperature drop, for instance power measurement, flux calculation etc...
7 on fixed temperature such as inlet coolant temperature.

All uncertainties must be assigned as standard deviations. The uncertainties with I = 7 must be expressed as ° C, the others as relative value of their effects on the corresponding temperature drop. For instance, if there is 6 °/o uncertainty in the power measurement at a 3σ confidence level, the value to be assigned into the program is 0.02.

E) N cards, each one containing one uncertainty - FORMAT (2I5, 10X, 10A4, 10X, F10.4), according as follows
   K as in the card D)
   I identification of the type of uncertainty according to the scheme given above
   KOMM free comment for identification of the uncertainty
   SDZ standard deviation defined as above.

Block 7 - Other uncertainties

If NBU ≠ 1 the subblocks must be preceded by cards of type A) in Block 3 and repeated NBU times, according to the following scheme:

Cards A) only if NBU ≠ 1
Subblock 7.1 zone uncertainties, identical to block-6, now K = 2
Subblock 7.2 subassembly uncertainties " " " K = 3
Subblock 7.3 channel uncertainties " " " K = 4
Subblock 7.4 local uncertainties identical to block-6, now K = 5, but uncertainties of type 7 (fixed temperature) are not considered by THEDRA. (The standard deviations must be defined as specific standard deviation, i. e. referred to a spot of length 1 cm).

II.4 Nominal temperature data set

NTDS is an unformatted data set containing the nominal temperature fields (° C) in the coolant, clad and fuel of the NZ subassemblies representative for the zones considered.

It has the following structure:

Block 1: DSN, DATUM, ZEIT, KOMM, NBE, TH1Q

<u>Block 2:</u> it must be repeated NBE times

<u>Subblock 2.1</u>

I1, I2, I3, NZBE, NST, NGES, KK, KUBE, KCE, KCA, KOBA, GGES, ETP2Q, TH2Q, P2, (Z(J),J=1,KK)

<u>Subblock 2.2</u> it must be repeated NGES times

JK, IK, ASTAB, (TH(J),J=1,KK), (TWAS(J), J=1,KK), (TWM(J),J=1,KK), (TWI(J),J=1, KK), (TBRA(J),J=1,KK), (TBRI(J),J=1,KK)

Definitions:

DSN	(8 Bytes)	Alphatext for data set identification
DATUM	" "	" " " data } of generation of NTDS
ZEIT	" "	" " " time } of generation of NTDS
KOMM	80 Bytes	" " " free comment

The other quantities have standard length (4 Bytes) and are integer or real according to the standard name convention.

NBE = number of subassemblies calculated (NBE=NZ)

TH1Q = nominal coolant temperature at core inlet

I1, I2, I3 = subassembly subscripts (see Fig. 5)

NZBE = number of subassemblies identical to the subassembly considered (I1, I2, I3)

NST = total number of pins in the subassembly

NGES = number of channels in the subassembly, for which the thermal calculations were performed (NGES $\leq$ 546)

KK = number of axial points in a channel, for which the temperatures are given (KK $\leq$ 30)

KUBE = subscript of axial blanket inlet

KCE = " " active zone inlet

KCA = " " " " outlet

KOBA = " " axial blanket outlet (see Fig. 6)

GGES = total coolant flow-rate in the subassembly (gr/sec)

ETP2Q = enthalpy (it does not enter into the calculations)

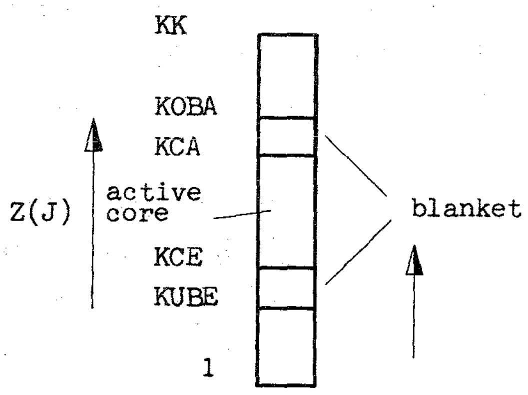

Fig. 6

TH2Q = nominal coolant temperature at subassembly outlet

P2 = pressure drop (it does not enter into the calculations)

Z(J) = axial abscissa (cm)

JK,IK = subscripts for identification of the channel (see Fig. 4)

ASTAB = by means of ASTAB the number of channels identical to the (JK,IK) one will be calculated.

ASTAB is the sum of the pin fractions surrounding the calculated cooling channels.

For instance: (see Fig. 7)

if all channels were calculated individually:

ASTAB = 1/6 for A

ASTAB = 1/2 for an inner (F) or boundary (D) channel

if A is assumed to be identical to B and the two channels A and B are not given separately, then ASTAB = 1/3.

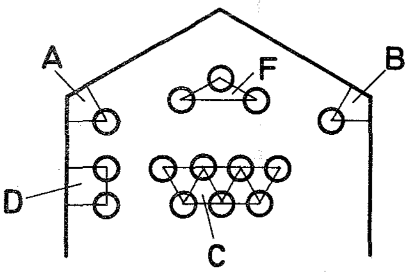

Fig. 7

If the 5 channels indicated as C in Fig. 7 have been assumed to be identical and are not given separately, then ASTAB = 5/2.

TH(J) coolant temperature at the point J in the channel (JK,IK)
TWA(J) outer clad temperature " " " "
TWM(J) mid clad " " " " "
TWI(J) inner clad " " " " "
TBRA(J) outer fuel temperature " " " "
TBRI(J) inner fuel " " " " "

II.5 Error messages

An error check is performed on the input data. If the checked variables are not assigned correctly an error message appears and the program execution is stopped. The error is identified by a number according to the following list: (IC = input cards)

ERROR 1 : NZ > 30 or NZ < 1 (IC)
2 : IB > NZ (IC)
3 : at least one variables out of NBU, NBF, NBT is ≤ 0
4 : block 2 (IC) the zones are not ordered according to increasing IZ
5 : ISZ < 1 or ISZ > 1 (IC)
6 : NBT greater than the total number of subzones (IC)
7 : NBF " " "
8 : NBU " " "

9 : blocks 3, 4 and 7 in IC (NA1, NA2) the zone subscript is < 1 or $> NZ$

10 : " " " subzone subscript is < 1 or greater than the subzone number

11 : " " " the subzone was already defined

12 : " " " at least one subzone was not defined

13 : one or more systematic factors are ≤ 0 (IC)

14 : K in at least one uncertainty card is not defined correctly (blocks 6, 7 IC)

15 : $\Sigma N1(I) \neq N$ (blocks 6, 7 IC)

16 : I is not defined correctly (blocks 6, 7 IC)

17 : NZ in IC is different from NBE in NTDS

18 : the zone defined by the subassembly (I1, I2, I3) in NTDS was not found

19 : the total number of subassemblies in the core calculated from IC is different from that calculated from NTDS

20 : in NTDS the total number of subchannels is wrong (i. e. or ASTAB or NGES or NST are wrong)

21 : XLCL is so small, that the number of axial clad spots is greater than 300 (IC)

22 : $XLCL \leq 0$ or $XLF \leq 0$ (IC)

23 : $NGES > 546$ (NTDS)

24 : $ICL < 1$ or $ICL > 3$ or $IFL < 1$ or $IFL > 2$ (IC)

25 : XLF is wrong (as XLCL for error 21) (IC)

II.6 Warning messages

The following warning messages about the precision of the calculations may appear:

"Precision not obtained": this means that in the integrations (included in the subroutine HØTSPT, HØTSA or HØTCR) the precision required in the code is not obtained. [This message did not appear in all study-cases calculated]

"EXPCH.GT.EXPNUM.AND.EQ" (HØTSPT)

From a theoretical standpoint, EXPNUM should always be $\geq$ EXPCH.

Due to the approximation in the calculations, it is possible in some cases that this does not hold true in the program. Then the code sets EXPNUM = EXPCH and sends a warning message in order to allow an assessment of the approximation performed.

The same holds true for HØTSA: "EXPSUB.GT.EXPCH.AND.EQ".

III. Fortran IV - Listing

III.1 Main Program

```
C
CN                                       THEDRA
C
CA     AMENDOLA
CD     15.7.71
CB           THERMAL DESIGN RELIABILITY ANALYSIS
C
C       ENHSCL,ENHSF CLAD(FUEL) HOT SPOT EXPECTATION IN A CHANNEL
C       ENCHC  HOT CHANNEL EXPECTATION
C       ENCHCL,ENCHFL   EXPECTATION OF CHANN.WITH CLAD (FUEL) HOT SPOTS
C       P1STAB,P2STAB HOT PIN EXPECT. 1 FOR CLAD,2 FOR FUEL
C       EHSPCL,EHSPFL HOT SPOT EXPECTATION IN A SUBASS.
C       EHCHC,EHCHCL,EHCHFL HOT CHANNEL EXPECTATION IN A SUBASS.
C       EXPSC,EXPSCL,EXPSFL HOT SUBASS. EXPECTATION
C       E1STAB,E2STAB HOT PIN EXPECTATION IN A SUBASS.
C       EXPEC(1,J) HOT ELEMENT EXPECTATION IN THE ACTIVE ZONE
C       EXPEC(2,J) HOT ELEMENT EXPECT. IN THE RADIAL BLANKET
C
      DIMENSION NERR(5),EXPEC(2,10),AA(6),BB(6),EHSPCL(30,5),EHSPFL(30,5
     A),E1STAB(30,5),E2STAB(30,5),P1STAB(19,19,5),P2STAB(19,19,5),NUN(2)
     1,IP(3),JP(3)
      COMMON EX,CC,KOMM(20),IN1(2,30),NUSUZ(30),NSASUZ(30,5),RTCS(30,5),
     1RTCLS(30,5),RTFLS(30,5),SIGSC(30,5),SIGSCL(30,5),TH(30),TWA(30),
     2TWM(30),TWI(30),TBRA(30),TBRI(30),Z(30),TCOOL(30),DUM0(150),TICOOL
     3(300),TICLA(300),TICLM(300),TICLI(300),TIFO(300),DUM1(600),DUM2(7)
     4,SEQSC(30,5),SEQSCL(30,5),SEQSFL(30,5),EXPSC(30,5),EXPSCL(30,5),
     5EXPSFL(30,5),DUM3(600),SIGSFL(30,5),SIGZC(30,5),SIGZFL(30,5),
     6SIGCC(30,5),SIGCCL(30,5),SIGCFL(30,5),SIGZCL(30,5),EQCHC(30,5),
     7EQCHCL(30,5),EQCHFL(30,5),DUM4(600),EQMSCL(30,5),EQMSFL(30,5),
     8EQMSC(30,5),CRTF(30,5),CRSTF(30,5),CRTCL(30,5),CRSTCL(30,5),TC,STC
     9,EHCHC(30,5),EHCHCL(30,5),EHCHFL(30,5),XNCH(546),RTMAX(3,5,546),
     ATIC(2,5,546),TIA(2,5,546),TICL(5,546),TIG(5,546),EQSIG(3,5,546),
     BEQMEAN(2,5,546),FLRT(30),TOUT(30) ,EXPEC ,TH1Q,TCC(30,5),TCA(30,5)
     C,NSUB(30)
      REAL*8 DSN,DATUM,ZEIT
      DATA EHSPFL,EHSPCL/300*0./ ,NERR,AA/5*0,5*0.,-100./
     A,NUN,E1STAB,E2STAB/2*0,300*0./
C
C      READING OF THE INPUT CARDS
C
      CALL LEGGI(NZ,IB,ICB,ICL,IFL,XLF,XLCL,AA,BB,NERR,NWRITE,NX,KCH,KCL
     1,KFL,PRMIN,PRCH,PRCL,PRFL)
C
C      READING OF THE NOMINAL TEMP.
C
C      DSN     NAME OF DATA SET
C      DATUM,ZEIT DATE,TIME
C      KOMM    FREE COMMENT FOR DATA SET IDENTIFICATION
C      NBE     NUMBER OF SUBASS. CALCULATED
C      TH1Q    NOM.INLET TEMP.
C
      READ(10) DSN,DATUM,ZEIT,KOMM,NBE,TH1Q
      WRITE(6,1029) DATUM,ZEIT,KOMM,TH1Q
      IF (ICB.NE.1) WRITE(6,1039)
```

```
      IF (ICB.EQ.1) WRITE(6,1040)
      IF (ICL.EQ.1) WRITE(6,1041)
      IF (ICL.EQ.2) WRITE(6,1042)
      IF (ICL.EQ.3) WRITE(6,1043)
      IF (IFL.EQ.1) WRITE(6,1044)
      IF (IFL.EQ.2) WRITE(6,1045)
C            ERROR CHECK
      IF(NBE.EQ.NZ) GO TO 201
      NERRA =17
      WRITE(6,1032) NBE
   33 WRITE(6,2000)NERRA
      STOP
  201 DO 300 II=1,NZ
C
C     I1,I2,I3 INDICES OF THE SUBASS.(FOR TRIHEX SEE LEGGI)
C     NZBE   NUMBER OF IDENTICAL SUBASSEMBLIES
C     NST    NUMBER OF PINS IN THE SUBASS.
C     NGES   NUMBER OF CHANNELS CALCULATED
C     KK     NUMBER OF AXIAL POINTS
C     KUBE   POINT OF BLANKET INLET
C     KCE    POINT OF CORE INLET
C     KCA    POINT OF CORE OUTLET
C     KOBA   POINT OF BLANKET OUTLET
C     GGES,FLRT SUBASS.FLOW-RATE
C     TH2Q,TOUT COOLANT OUTLET TEMP.
C     Z      AXIAL ABSCISSA
C
      READ(10) I1,I2,I3,NZBE,NST,NGES ,KK,KUBE,KCE,KCA,KOBA,GGES,ETP2Q,
     1TH2Q,P2,(Z(J),J=1,KK)
C            ERROR CHECK
      IF(NGES.GT.546) NERR(1)=23
C     XLL    CORE AXIAL LENGTH
C     KCLAD,KFUEL NUMBER OF SPOTS CONSIDERED FOR CLAD AND FUEL
      XLL=ABS(Z(KCA)-Z(KCE))
      IF(ICB.EQ.1) KKK=KOBA
      IF(ICB.NE.1) KKK=KCA
      KCLAD=XLL/XLCL+0.001
      KFUEL=XLL/XLF+0.001
C
      IF(KCLAD.GT.300) NERR(2)=21
      IF(KFUEL.GT.300) NERR(3)=25
      CALL TRIHEX(I1,I2,I3,KOMM(1),KOMM(2))
      DO 202 I=1,NZ
      IF(IN1(1,I).NE.KOMM(1).OR.IN1(2,I).NE.KOMM(2)) GO TO 203
      K=I
      GO TO 204
  203 IF(I.LT.NZ) GO TO 202
      NERR(4)=18
      WRITE(6,1030) I1,I2,I3
  202 CONTINUE
  204 CALL MESSER(NERR,4,NSS,1)
      NA=NUSUZ(K)
      FLRT(K)=GGES
      TOUT(K)=TH2Q
```

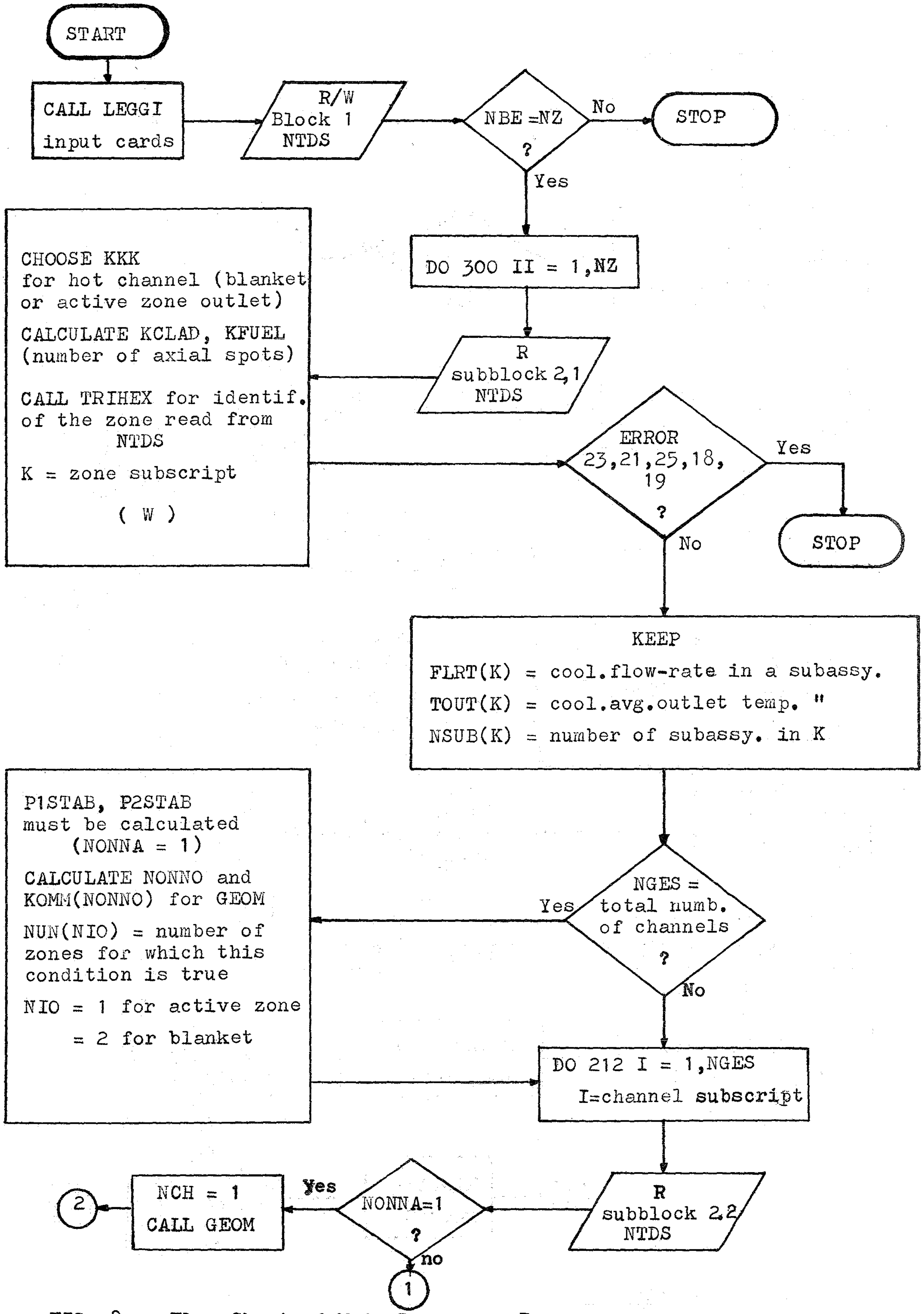

FIG. 8-a. Flow-Chart of Main Program - I

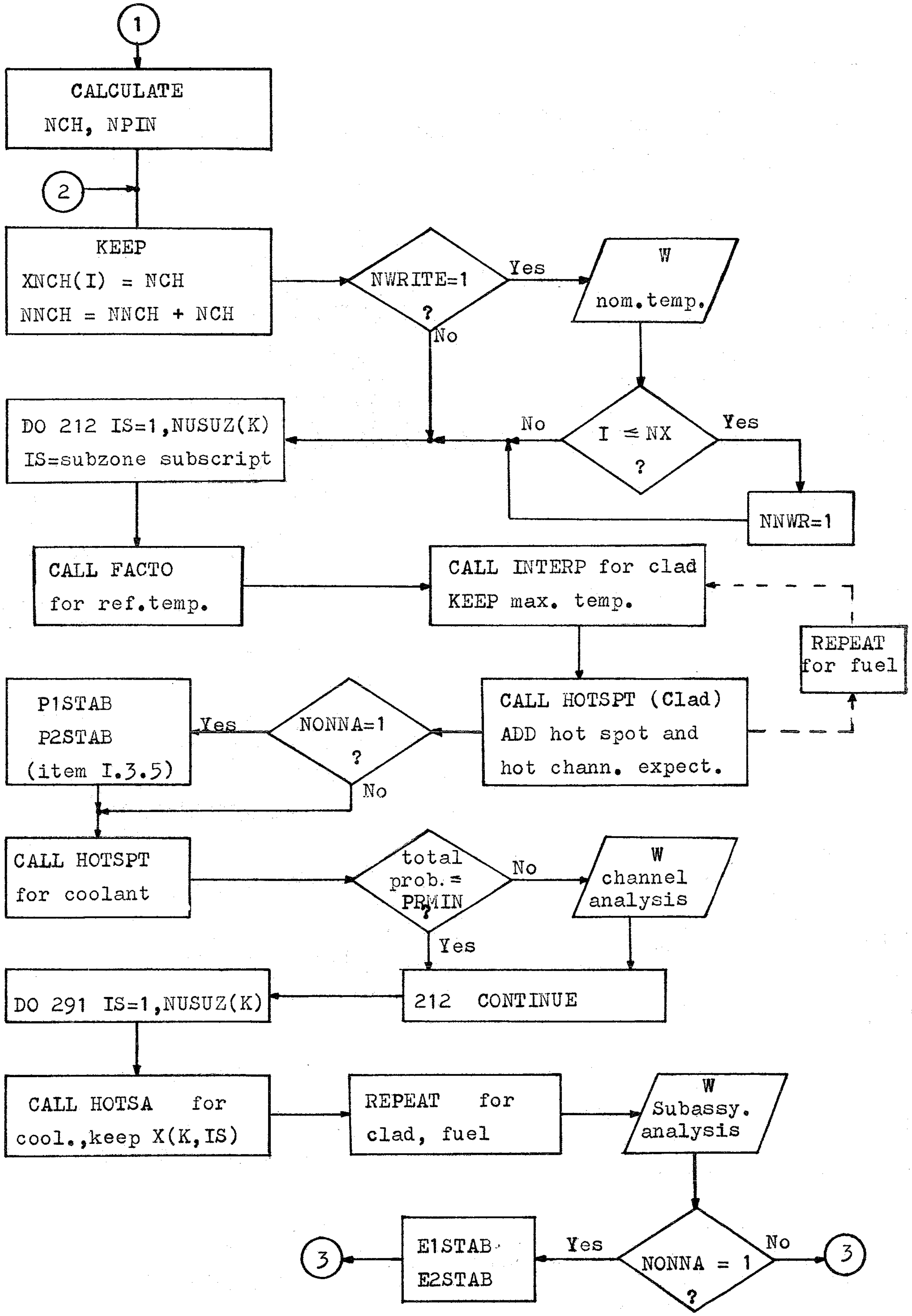

FIG. 8b- Main-II

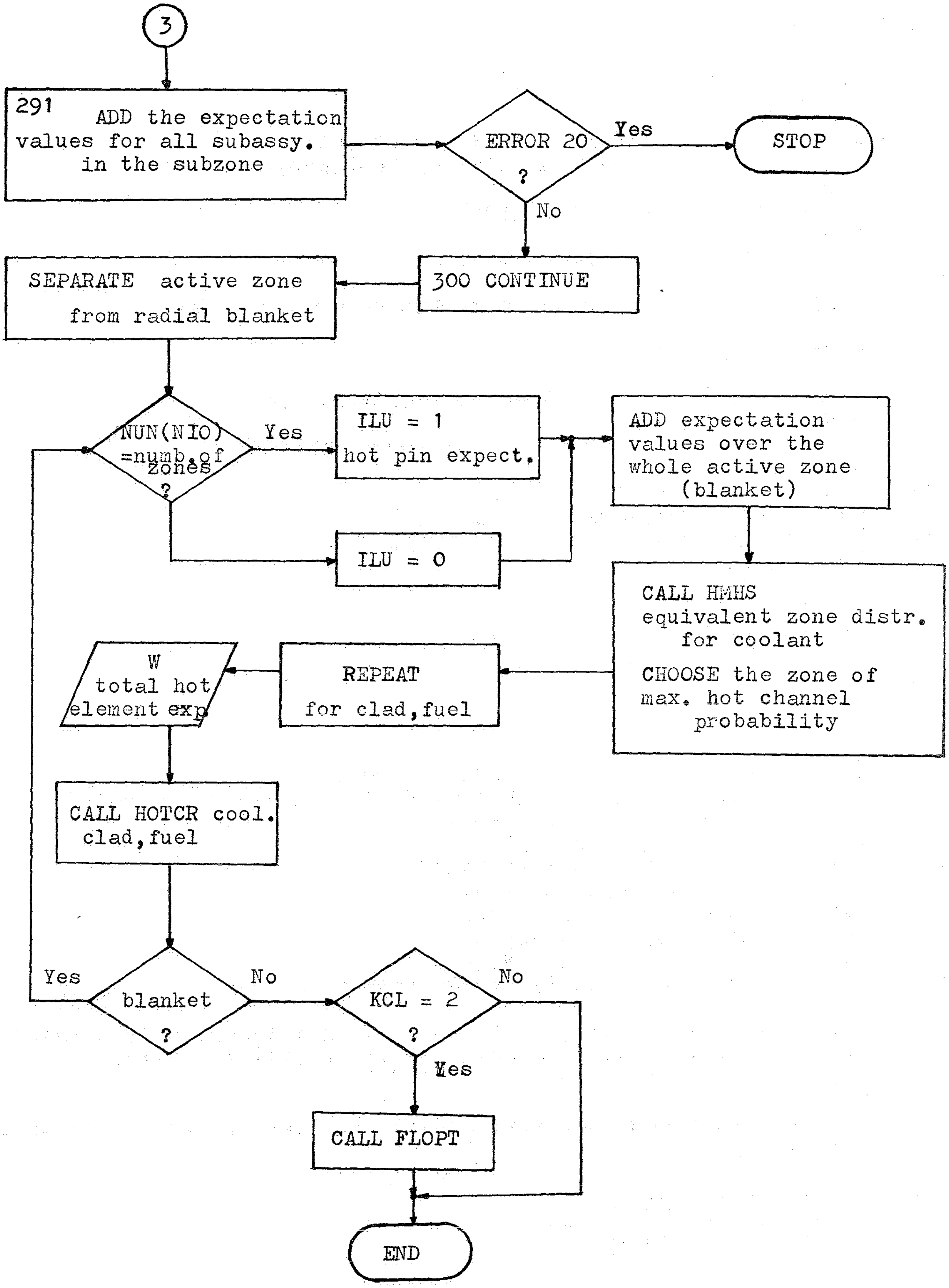

FIG. 8c Main-III

```
      DO 205 I=1,NA
  205 NSS=NSS+NSASUZ(K,I)
      NSUB(K)=NSS
      IF (NSS.EQ.NZBE) GO TO 206
      NERRA =19
      GO TO 33
  206 WRITE(6,1031) K,FLRT(K),TOUT(K),NGES,NST
      IF(NWRITE.EQ.1) WRITE(6,1033) KK,KUBE,KCE,KCA,KOBA
      NIO=1
      IF(IB.GT.0.AND.K.GE.IB) NIO=2
      NONNA=0
      IF(NGES.NE.2*(NST+2)) GO TO 34
C
C     CALCULATION OF NONNO UND KOMM FOR GEOM (SEE GEOM)
C
      NUN(NIO)=NUN(NIO)+1
      NONNA=1
      NONNO=(3.+SQRT(9.+12.*FLOAT(NST-1)))/6.+0.1
      NONNI=2*NONNO-1
      NONNE=NONNO+1
      DO 35 NON=1,NONNO
 35   KOMM(NON)=NONNO+NON-1
      DO 36 NON=NONNE,NONNI
 36   KOMM(NON)=3*NONNO-NON-1
      DO 38 KU1=1,NONNI
      DO 38 KU2=1,NONNI
      DO 38 KU3=1,5
      P1STAB(KU1,KU2,KU3)=0.
 38   P2STAB(KU1,KU2,KU3)=0.
 34   NNWR=0
      NNCH=0
      DO 212 I=1,NGES
C
C     JK,IK  INDEX OF THE CONSIDERED CHANNEL
C     ASTAB  QUANTITY FOR CALCULATION OF THE NUMBER OF CHANNELS
C            IDENTICAL TO JK,IK (NCH)
C     TH     COOLANT NOMINAL TEMP.
C     TWA    OUTER CLAD  NOMINAL TEMP.
C     TWM    MIDPOINT CLAD NOM.TEMP.
C     TWI    INNER    CLAD NOM.TEMP.
C     TBRA   OUTER FUEL    NOM.TEMP.
C     TBRI   INNER FUEL    NOM.TEMP.
C     NPIN   NUMBER OF PINS ABOUT THE CHANNEL
C
      READ(10) JK,IK,ASTAB,(TH(J),J=1,KK),(TWA(J),J=1,KK),(TWM(J),J=1,KK
     1), (TWI(J),J=1,KK), (TBRA(J),J=1,KK), (TBRI(J),J=1,KK)
      IF(NONNA.NE.1) GO TO 37
      NCH=1
      CALL GEOM(NONNO,JK,IK,IP(1),JP(1),IP(2),JP(2),IP(3),JP(3),NPIN)
      ACCA=1./FLOAT(NPIN)
      GO TO 207
 37   NPIN=6.*ASTAB+0.1
      IF(NPIN.GT.3) GO TO 208
      IF(NPIN.EQ.2) GO TO 211
```

```
      NCH=1
      GO TO 207
  211 NPIN=1
      NCH=2
      GO TO 207
  208 NCH=NPIN/3
      NPIN=3
  207 XNCH(I) = FLOAT(NCH)
      NNCH=NNCH+NCH
      IF(NWRITE.NE.1) GO TO 213
      WRITE(6,1034) I,JK,IK,NCH,NPIN,ASTAB
      IF(I.LE.NX)NNWR=1
      WRITE(6,1035)
      DO 210 J=1,KK
  210 WRITE(6,1036)Z(J),TH(J),TWA(J),TWM(J),TWI(J),TBRA(J),TBRI(J)
C
C     INDIVIDUAL CHANNEL ANALYSIS
C
  213 DO 212 IS=1,NA
      CALL FACTO(K,IS,ICB,NNWR,KUBE,KCE,KCA,KOBA)
      CALL INTERP(1,ICL,KCE,KCA,RTMAX(1,IS,I),ZCLMAX,KCLAD,IZCL)
      TIC(1,IS,I)=TICOOL(IZCL)
      TIA(1,IS,I)=TICLA(IZCL)
      CALL HOTSPT (1,ICL,KCLAD,IZCL,K,IS,TH(KCE),XLCL,TOTSCL,ENHSCL,
     1SPOTCL,EQNSPC,0.,NPIN,EQMEAN(1,IS,I),SCHCL,EQSIG(1,IS,I),ENCHCL)
      EHSPCL(K,IS)=EHSPCL(K,IS)+ENHSCL*FLOAT(NCH)
      EHCHCL(K,IS)=EHCHCL(K,IS)+ENCHCL*FLOAT(NCH)
      CALL INTERP(2,IFL,KCE,KCA,RTMAX(2,IS,I),ZFMAX,KFUEL,IZFL)
      TIC(2,IS,I)=TICOOL(IZFL)
      TIA(2,IS,I)=TICLA(IZFL)
      TICL(IS,I)=TICLI(IZFL)
      TIG(IS,I)=TIFO(IZFL)
      CALL HOTSPT (2,IFL,KFUEL,IZFL,K,IS,TH(KCE),XLF,TOTSF, ENHSF,
     1SPOTFL,EQNSPF,0.,NPIN,EQMEAN(2,IS,I),SCHFL,EQSIG(2,IS,I),ENCHFL)
      IF(NONNA.NE.1.OR.(ENCHFL.EQ.0..AND.ENCHCL.EQ.0.)) GO TO 39
      DO 40 NON=1,NPIN
      NIN=IP(NON)
      NAN=JP(NON)
      BACCO=ENHSF*ACCA
      BICI=ENHSCL*ACCA
      IF (BACCO.GT.ENCHFL) BACCO=ENCHFL
      IF (BICI.GT.ENCHCL) BICI=ENCHCL
      P1STAB(NIN,NAN,IS)=BICI +P1STAB(NIN,NAN,IS)
 40   P2STAB(NIN,NAN,IS)=BACCO  +P2STAB(NIN,NAN,IS)
 39   EHSPFL(K,IS)=EHSPFL(K,IS)+ENHSF *FLOAT(NCH)
      EHCHFL(K,IS)=EHCHFL(K,IS)+ENCHFL*FLOAT(NCH)
      CALL HOTSPT(0,0,0,0,K,IS,TH(KCE),XLL,TOTSC,EN,SPOTC,EQ,
     1TCOOL(KKK),1,CMPEQ,SCHC,EQSIG(3,IS,I),ENCHC)
      RTMAX(3,IS,I)=TCOOL(KKK)
      EHCHC(K,IS)=EHCHC(K,IS)+ENCHC    *FLOAT(NCH)
      IF (ENCHC+ENCHCL+ENCHFL.LE.PRMIN) GO TO 212
      IF(NWRITE.NE.1.AND.IS.EQ.1) WRITE(6,1034) I,JK,IK,NCH,NPIN,ASTAB
      WRITE(6,1046) IS,TCOOL(KKK),(RTMAX(L,IS,I),L=1,2),Z(KKK),ZCLMAX,ZF
     1MAX,TOTSC,TOTSCL,TOTSF,ENHSCL,ENHSF,ENCHC,ENCHCL,ENCHFL,SPOTC,SPOT
```

```
     2CL,SPOTFL,EQNSPC,EQNSPF,SCHC,SCHCL,SCHFL,CMPEQ,(EQMEAN(L,IS,I),L=1
     3,2),EQSIG(3,IS,I),(EQSIG(L,IS,I),L=1,2)
  212 CONTINUE
      WRITE(6,1050)
C
C     SUBASSEMBLY ANALYSIS
C
      DO 291 IS=1,NA
      CALL HOTSA(NGES,IS,0,RTCS(K,IS),K,0,TH(KCE),SIGSC(K,IS)
     1,SIGZC(K,IS),SIGCC(K,IS),EQMSC(K,IS),EQCHC(K,IS),AA(1),AA(4))
      CALL HOTSA(NGES,IS,1,RTCLS(K,IS) ,K,ICL,TH(KCE),SIGSCL(K,IS),
     1SIGZCL(K,IS),SIGCCL(K,IS),EQMSCL(K,IS),EQCHCL(K,IS),AA(2),AA(5))
      CALL HOTSA(NGES,IS,2,RTFLS(K,IS),K,IFL,TH(KCE),SIGSFL(K,IS),
     1SIGZFL(K,IS),SIGCFL(K,IS),EQMSFL(K,IS), EQCHFL(K,IS),AA(3),AA(6))
      CALL PONI(SEQSC(K,IS),SEQSCL(K,IS),SEQSFL(K,IS),EXPSC(K,IS),EXPSCL
     1(K,IS),EXPSFL(K,IS),AA,6)
      WRITE(6,1048) IS,RTCS(K,IS),RTCLS(K,IS),RTFLS(K,IS),SIGSC(K,IS),
     1SIGSCL(K,IS),SIGSFL(K,IS),SIGZC(K,IS),SIGZCL(K,IS),SIGZFL(K,IS),
     2SIGCC(K,IS),SIGCCL(K,IS),SIGCFL(K,IS),EQCHC(K,IS),EQCHCL(K,IS),EQC
     3HFL(K,IS),EQMSC(K,IS),EQMSCL(K,IS),EQMSFL(K,IS),SEQSC(K,IS),SEQSCL
     4(K,IS),SEQSFL(K,IS),EHSPCL(K,IS),EHSPFL(K,IS),EHCHC(K,IS),EHCHCL(K
     5,IS),EHCHFL(K,IS),EXPSC(K,IS),EXPSCL(K,IS),EXPSFL(K,IS)
      EN=FLOAT(NSASUZ(K,IS))
      IF(NONNA.NE.1.OR.(EHSPFL(K,IS).EQ.0.0.AND.EHSPCL(K,IS).EQ.0.)) GO
     1TO 52
      WRITE(6,1056)
      DO 50 KU1=1,NONNI
      NONNE=KCMM(KU1)
      DO 50 KU2=1,NONNE
      IF(EXPSCL(K,IS).EQ.0.) GO TO 61
      P1STAB(KU1,KU2,IS)=P1STAB(KU1,KU2,IS)/EXPSCL(K,IS)
      IF (P1STAB(KU1,KU2,IS).GT.1.) P1STAB(KU1,KU2,IS)=1.
      E1STAB(K,IS)=E1STAB(K,IS)+P1STAB(KU1,KU2,IS)
 61   IF(EXPSFL(K,IS).EQ.0.) GO TO 63
      P2STAB(KU1,KU2,IS)=P2STAB(KU1,KU2,IS)/EXPSFL(K,IS)
      IF (P2STAB(KU1,KU2,IS).GT.1.) P2STAB(KU1,KU2,IS)=1.
      E2STAB(K,IS)=E2STAB(K,IS)+P2STAB(KU1,KU2,IS)
 63   IF (P1STAB(KU1,KU2,IS)+P2STAB(KU1,KU2,IS).EQ.0.) GO TO 50
      WRITE(6,1057) KU1,KU2,P1STAB(KU1,KU2,IS),P2STAB(KU1,KU2,IS)
 50   CONTINUE
      WRITE(6,1058) E1STAB(K,IS),E2STAB(K,IS)
      E1STAB(K,IS)=E1STAB(K,IS)*EN *EXPSCL(K,IS)
      E2STAB(K,IS)=E2STAB(K,IS)*EN *EXPSFL(K,IS)
 52   EHSPCL(K,IS)= EHSPCL(K,IS)*EN
      EHSPFL(K,IS)= EHSPFL(K,IS)*EN
      EHCHC (K,IS)= EHCHC (K,IS)*EN
      EHCHCL(K,IS)= EHCHCL(K,IS)*EN
      EHCHFL(K,IS)= EHCHFL(K,IS)*EN
      EXPSC (K,IS)= EXPSC (K,IS)*EN
      EXPSCL(K,IS)= EXPSCL(K,IS)*EN
  291 EXPSFL(K,IS)= EXPSFL(K,IS)*EN
C             ERROR CHECK
      NNNCH=2*(NST+2)
      IF(NNNCH.EQ.NNCH) GO TO 300
```

```
      WRITE(6,1037) NNNCH,NNCH
      NERRA=20
      GO TO 33
  300 CONTINUE
C
C     SUMMARY OF HOT ELEMENT EXPECTATION
C
      ILU=0
      IF (IB-1) 301,302,303
  301 II=NZ
      GO TO 304
  303 II=IB-1
  304 K=1
      WRITE(6,1051)
      I1=1
  305 WRITE(6,1053)
      IF(NUN(I1).EQ.II-K+1) ILU=1
      DO 320 I=1,2
      DO 320 J=1,10
  320 EXPEC(I,J)=0.
      A=10000.
      B=10000.
      C=10000.
      DO 310 I=K,II
      NA= NUSUZ(I)
      DO 310 J=1,NA
      EXPEC(I1,1)=EXPEC(I1,1)+EXPSC (I,J)
      EXPEC(I1,2)=EXPEC(I1,2)+EHCHC (I,J)
      EXPEC(I1,3)=EXPEC(I1,3)+EXPSCL(I,J)
      EXPEC(I1,4)=EXPEC(I1,4)+EHCHCL(I,J)
      EXPEC(I1,5)=EXPEC(I1,5)+EHSPCL(I,J)
      EXPEC(I1,6)=EXPEC(I1,6)+EXPSFL(I,J)
      EXPEC(I1,7)=EXPEC(I1,7)+EHCHFL(I,J)
      EXPEC(I1,8)=EXPEC(I1,8)+EHSPFL(I,J)
      IF (ILU.NE.1) GO TO 60
      EXPEC(I1,9)=EXPEC(I1,9)+E1STAB(I,J)
      EXPEC(I1,10)=EXPEC(I1,10)+E2STAB(I,J)
 60   EN=FLOAT(NSASUZ(I,J))
      CALL HMHS(SEQSC(I,J),EN,E,D)
      RTMAX(1,J,I)=E+EQMSC(I,J)
      EQSIG(1,J,I)=D**2+SIGZC(I,J)**2
      CALL HMHS(SEQSCL(I,J),EN,E,D)
      RTMAX(2,J,I)=E+EQMSCL(I,J)
      EQSIG(2,J,I)=D**2+SIGZCL(I,J)**2
      CALL HMHS(SEQSFL(I,J),EN,E,D)
      RTMAX(3,J,I)=E+EQMSFL(I,J)
      EQSIG(3,J,I)=D**2+SIGZFL(I,J)**2
      D=TC-(RTCS(I,J)+RTMAX(1,J,I)+3*SQRT(EQSIG(1,J,I)+SIGCC(I,J)**2+STC
     1**2))
      IF(D.GE.A) GO TO 306
      A=D
      KO1=I
      KO2=J
  306 D=CRTCL(I,J)-(RTCLS(I,J)+RTMAX(2,J,I)+3*SQRT(EQSIG(2,J,I)+SIGCCL(I
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```
     1,J)**2+CRSTCL(I,J)**2))
      IF(D.GE.B) GO TO 307
      B=D
      K03=I
      K04=J
  307 D=CRTF(I,J)-(RTFLS(I,J)+RTMAX(3,J,I)+3*SQRT(EQSIG(3,J,I)+SIGCFL(I,
     1J)**2+CRSTF(I,J)**2))
      IF(D.GE.C) GO TO 308
      C=D
      K05=I
      K06=J
  308 DO 309 I2=1,3
  309 EQSIG(I2,J,I)=SQRT(EQSIG(I2,J,I))
      WRITE(6,1054) I,J,EXPSC(I,J),EHCHC(I,J),EXPSCL(I,J),EHCHCL(I,J),
     1EHSPCL(I,J),EXPSFL(I,J),EHCHFL(I,J),EHSPFL(I,J)
      IF(ILU.NE.1) GO TO 310
      WRITE(6,1059) E1STAB(I,J),E2STAB(I,J)
 310  CONTINUE
      WRITE(6,1055) (EXPEC(I1,I),I=1,8),K01,K02,K03,K04,K05,K06,RTCS(K01
     1,K02),RTCLS(K03,K04),RTFLS(K05,K06), TC,CRTCL(K03,K04),CRTF(K05,K0
     26),RTMAX(1,K02,K01),RTMAX(2,K04,K03),RTMAX(3,K06,K05),EQSIG(1,K02,
     3K01),EQSIG(2,K04,K03),EQSIG(3,K06,K05)
C
C     CORE ANALYSIS
C
      CALL HOTCR(I1,K01,K02,KCH,K,II,1,PRCH,ILU)
      CALL HOTCR(I1,K05,K06,KFL,K,II,3,PRFL,ILU)
      CALL HOTCR(I1,K03,K04,KCL,K,II,2,PRCL,ILU)
      IF (IB.LE.0.OR.I1.EQ.2) GO TO 350
  302 II=NZ
      K=IB
      I1=2
      WRITE(6,1052)
      GO TO 305
C
C     FLOW-RATE OPTIMIZATION
C
  350 IF(KCL.EQ.2) CALL FLOPT(NZ)
C
C                         FORMAT STATEMENTS
C
 1029 FORMAT(1H1,'NOMINAL THERMAL DESIGN',5X,'DATE ',A8,5X,'TIME ',A8///
     21X,'INFO =',20A4///1X,
     1,'ALL TEMPERATURES AND STANDARD DEVIATIONS ARE EXPRESSED IN CENT.
     2DEGREES'///1X, 'NOMINAL COOLANT INLET TEMP.=',F10.2///)
 1030 FORMAT(1X,'SUB. INDEX=',3I5)
 1031 FORMAT(1H1,40X,'ZONE ',I2//1X,'FLOW RATE =',F10.2,' GR/SEC',25X,'A
     1VER.COOLANT OUTLET TEMP.=',F10.2//1X,'NUMBER OF SUBCHANNELS CALCUL
     2ATED =',I5,15X,'TOTAL NUMBER OF PINS =',I5////20X,'1.CHANNEL ANALY
     4SIS'///)
 1032 FORMAT(1X,'NBE=',I10)
 1033 FORMAT(1X,'KK=',I3,5X,'KUBE=',I3,5X,'KCE=',I3,5X,'KCA=',I3,5X,'KOB
     1A=',I3///)
 1034 FORMAT(1X,'SUBCHANNEL',I5,' (',I3,',',I3,')',10X,'NUMBER OF IDENT.
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     1 SUBCHAN.',I5,10X,'NUMBER OF SPOTS ',I2,'(ASTAB=',F8.2,')'/1X,65(2
     2H--)///)
1035 FORMAT(10X,'Z',15X,'TH',14X,'TWA',13X,'TWM',13X,'TWI',13X,'TBRA',
     112X,'TBRI')
1036 FORMAT(3X,F10.2,6(7X,F10.2))
1037 FORMAT(1X,'NNNCH=',I5,'NNCH=',I5)
1039 FORMAT(1X,'HOT CHANNEL CONSIDERED AT OUTLET OF ACTIVE ZONE'//)
1040 FORMAT(1X,'HOT CHANNEL CONSIDERED AT OUTLET OF AXIAL BLANKET'//)
1041 FORMAT(1X,'HOT SPOT CONSIDERED ON THE CLAD OUTER SURFACE'//)
1042 FORMAT(1X,'HOT SPOT CONSIDERED AT CLAD MIDPOINT'//)
1043 FORMAT(1X,'HOT SPOT CONSIDERED ON THE CLAD INNER SURFACE'//)
1044 FORMAT(1X,'HOT SPOT CONSIDERED ON THE FUEL OUTER SURFACE'//)
1045 FORMAT(1X,'HOT SPOT CONSIDERED ON THE SURFACE OF THE FUEL INNER CH
     1ANNEL'//)
1046 FORMAT(40X,'SUBZONE',I2/30X,' COOLANT  ',20X,'   CLAD   ',20X,'
     1FUEL'/1X,'REFERENCE TEMPERATURES',7X,F10.2,2(20X,F10.2)/1X,'AT HEI
     2GHT  (CM)',14X,F10.2,2(20X,F10.2)/1X,'TOTAL STANDARD DEVIATIONS',4
     3X,F10.2,2(20X,F10.2)/1X,'EXPECTED NUMB.OF HOT SPOTS',13X,2(20X,E10
     4.3)/1X,    'HOT CHANNEL EXPECTATION',6X,E10.3,2(20X,E10.3)/1X,
     1'LOCAL STAND.DEVIATIONS',7X,F10.2,2(20X,F10.2)/1X,'EQUIV.NUMBER OF
     2 HOT SPOTS',14X,2(20X,F10.2)/1X, 'CHANNEL STAND.DEVIATIONS',5X,
     3F10.2,2(20X,F10.2)/1X,'M-CH-EQ',2X,3(20X,F10.2)/1X,'S-CH-EQ',2X,
     43(20X,F10.2)///)
1048 FORMAT(40X,'SUBZONE',I2///41X,'COOLANT',25X,'CLAD',26X,'FUEL'//1X,
     1'REFERENCE TEMPERATURES',17X,F10.2,2(20X,F10.2)/1X,'SUBASS. STAND.
     2DEVIATION',16X,F10.2,2(20X,F10.2)/1X,'ZONE STAND.DEVIATION',19X,F1
     30.2,2(20X,F10.2)/1X,'CORE STAND.DEVIATION',19X,F10.2,2(20X,F10.2)/
     41X,'EQUIV.NUMBER OF CHANNELS',15X,F10.2,2(20X,F10.2)/1X,'M-S-EQ',
     513X,3(20X,F10.2)/1X,'S-S-EQ',13X,3(20X,F10.2)/1X,'HOT SPOT EXPECTA
     6TION IN A SUBASS.',16X,2(20X,E10.3)/1X,'HOT CHANNEL EXPECTATION IN
     7 A SUBASS.',3X,E10.3,2(20X,E10.3)/1X,'HOT SUBASS.EXPECTATION',17X,
     8E10.3,2(20X,E10.3)/1X,65(2H--)///)
1050 FORMAT(1H1,20X,'2.SUBASSEMBLY ANALYSIS'///)
1051 FORMAT(1H1,40X,'ACTIVE ZONE'///)
1052 FORMAT(1H1,40X,'BLANKET'///)
1053 FORMAT(' SUMMARY OF HOT ELEMENT EXPECTATION'/' ZONE,SUBZ.  ',9X,'C
     1OOLANT',29X,'CLAD',39X,'FUEL'/14X,'SUBASS.',6X,'CHANNEL ',2(9X,'SU
     2BASS.',6X,'CHANNEL',6X,'SPOT   ')/)
1054 FORMAT(1X,I3,',',I2,4X,2(E10.3,3X),2(4X,3(E10.3,3X)))
1055 FORMAT(1X,65(2H--)/' TOTAL',5X,2(E10.3,3X),2(4X,3(E10.3,3X))///' R
     1EFER.ZONE',9X,I4,',',I2,28X,I4,',',I2,37X,I4,',',I2/' REFER.TEMP.'
     2,7X,F10.2,25X,F10.2,34X,F10.2/' CRIT.TEMP.',8X,F10.2,25X,F10.2,34X
     A,F10.2/' M-Z-EQ',12X, F10.2,25X,F10.2,34X,
     3F10.2/' S-Z-EQ',12X,F10.2,25X,F10.2,34X,F10.2/)
1056 FORMAT(' HOT PIN EXPECTATION PER SUBASS.'/4X,'I1',3X,'I2',26X,'CLA
     1D',26X,'FUEL')
1057 FORMAT(1X,2I5,2(20X,F10.2))
1058 FORMAT(1X,65(2H--)//' TOTAL',5X,2(20X,F10.2)///)
1059 FORMAT(54X,E10.3,33X,E10.3,15X,'(PINS)')
2000 FORMAT(1X,'ERROR',I2)
     STOP
     END
```

```
      III.2 SUBROUTINE LEGGI(NZ,IB,ICB,ICL,IFL,XLF,XLCL,AA,BB,NERR,NWRITE,NX,
     1KCH,KCL,KFL,PRMIN,PRCH,PRCL,PRFL)
C
C     SUBROUTINE FOR READING THE INPUT CARDS
C
C     NZ      =NUMBER OF ZONES
C     IB      =INDEX OF THE FIRST RADIAL BLANKET ZONE
C              IF (IB.LE.0) THERE IS NO RADIAL BLANKET
C     ICB     =IF(ICB.EQ.1) THE HOT CHANNEL IS CONSIDERED AT AXIAL
C              BLANKET OUTLET,ELSE AT ACTIVE ZONE OUTLET
C     ICL     =IF (ICL.EQ.1) HOT SPOT ON THE CLAD OUTER SURFACE
C               IF (ICL.EQ.2) HOT SPOT AT CLAD MIDPOINT
C               IF (ICL.EQ.3) HOT SPOT ON THE CLAD INNER SURFACE
C     IFL     =IF(IFL.EQ.1)  HOT SPOT ON THE FUEL OUTER SURFACE
C               IF(IFL.EQ.2)  HOT SPOT ON THE SURFACE OF FUEL INNER CHANNEL
C     XLF     =LENGTH OF FUEL HOT SPOT
C     XLCL    =LENGTH OF CLAD HOT SPOT
C     AA,BB   =ONE DIMENS.ARRAYS -AUXILARY QUANTITIES
C     NERR    =ONE DIMENS.ARRAY FOR ERROR MESSAGES
C     NWRITE  =QUANTITY CONTROLLING THE OUTPUTS.IF.EQ.1 ALL NOM.TEMP.ARE
C              PRINTED
C     NX      =QUANTITY CONTROLLING THE PRINTING OF THE NOM.TEMP.MODIFIED
C              BY THE SYSTEM.FACTORS
C     KCH     =IF(KCH.GT.0) THE EXPECT.MAX.TEMP. FOR THE COOLANT IS
C              EVALUATED AS A FUNCTION OF THE CONF.LEVEL
C     KCL,KFL=THE SAME AS KCH FOR CLAD AND FUEL RESPECTIVELY
C              IF (KCL.EQ.2) THE FLOW RATE DISTRIBUTION WILL BE OPTIMIZED
C     PRMIN   =THE INTERMEDATE QUANTITIES ARE PRINTED ONLY FOR THE
C              CHANNELS FOR WHICH THE HOT SPOT PROB. IS.GT.PRMIN
C     PRCH,PRCL,PRFL=PREASSIGNED CONFIDENCE LEVEL FOR COOLANT,CLAD,FUEL
C              RESPECT.,GIVEN AS RATIO OF DEVIATION TO STAND.DEV.
C              IF.LE.0 A HOT SPOT FACTOR FOR A SUCCESSIVE ITERATION WILL
C              NOT BE CALCULATED
C
      DIMENSICN CRTF(30,5),CRSTF(30,5),CRTCL(30,5),CRSTCL(30,5),NA1(150)
     2        ,NA2(150),SFC(30,5),SFA(30,5),SFG(30,5),SFF(30,5),SFP(30,5)
     3   ,ZSDTC(30,5),ZSDTA(30,5),ZSDTCL(30,5),ZSDTG(30,5),ZSDTF(30,5),
     4    SSDTC(30,5),SSDTA(30,5),SSDTCL(30,5),SSDTG(30,5),SSDTF(30,5),
     5    PSDTC(30,5),PSDTA(30,5),PSDTCL(30,5),PSDTG(30,5),PSDTF(30,5),
     6    LSDTC(30,5),LSDTA(30,5),LSDTCL(30,5),LSDTG(30,5),LSDTF(30,5),
     7    ZSDP(30,5),ZSDFT(30,5),AA(6),BB(6),CC(6),DD(6),EE(6),EF(6),
     8    SSDP(30,5),SSDFT(30,5),PSDP(30,5),PSDFT(30,5),GG(6),
     9    LSDP(30,5),NERR(5)
      DIMENSION Z(30),TH(30),TWA(30), TWM(30),TWI(30),TBRA(30),TBRI(30),
     1FLRI(30),TOUT(30),TCOOL(30),TCLA(30),TCLM(30),TCLI(30),TFO(30),
     2TFI(30),TICOOL(300),TICLA(300),TICLM(300),TICLI(300),TIFO(300),
     3 TIFI(300),ZI(300) ,EHCHC(30,5),EHCHCL(30,5),EHCHFL(30,5)
      COMMON EXP,CONST,KOMM(20),IN1(2,30),NUSUZ(30),NSASUZ(30,5)
      COMMON SFC,SFA,SFG,SFF,SFP,TH,TWA,TWM,TWI,TBRA,TBRI,Z,TCOOL,
     1TCLA,TCLM,TCLI,TFO,TFI,TICOOL,TICLA,TICLM,TICLI,TIFO,TIFI,ZI,CSDTC
     2,CSDTA,CSDTCL,CSDTG,CSDTF,CSDP,CSDFT,ZSDTC,ZSDTA,ZSDTCL,ZSDTG,ZSDT
     3F,SSDTC,SSDTA,SSDTCL,SSDTG,SSDTF,PSDTC,PSDTA,PSDTCL,PSDTG,PSDTF,LS
     4DTC,LSDTA,LSDTCL,LSDTG,LSDTF,ZSDP,ZSDFT,SSDP,SSDFT,PSDP,PSDFT,LSDP
     5,CRTF,CRSTF,CRTCL,CRSTCL ,TC,STC , EHCHC,EHCHCL,EHCHFL
```

```
      REAL LSDTC,LSDTCL,LSDTA,LSDTG,LSDTF,LSDP
      DATA NERRA,NERRB/2*0/
C
C     KOMM   =FREE COMMENT FOR JOB IDENTIFICATION
C     NBU    =NUMBER OF BLOCKS OF INPUT CARDS FOR THE UNCERTAINTIES
C     NBF    =NUMBER OF BLOCKS OF INPUT CARDS FOR THE SYSTEM. FACTORS
C     NBT    =NUMBER OF BLOCKS OF INPUT CARDS FOR THE CRITIC.TEMP.
C
      READ(5,1000)KOMM,NZ,IB,NBU,NBF,NBT,ICB,ICL,IFL,KCH,KCL,KFL,NWRITE,
     1NX,PRCH,PRCL,PRFL,PRMIN
      WRITE(6,1001) KOMM,NZ,IB,NBU,NBF,NBT,ICB,ICL,IFL,KCH,KCL,KFL,NWRIT
     1E,NX,PRCH,PRCL,PRFL,PRMIN
C                    ERROR CHECK
      IF(NZ.LT.1.OR.NZ.GT.30) NERR(1) = 1
      IF(IB.GT.NZ) NERR(2)=2
      IF (NBU.LE.0.OR.NBF.LE.0.OR.NBT.LE.0) NERR(3)=3
      IF (ICL.LT.1.OR.ICL.GT.3.OR.IFL.LT.1.OR.IFL.GT.2) NERR(4)=24
      CALL MESSER(NERR,4,NA,1)
C
C                    NUMBER OF SUBASSEMBLIES IN THE SUBZONES
C
C     IZ     =ZONE INDEX
C     I1,I2,I3=INDICES OF THE SUBASS.CHARACTERIZING THE ZONE,IN A TRI-
C     COORDINATE SYSTEM.  THEY ARE TRANSFORMED IN THE TWO NON-REDUNDANT
C     INDICES IN1,IN2 BY THE SUBROUTINE TRIHEX
C     ISZ,NUSUZ(I)= NUMBER OF SUBZONES IN THE ZONE I
C     KOMM,NSASUZ(I,J)=NUMBER OF SUBASS. IN THE SUBZONE J OF THE ZONE I
C
      WRITE(6,1003)
      DO 20 I=1,NZ
      READ(5,1009) IZ,I1,I2,I3        ,ISZ,(KOMM(J),J=1,5)
C                    ERROR CHECK
      IF(IZ.NE.I)   NERR(1)=4
      IF(ISZ.LT.1.OR.ISZ.GT.5) NERR(2)=5
      CALL MESSER(NERR,2,NA,0)
      NUSUZ(I)=ISZ
      CALL TRIHEX(I1,I2,I3,IN1(1,I),IN1(2,I))
      IF (NA.EQ.0) GO TO 11
      NERR(1)=0
      NERR(2)=0
      ISZ=5
      NERRA=1
   11 DO 12 J=1,ISZ
   12 NSASUZ(I,J)=KOMM(J)
   20 WRITE(6,1005) IZ,I1,I2,I3        ,NUSUZ(I),(NSASUZ(I,J),J=1,ISZ)
      WRITE(6,1006)
      IF(NERRA.GT.0) STOP
C
C          CRITICAL TEMPERATURE AND SPOT LENGTH
C
C     TC     =CRITICAL COOLANT TEMP.        ( C )
C     STC    =STAND.DEV. OF TC              ( C )
C     CRTF   =CRITICAL FUEL TEMP.           ( C )
C     CRTCL  =CRITICAL CLAD TEMP.           ( C )
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```
C     CRSTF  =STAND.DEV. OF CRTF           ( C )
C     CRSTCL =STAND.DEV. OF CRTCL          ( C )
C
C     INITIAL VALUE FOR EHCHCL,EHCHFL,EHCHC,SFC,PSDTC
C
      IF (NBT.NE.1) GO TO 800
      READ(5,1007) XLF,XLCL,TC,STC,AA(1),(BB(L),L=1,3)
                   WRITE(6,1008) XLF,AA(1),BB(1),XLCL,BB(2),BB(3),TC,STC
      GO TO 801
  800 READ(5,1007) XLF,XLCL,TC,STC
      WRITE(6,1012) XLF,XLCL,TC,STC
  801 DO 32 I=1,NZ
      NA=NUSUZ(I)
      NERRB=NERRB+NUSUZ(I)
      DO 32 J=1,NA
      IF(NBT.EQ.1) CALL PONI(CRSTF(I,J),CRTCL(I,J),CRSTCL(I,J),A,B,C,BB,
     13)
   32 CALL PONI(CRTF(I,J),EHCHCL(I,J),EHCHFL(I,J),EHCHC(I,J),SFC(I,J),
C            ERROR CHECK
     1PSDTC(I,J),AA,6)
      IF (NBT.GT.NERRB) NERR(1)=6
      IF (NBF.GT.NERRB) NERR(2)=7
      IF (NBU.GT.NERRB) NERR(3)=8
      IF(XLCL.LE.0.0. OR.XLF.LE.0.) NERR(4)=22
      CALL MESSER(NERR,4,NA,1)
      IF(NBT.EQ.1) GO TO 100
      CALL CRTSF(0,NERR,NBT,CRTF,CRSTF,CRTCL,CRSTCL,SFP,NZ,NERRB,
     1NA1,NA2)
      WRITE(6,1006)
C
C          SYSTEMATIC FACTORS
C
C     SFC    =SYSTEMATIC FACTOR FOR COOL.TEMP.RISE
C     SFA    =SYSTEMATIC FACTOR FOR COOL.-CLAD HEAT TRANSFER
C     SFG    =SYSTEMATIC FACTOR FOR FUEL -CLAD HEAT TRANSFER
C     SFF    =SYSTEMATIC FACTOR FOR INNER FUEL TEMP.DROP
C     SFP    =SYSTEMATIC FACTOR FOR POWER
C     EXP,CONST=QUANTITIES FOR CORRELATION BETWEEN COOL.FLOW-RATE AND
C            COOL-CLAD HEAT TRANSFER (SEE HCLNT)
C
  100 WRITE(6,1014)
      IF(NBF.NE.1) GO TO 115
      READ(5,1007) (AA(L),L=1,5)
      WRITE(6,1016) (AA(L),L=1,5)
C                      ERROR MESSAGE
      IF (AA(1).LE.0.0.OR.AA(2).LE.0.0.OR.AA(3).LE.0.0.OR.AA(4).LE.0.0.
     1OR.AA(5).LE.0.0) NERR(5)=13
      DO 112 I=1,NZ
      NA=NUSUZ(I)
      DO 112 J=1,NA
  112 CALL PONI(SFC(I,J),SFA(I,J),SFG(I,J),SFF(I,J),SFP(I,J),A,AA,5)
      GO TO 130
  115 CALL CRTSF(1,NERR,NBF,SFC,SFA,SFG,SFF,SFP,NZ,NERRB,NA1,NA2)
      WRITE(6,1006)
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  130 READ(5,1007) EXP,CONST
      WRITE(6,1038)EXP,CONST
C
C     NOTATION FOR THE UNCERTAINTIES
C     XSDYY
C     X= C CORE, Z ZONE, S SUBASS. ,P PIN OR CHANNEL, L LOCAL
C     SD=STAND. DEV.
C     YY      = TC COOLANT TEMP.RISE             AT THIS POINT REL.VALUE
C             TA CLAD-COOL.TEMP.DROP             AT THIS POINT REL.VALUE
C             TCL TEMP.DROP ACROSS THE CLAD      AT THIS POINT REL.VALUE
C             TG FUEL-CLAD TEMP.DROP             AT THIS POINT REL.VALUE
C             TF INNER FUEL TEMP.DROP            AT THIS POINT REL.VALUE
C             P POWER                            AT THIS POINT REL.VALUE
C             FT FIXED TEMP.                                   ( C )
C
C     FOR INST. CSDTG=STAND.DEV. OF CORE UNCERT.ACTING ON THE TEMP.DROP
C             FUEL-CLAD
C
C           CORE UNCERTAINTIES
C
      CALL UNCERT(1,CSDTC,CSDTA,CSDTCL,CSDTG,CSDTF,     CSDP,CSDFT,NATO)
      WRITE(6,1006)
      WRITE(6,1020)
      WRITE(6,1021)CSDTC,CSDTA,CSDTCL,CSDTG,CSDTF,CSDP,CSDFT
C
C             OTHER UNCERTAINTIES
C
      DO 200 I=1,NBU
      WRITE(6,1022)
      IF(NBU.EQ.1) GO TO 132
      READ(5,1009) N,(NA1(J) ,NA2(J),J=1,N)
      NERRA=NERRA+N
      WRITE(6,1023) (NA1(J),NA2(J),J=1,N)
      WRITE(6,1006)
  132 DO 140 J=2,5
      IF (J.EQ.2) WRITE(6,1024)
      IF (J.EQ.3) WRITE(6,1025)
      IF (J.EQ.4) WRITE(6,1026)
      IF (J.EQ.5) WRITE(6,1027)
      NJ=J-1
      CALL UNCERT(J,AA(NJ),BB(NJ),CC(NJ),DD(NJ),EE(NJ),EF(NJ),GG(NJ),
     1NATA)
      NATO=NATO+NATA
  140 WRITE(6,1006)
      IF(NBU.NE.1) GO TO 150
      N=NERRB
      NERRA=N
      K=0
      DO 151 J=1,NZ
      NA=NUSUZ(J)
      DO 151 KK=1,NA
      K=K+1
      NA1(K)=J
  151 NA2(K)=KK
```

```
  150 DO 145 J=1,N
      NA3=NA1(J)
      NA4=NA2(J)
C             ERROR CHECK
      IF(NA3.LT.1.OR.NA3.GT.NZ) GO TO 141
      IF(NA4.LT.1.OR.NA4.GT.NUSUZ(NA3)) GO TO 142
      IF(PSDTC(NA3,NA4).GE.0.0.AND.NBU.NE.1) GO TO 143
      CALL PONI(ZSDTC(NA3,NA4),SSDTC(NA3,NA4),PSDTC(NA3,NA4),LSDTC(NA3,N
     1A4),A,B,AA,4)
      CALL PONI(ZSDTA(NA3,NA4),SSDTA(NA3,NA4),PSDTA(NA3,NA4),LSDTA(NA3,N
     1A4),A,B,BB,4)
      CALL PONI(ZSDTCL(NA3,NA4),SSDTCL(NA3,NA4),PSDTCL(NA3,NA4),LSDTCL(
     1NA3,NA4),A,B,CC,4)
      CALL PONI(ZSDTG(NA3,NA4),SSDTG(NA3,NA4),PSDTG(NA3,NA4),LSDTG(NA3,N
     1A4),A,B,DD,4)
      CALL PONI(ZSDTF(NA3,NA4),SSDTF(NA3,NA4),PSDTF(NA3,NA4),LSDTF(NA3,N
     1A4),A,B,EE,4)
      CALL PONI(ZSDP(NA3,NA4),SSDP(NA3,NA4),PSDP(NA3,NA4),LSDP(NA3,NA4),
     1A,B,EF,4)
      CALL PONI(ZSDFT(NA3,NA4),SSDFT(NA3,NA4),PSDFT(NA3,NA4),A,B,C,GG,3)
      GO TO 145
  141 NERR(1)=9
      GO TO 145
  142 NERR(2)=10
      GO TO 145
  143 NERR(3)=11
  145 CONTINUE
  200 CONTINUE
      IF(NERRA.NE.NERRB) NERR(4)=12
      WRITE(6,1022)
      DO 190 K=1,4
      IF(K.EQ.1) WRITE(6,1024)
      IF(K.EQ.2) WRITE(6,1025)
      IF(K.EQ.3) WRITE(6,1026)
      IF(K.EQ.4) WRITE(6,1027)
      WRITE(6,1020)
      DO 180 I=1,NZ
      NA=NUSUZ(I)
      DO 180 J=1,NA
      GO TO(181,182,183,184),K
  181 WRITE(6,1028) I,J,ZSDTC(I,J),ZSDTA(I,J),ZSDTCL(I,J),ZSDTG(I,J),
     1 ZSDTF(I,J),ZSDP(I,J),ZSDFT(I,J)
      GO TO 185
  182 WRITE(6,1028) I,J,SSDTC(I,J),SSDTA(I,J),SSDTCL(I,J),SSDTG(I,J),
     1 SSDTF(I,J),SSDP(I,J),SSDFT(I,J)
      GO TO 185
  183 WRITE(6,1028) I,J,PSDTC(I,J),PSDTA(I,J),PSDTCL(I,J),PSDTG(I,J),
     1 PSDTF(I,J),PSDP(I,J),PSDFT(I,J)
      GO TO 185
  184 WRITE(6,1028) I,J,LSDTC(I,J),LSDTA(I,J),LSDTCL(I,J),LSDTG(I,J),
     1 LSDTF(I,J),LSDP(I,J)
  185 IF(NBU.EQ.1.AND.J.EQ.1) GO TO 191
  180 CONTINUE
  191 WRITE(6,1006)
```

```
  190 CONTINUE
      CALL MESSER(NERR,5,NB,1)
      IF(NATO.GT.0) STOP
C
C               FORMAT STATEMENTS
C
 1000 FORMAT(20A4/13I5/4F10.7)
 1001 FORMAT(1H1,55X,'THEDRA'////1X,20A4///1X, 'NZ=NUMBER OF RADIAL ZONE
     1S= ',I3//1X,'(IB=',I3,8X,'NBU=',I3,8X,'NBF=',I3,8X,'NBT=',I3,8X,
     2'ICB=',I3,8X,'ICL=',I3,8X,'IFL=',I3/' KCH=',I3,8X,'KCL=', I3,8X,
     3'KFL=', I3,8X,'NWRITE=',I3,5X,'NX =',I3/' PRCH=', F6.3,8X,'PRCL=',
     4 F6.3,8X,'PRFL=', F6.3,8X,'PRMIN=',E10.3,' )'///)
 1003 FORMAT(6X, ' ZONE INDEX    ','SUBZONE NUMBER ','       NSUB1    ',
     16X,'NSUB2',10X,'NSUB3',10X ,'NSUB4',10X,'NSUB5'/)
 1005 FORMAT(1X, I2,' (',I3,',',I3,',',I3,')',8X,7(I5,10X))
 1006 FORMAT(1X,65(2H--)///)
 1007 FORMAT(8F10.4)
 1008 FORMAT(20X,'SPOT LENGTH',9X,'CRITIC.TEMP.',8X,'ST.DEV.'/24X,'CM',1
     17X,' C',16X,' C'//1X,'FUEL',15X,F10.2,9X,F10.2,8X,F10.2 /1X,'CLAD'
     2,15X,F10.2,9X,F10.2,8X, F10.2 /1X,'COOLANT',31X,F10.2,8X,F10.2///)
 1009 FORMAT(16I5)
 1012 FORMAT(1X,'FUEL SPOT LENGTH =',F10.2,' CM',31X,'CLAD SPOT LENGTH =
     1',F10.2,' CM'/1X,'COOL.CRITC.TEMP. =',F10.2,' OC',31X,'ST.DEV. =',
     229X,F10.2,' OC'///)
 1014 FORMAT(1X,'SYSTEMATIC FACTORS',12X,'COOLANT FLOW RATE',5X,  'CLAD-
     1COOL. DT',13X,'GAP DT ',6X,'INNER FUEL DT',13X,'POWER')
 1016 FORMAT(35X,4(F10.4,10X),F10.4///)
 1020 FORMAT(1X,'ST.DEV.',12X,'COOL.T.RISE',4X,'CLAD-COOL. DT ',3X,
     1'CLAD DT ',6X,'FUEL-CLAD DT ',4X,'INT.FUEL DT',6X,'POWER',7X,'FIXE
     2D TEMP.' /25X,6('R.V.',11X),' C'/1X,'ZONE',8X,'SUBZONE')
 1021 FORMAT(16X,7(5X,F10.4))
 1022 FORMAT(1H1)
 1023 FORMAT(1X,'UNCERTAINTIES FOR THE SUBZONES',1X,14(I2, ',',I1,' -'))
 1024 FORMAT(1X,'ZONE UNCERTAINTIES'///)
 1025 FORMAT(1X,'SUBASSEMBLY UNCERTAINTIES'///)
 1026 FORMAT(1X,'CHANNEL UNCERTAINTIES'///)
 1027 FORMAT(1X,'LOCAL UNCERTAINTIES'///)
 1028 FORMAT(1X,I7,I8,7(5X,F10.4))
 1038 FORMAT(1X,'CORRELATION BETWEEN HEAT TRANSFER AND FLOW RATE=FA=FFR*
     1*EXP-CONST*EXP *(FFR-1)'/1X,'EXP=',F10.4,20X,'CONST=',F10.4/1H1,40
     3X,'CORE UNCERTAINTIES'///)
      RETURN
      END
```

```
III.3  SUBROUTINE TRIHEX(I1,I2,I3,IRING,IUMF)
       IN1=I1+I2
       IN3=I3+I2
       IF(IN1)1,3,3
     1 IF(IN3)4,1003,1003
     4 IF(IN3-IN1)1005,1005,1004
     3 IF(IN3)1006,1001,5
     5 IF(IN3-IN1)1001,1002,1002
  1001 IRING=IN1
C    SECTION 1
       IUMF=IN3
       GO TO 99
  1002 IRING=IN3
C    SECTION 2
       IUMF=IRING+IN3-IN1
       GO TO 99
  1003 IRING=IN3-IN1
C    SECTION 3
       IUMF=2*IRING-IN1
       GO TO 99
  1004 IRING=-IN1
C    SECTION 4
       IUMF=3*IRING-IN3
       GO TO 99
  1005 IRING=-IN3
C    SECTION 5
       IUMF=4*IRING-IN3+IN1
       GO TO 99
  1006 IRING=-IN3+IN1
C    SECTION 6
       IUMF=5*IRING+IN1
    99 RETURN
       END
```

```
III.4  SUBROUTINE MESSER(NERR,N,NA,NB)
C
C      SUBROUTINE FOR ERROR CHECK
C
C      NERR   ONE DIMENSIONAL ARRAY CONTAINING ALL 0'S IF THERE ARE NO
C             ERRORS
C      N      NUMBER OF ERRORS TO BE CHECKED
C      NA     IS SET =1,IF AT LEAST ONE ERROR OCCURS
C      NB     IF.EQ.1,EXFCUTION IS STOPPED IF AN ERROR OCCURS
C
       DIMENSION NERR(5)
       NA=0
       DO 10 I =1,N
       IF(NERR(I).EQ.0) GO TO 10
       NA=1
       WRITE(6,2000) NERR(I)
    10 CONTINUE
  2000 FORMAT(1X,'ERROR',I2)
       IF(NB.EQ.1.AND.NA.EQ.1) STOP
       RETURN
       END
```

III.5 SUBROUTINE UNCERT(KG,DTC,DTA,DTCL,DTG,DTF,DP,DFT,NERRA)

```
C
C      READING OF AN UNCERTAINTY CARD BLOCK
C
C      KG = BLOCK TYPE (CORE,ZONE,SUBASS.,CHANNEL,LOCAL)
C
C      DTC = UNCERT.  ON FLOW RATE
C      DTA =    "     "    HEAT TRANSFER CLAD - COOLANT
C      DTCL =   "     "       "       "      CLAD
C      DTG  =   "     "       "       "      GAP FUEL-CLAD
C      DTF  =   "     "       "       "      FUEL
C      DP   =   "     "    POWER
C      DFT  =   "     "    FIXED TEMPERATURE (E.G. INLET TEMP.)
C
C      NERRA ERROR MESSAGE
C
       DIMENSION KOMM(20) ,N1(7),SD1(7)
       COMMON EX,CO,KOMM
       NERRA=0
C
C      K=KG   N=TOTAL NUMBER OF CARDS   N1(I)=NUMBER OF CARDS PER UNCERT.
C      TYPE
C
       READ(5,1000) K,N,(N1(I),I=1,7)
 1000  FORMAT(9I5)
       IF(K.EQ.KG) GO TO 1
       NERRA = NERRA+1
       NERR=14
       WRITE(6,2000) NERR
 2000  FORMAT(1X,'ERROR',I2)
    1  N2=0
       DO 2 I=1,7
    2  N2=N2+N1(I)
       IF(N2.EQ.N) GO TO 3
       NERR=15
       WRITE(6,2000) NERR
       STOP
    3  DO 100 I=1,7
       IF(N1(I).GT.0) GO TO 5
       SD1(I)=0.
       GO TO 100
    5  SD=0.
       N2=N1(I)
       DO 50 J=1,N2
C
C      READING OF AN UNCERTAINTY CARD
C      K=KG   N=IDENTIFICATION OF UNCERT.TYPE   KOMM=COMMENT
C      SD2 = STANDARD DEVIATION
C
       READ(5,1001) K,N,(KOMM(NN),NN=1,10),SD2
 1001  FORMAT(2I5,10X,10A4,10X,F10.4)
       WRITE(6,1002) N,(KOMM(NN),NN=1,10),SD2
 1002  FORMAT(1X,'TYPE',I5,10X,10A4,10X,F10.4)
       IF(K.EQ.KG) GO TO 6
```

```
      NERR=14
      NERRA=NERRA+1
      WRITE(6,2000) NERR
    6 IF(N.EQ.I) GO TO 50
      NERRA=NERRA+1
      NERR=16
      WRITE(6,2000)NERR
   50 SD=SD+SD2**2
      SD1(I)=SQRT(SD)
  100 CONTINUE
      DTC =SD1(1)
      DTA=SD1(2)
      DTCL=SD1(3)
      DTG=SD1(4)
      DTF=SD1(5)
      DP=SD1(6)
      DFT=SD1(7)
      IF(NERRA.EQ.0) RETURN
      WRITE(6,2001) NERRA
 2001 FORMAT(1X,'TOTAL NUMBER OF ERRORS IN THIS GROUP',I5)
      RETURN
      END
```

III.6 SUBROUTINE PONI(A,B,C,D,F,G,E,N)

```
C
C     SUBROUTINE TO ASSIGN THE VALUE E(N) TO A,B,C,D,F,G
C
      DIMENSION E(6)
      A=E(1)
      B=E(2)
      C=E(3)
      IF (N.EQ.3) RETURN
      D=E(4)
      IF (N.EQ.4) RETURN
      F=E(5)
      IF (N.EQ.5) RETURN
      G=E(6)
      RETURN
      END
```

III.7 SUBROUTINE CRTSF(M,NERR,NBF,SFC,SFA,SFG,SFF,SFP,NZ,NERRB,NA1,NA2)

```
C
C     SUBROUTINE FOR MEMORIZING THE CRITICAL TEMP. OR THE SYST.FACTORS
C              AFTER AN ERROR CHECK
C
C     M        =0 FOR CRIT.TEMP- 1 FOR SYST.FACT.
C     NERR     ARRAY FOR ERROR CHECK
C     NBF      NBT,NBF (SEE LEGGI)
C     SFA      CRSTF,SFA  ( SEE LEGGI)
C     SFG      CRTCL,SFG  ( SEE LEGGI)
C     SFF      CRSTCL,SFF ( SEE LEGGI)
C     SFP      SFP        ( SEE LEGGI)
C     NZ       NUMBER OF ZONES
C     NA1,NA2  INDEX OF ZONES AND SUBZONES RESPECT.
C
      DIMENSION NUSUZ(30),SFC(30,5),SFA(30,5),SFG(30,5),SFF(30,5),SFP(30
     1,5),NERR(5),NA1(150),NA2(150),FC(6)
      COMMON DUMM(82),NUSUZ
      L=4+M
      NERRA=0
      DO 125 I=1,NBF
      READ(5,1009) N,(NA1(J),NA2(J),J=1,N)
      NERRA=NERRA+N
      READ(5,1007) (FC(J),J=1,5)
      IF (M.EQ.0) GO TO 80
      DO 1 J=1,5
      IF (FC(J).LE.0.) NERR(5)=13
    1 CONTINUE
   80 DO 125 J=1,N
      NA3=NA1(J)
      NA4=NA2(J)
C                      ERROR CHECK
      IF(NA3.LT.1.OR.NA3.GT.NZ) GO TO 121
      IF(NA4.LT.1.OR.NA4.GT.NUSUZ(NA3)) GO TO 122
      IF(SFC(NA3,NA4).NE.0.) GO TO 123
      CALL PONI(SFC(NA3,NA4),SFA(NA3,NA4),SFG(NA3,NA4),SFF(NA3,NA4),SFP(
     1 NA3,NA4),A,FC,L)
      GO TO 125
C                      ERROR
  121 NERR(1)=9
      GO TO 125
  122 NERR(2)=10
      GO TO 125
  123 NERR(3)=11
C
  125 CONTINUE
C
C                      ERROR MESSAGE
C
      IF(NERRA.NE.NERRB) NERR(4)=12
      IF (M.EQ.0) WRITE (6,1011)
      IF (M.EQ.1) WRITE (6,1018)
      DO 127 I=1,NZ
      NAA=NUSUZ(I)
```

```
      DO 127 J=1,NAA
      IF (M.EQ.1) WRITE(6,1017) I,J,SFC(I,J),SFA(I,J),SFG(I,J),SFF(I,J),
     1SFP(I,J)
      IF (M.EQ.0) WRITE(6,1013) I,J,SFC(I,J),SFA(I,J),SFG(I,J),SFF(I,J)
  127 CONTINUE
      CALL MESSER(NERR,L,NA,1)
 1007 FORMAT(8F10.4)
 1009 FORMAT(16I5)
 1011 FORMAT(7X,'ZONE INDEX',4X,'SUBZONE INDEX',10X,'FUEL.CRIT.TEMP.',4X
     1, 'ST.DEV.', 10X,'CLAD CRIT.TEMP.',4X,'ST.DEV.'/50X,'OC',13X,'OC',
     2 20X,'OC',12X,'OC'/ )
 1013 FORMAT(12X,I2,14X,I1,17X,F10.4,5X,F10.4,12X,F10.4,5X,F10.4)
 1014 FORMAT(1X,'SYSTEMATIC FACTORS',12X,'COOLANT FLOW RATE',5X,  'H.T.
     1CLAD-COOL.',  5X,'H.T. FUEL-CLAD ',5X,  'FUEL TEMP.DROP',11X, 'POW
     2ER')
 1017 FORMAT(5X,I2,12X,I1,15X,4(F10.4,10X),F10.4)
 1018 FORMAT(1X,'ZONE INDEX',2X,'SUBZONE INDEX')
      RETURN
      END
```

III.8 SUBROUTINE GEOM(N,K1,K2,IP1,JP1,IP2,JP2,IP3,JP3,NS)

```
C
C     SUBROUTINE FOR IDENTIFICATION OF THE PINS SURROUNDING A GIVEN
C            CHANNEL
C
C     N      NUMBER OF PINS IN THE FIRST ROW OF A SUBASS.
C     NP     ONE DIMENS.ARRAY CONTAINING THE NUMBER OF PINS PER ROW
C     K1,K2  INDICES OF THE CHANNEL
C     NS     NUMBER OF PINS SURROUNDING THE CHANNEL K1,K2
C     IP1,JP2 INDICES OF THE FIRST PIN
C     IP2,JP2 INDICES OF THE SECOND PIN (SIGNIF. IF NS.GT.1)
C     IP3,JP3 INDICES OF THE THIRD  PIN (SIGNIF. IF NS.EQ.3)
C
      COMMON EX,CO,NP(20)
      IF(K1.EQ.N.AND.K2.GT.4*N-3) GO TO 40
      IF(K1.NE.1) GO TO 10
      IP1=K1
      IF(K2.NE.1) GO TO 1
      JP1=1
      GO TO 100
 1    IF(K2.NE.N+1) GO TO 2
      JP1=N
      GO TO 100
 2    IP2=1
      JP1=K2-1
      JP2=K2
      GO TO 200
 10   IP1=K1-1
      IF(K1.EQ.2*N) GO TO 50
      IF(K2.EQ.1) GO TO 30
      IF((K1.LE.N.AND.K2.EQ.2*NP(K1)-1).OR.(K1.GT.N.AND.K2.EQ.2*NP(K1)+1
     1)) GO TO 20
      KK=K2/2
      IF(FLOAT(K2)*0.5.GT.FLOAT(KK)+0.1) GO TO 15
      JP1=KK
      IF (K1.GT.N) GO TO 80
      IP2=K1
      IP3=IP2
```

```
      JP2=JP1
      JP3=JP2+1
      GO TO 300
80    JP2=KK+1
      IP2=IP1
      JP3=JP1
      IP3=IP2+1
      GO TO 300
15    IF(K1.GT.N) GO TO 90
      JP1=KK
      IP2=IP1
      JP2=KK+1
      IP3=IP1+1
      JP3=JP2
      GO TO 300
90    JP1=KK+1
      IP2=IP1+1
      IP3=IP2
      JP2=KK
      JP3=JP1
      GO TO 300
40    IP1=K1
      IF(K2.EQ.4*N-2) GO TO 41
      JP1=NP(N)
      GO TO 100
41    JP1=1
      GO TO 100
30    IP2=K1
      JP1=1
      JP2=1
      GO TO 200
20    IP2=K1
      JP1=NP(IP1)
      JP2=NP(IP2)
      GO TO 200
50    IF(K2.NE.1) GO TO 60
      JP1=1
      GO TO 100
60    IF(K2.NE.N+1) GO TO 70
      JP1=N
      GO TO 100
70    IP2=IP1
      JP1=K2-1
      JP2=K2
      GO TO 200
100   NS=1
      RETURN
200   NS=2
      RETURN
300   NS=3
      RETURN
      END
```

III.9 SUBROUTINE FACTO(K,IS,KK,NN,K1,K2,K3,K4)

```
C
C     EFFECTS OF THE SYSTEMATIC FACTORS
C
C     K = ZONE INDEX
C     IS = SUBZONE INDEX
C
C     KK =1, IF THE COOLANT TEMP. AT OUTLET INCLUDES THE UPPER BLANKET
C
C     NN QUANTITY CONTROLLING THE PRINTING
C
C     K1 = LOWER BLANKET INLET ABSCISSA
C     K2 = ACTIVE CORE INLET     "  "
C     K3 =  "  "        "OUTLET   "  "
C     K4 = UPPER BLANKET   "      "  "
C
C     SFC,SFA,SFG,SFF,SFP = SYSTEMATIC FACTORS AS IN MAIN
C     TCOOL  = TH   (S. MAIN)   MODIFIED BY SYSTEMATIC FACTORS
C     TCLA = TWA "  "  "  "  "  "  "  "  "  "  "  "  "  "
C     TCLM = TWM "  "  "  "  "  "  "  "  "  "  "  "  "  "
C     TCLI = TWI "  "  "  "  "  "  "  "  "  "  "  "  "  "
C     TFO = TBRA "  "  "  "  "  "  "  "  "  "  "  "  "  "
C     TFI = TBRI "  "  "  "  "  "  "  "  "  "  "  "  "  "
C
C     Z = AXIAL ABSCISSA
C
      COMMON DUM(262),SFC(30,5),SFA(30,5),SFG(30,5),SFF(30,5),SFP(30,5),
     1TH(30),TWA(30),TWM(30),TWI(30),TBRA(30),TBRI(30),Z(30),
     2TCOOL(30),TCLA(30),TCLM(30),TCLI(30),TFO(30),TFI(30)
      SC=SFC(K,IS)*SFP(K,IS)
      HCL=HCLNT(SFC(K,IS)) *SFA(K,IS)*SFP(K,IS)
      SG=SFG(K,IS)*SFP(K,IS)
      SF=SFF(K,IS)*SFP(K,IS)
      DO 1 I=K2,K3
      TCOOL(I)=TH(K1)+(TH(I)-TH(K1))*SC
      TCLA(I)=TCOOL(I)+(TWA(I)-TH(I))*HCL
      TCLM(I)=TCLA(I)+(TWM(I)-TWA(I))*SFP(K,IS)
      TCLI(I)=TCLM(I)+(TWI(I)- TWM(I))*SFP(K,IS)
      TFO(I)=TCLI(I)+(TBRA(I)-TWI(I))*SG
    1 TFI(I)=TFO(I)+(TBRI(I)-TBRA(I))*SF
      IF(KK.EQ.1) TCOOL(K4)=TH(K1)+(TH(K4)-TH(K1))*SC
      IF(NN.NE.1) RETURN
      WRITE(6,1001)
 1001 FORMAT(1X,'TEMPERATURES TAKING INTO ACCOUNT THE SYSTEMATIC FACTORS
     1'/1X,'SUBZONE')
      DO 2 I=K2,K3
    2 WRITE(6,1000)IS,Z(I),TCOOL(I),TCLA(I),TCLM(I),TCLI(I),TFO(I),TFI(I
     1)
 1000 FORMAT(1X,I1,1X,F10.2,6(7X,F10.2))
      IF(KK.EQ.1) WRITE(6,1000 )IS,Z(K4),TCOOL(K4)
      WRITE(6,1006)
 1006 FORMAT(1X,65(2H--)///)
      RETURN
      END
```

III.10 SUBROUTINE INTERP(I1,I2,K2,K3,TMAX,ZMAX,K,IZ)

```
C
C     SUBROUTINE FOR QUADR.INTERPOLATION OF THE REF.TEMP.
C
C     I1      1 FOR CLAD...2 FOR FUEL
C     I2      ICL,IFL (SEE LEGGI)
C     K2,K3   KCE,KCA (SEE MAIN)
C     TMAX    MAX.REF.TEMP
C     ZMAX    ABSCISSA OF MAX.REF.TEMP.    (CM)
C     K       KCLAD,KFUEL (SEE MAIN)
C     IZ      SEGMENT OF MAX.REF.TEMP
C     TICOOL  TCOOL    AFTER INTERP.
C     TICLA   TCLA     AFTER INTERP.
C     TICLM   TCLM     AFTER INTERP.
C     TICLI   TCLI     AFTER INTERP.
C     TIFO    TFO      AFTER INTERP.
C     TIFI    TFI      AFTER INTERP.
C     ZA      Z        AFTER INTERP.
C
      COMMON DUNN(1192),Z(30),TCOOL(30),TCLA(30),TCLM(30),TCLI(30),TFO(3
     10),TFI(30),TICOOL(300),TICLA(300),TICLM(300),TICLI(300),TIFO(300),
     2TIFI(300),ZA(300)
      FUN(DZ,DZ32,DZ21,DZ31,DY,Y1,Y2,Y3,DX)=DZ*((((Y3-Y2)/DZ32-(Y2-Y1)/
     1DZ21)/DZ31)*(DZ-DX)+DY/DX)+Y2
      TMAX=0.
      ZETA=(Z(K3)-Z(K2))/FLOAT(K)
      A=Z(K2)-0.5*ZETA
      J=K2+1
      DO 1 I=1,K
      ZA(I)=ZETA*FLOAT(I)+A
      IF(ZA(I)-Z(J))2,3,4
    3 TICOOL(I)=TCOOL(J)
      TICLA(I)=TCLA(J)
      IF(I1.EQ.1) GO TO (10,5,9),I2
    9 TICLI(I)=TCLI(J)
      IF(I1.EQ.1) GO TO 12
      TIFO(I)=TFO(J)
      IF(I2.EQ.1) GO TO 13
      TIFI(I)=TFI(J)
      GO TO 14
    5 TICLM(I)=TCLM(J)
      GO TO 11
    2 IF(J.EQ.K3) GO TO 6
      Z1=Z(J-1)
      Z2=Z(J)
      Z3=Z(J+1)
      JJ=J
      GO TO 7
    6 Z1=Z(J-2)
      Z2=Z(J-1)
      Z3=Z(J)
      JJ=J-1
    7 DZ31=Z3-Z1
      DZ32=Z3-Z2
```

```
      DZ21=Z2-Z1
      DZ=ZA(I)-Z2
      IF(DZ32/DZ21.GE.1.) GO TO 100
      DX=DZ21
      M=JJ
      N=JJ-1
  203 DY1=TCOOL(M)-TCOOL(N)
      DY2=TCLA(M)-TCLA(N)
      IF(I1.EQ.1) GO TO (200,201,202),I2
  202 DY3=TCLI(M)-TCLI(N)
      IF(I1.EQ.1) GO TO 200
      DY4=TFO(M)-TFO(N)
      IF(I2.EQ.1) GO TO 200
      DY5=TFI(M)-TFI(N)
      GO TO 200
  201 DY6=TCLM(M)-TCLM(N)
      GO TO 200
  100 DX=DZ32
      M=JJ+1
      N=JJ
      GO TO 203
  200 M=JJ-1
      N=JJ+1
      TICOOL(I)=FUN(DZ,DZ32,DZ21,DZ31,DY1,TCOOL(M),TCOOL(JJ),TCOOL(N),
     1DX)
      TICLA(I)=FUN(DZ,DZ32,DZ21,DZ31,DY2,TCLA(M),TCLA(JJ),TCLA(N),DX)
      IF(I1.EQ.1) GO TO (10,15,16),I2
   16 TICLI(I)=FUN(DZ,DZ32,DZ21,DZ31,DY3,TCLI(M),TCLI(JJ),TCLI(N),DX)
      IF(I1.EQ.1) GO TO 12
      TIFO (I)=FUN(DZ,DZ32,DZ21,DZ31,DY4,TFO(M),TFO(JJ),TFO(N),DX)
      IF(I2.EQ.1) GO TO 13
      TIFI (I)=FUN(DZ,DZ32,DZ21,DZ31,DY5,TFI(M),TFI(JJ),TFI(N),DX)
      GO TO 14
   15 TICLM(I)=FUN(DZ,DZ32,DZ21,DZ31,DY6,TCLM(M),TCLM(JJ),TCLM(N),DX)
      GO TO 11
    4 J=J+1
      GO TO 2
   10 T=TICLA(I)
      GO TO 20
   11 T=TICLM(I)
      GO TO 20
   12 T=TICLI(I)
      GO TO 20
   13 T=TIFO(I)
      GO TO 20
   14 T=TIFI(I)
   20 IF(T.LE.TMAX) GO TO 1
      TMAX=T
      ZMAX=ZA(I)
      IZ=I
    1 CONTINUE
      RETURN
      END
```

III.11 FUNCTION SIGMA(I1,I2,T,T1,T2,T3,T4,T5,A,B,C,D,E,F,P,PL1,PL2)

```
C
C     FUNCTION FOR CALCULATING THE STAND.DEV. ( C ) FROM THE REL.VALUE
C             OF THE UNCERT. AND THE REF.TEMP.
C
C     I1      0,1,2 FOR COOL.,CLAD,FUEL RESPECT.
C     I2      ICL,IFL (SEE LEGGI)
C     T       COOL.INLET TEMP.
C     T1      COOL. TEMP.
C     T2      OUTER CLAD TEMP.
C     T3      INNER OR MIDPOINT CLAD TEMP.
C     T4      OUTER FUEL TEMP.
C     T5      INNER FUEL TEMP.
C     A       TOTAL UNCERT. ON COOL.FLOW-RATE
C     B       TOTAL UNCERT. ON HEAT TRANSFER CLAD-COOL.
C     C       TOTAL UNCERT. ON CLAD TEMP. DROP
C     D       TOTAL UNCERT. ON GAP FUEL-CLAD TEMP.DROP
C     E       TOTAL UNCERT. ON INNER FUEL TEMP.DROP
C     F       TOTAL UNCERT. ON FIXED TEMP.
C     P       TOTAL UNCERT. ON GLOBAL POWER
C     PL1     TOTAL UNCERT.ON LOCAL POWER (FUEL-COOL.TEMP.DROP)
C     PL2     TOTAL UNCERT.ON LOCAL POWER (COOL-TEMP.RISE)
C
      IF (I1.GT.0) GO TO 1
      SIGMA=SQRT((A**2+P**2+PL2**2)*(T1-T)**2+F**2)
      RETURN
    1 DT1=T1-T
      DT2=T2-T1
      SIGMA=(A*DT1+(HCLNT(1.+A)-1.)*DT2)**2+(B*DT2)**2+(PL2*DT1)**2+F**2
      IF (I1.EQ.2) GO TO (3,4),I2
      IF(I2.GE.2) GO TO 2
      SIGMA=SQRT(SIGMA   +(P*(T2-T))**2+(PL1*DT2)**2)
      RETURN
    2 SIGMA=SQRT(SIGMA   +(C*(T3-T2))**2+(P*(T3-T))**2+(PL1*(T3-T1))**2)
      RETURN
    3 SIGMA=SQRT(SIGMA   +(C*(T3-T2))**2+(D*(T4-T3))**2+(P*(T4-T))**2+(
     1PL1*(T4-T1))**2 )
      RETURN
    4 SIGMA=SQRT(SIGMA   +(C*(T3-T2))**2+(D*(T4-T3))**2+(E*(T5-T4))**2+(
     1P*(T5-T))**2+(PL1*(T5-T1))**2)
      RETURN
      END
```

III.12 FUNCTION HCLNT(A)

```
C
C     CORRELATION BETWEEN HEAT TRANSFER AND FLOW RATE
C
C     A = RATIO OF NOMINAL TO DEVIATED FLOW RATE
C
C     B,C = QUANTITIES DEPENDING ON COOLANT TYPE
C
      COMMON B,C
      HCLNT=A**B*(1.-B*C*(A-1.))
      RETURN
      END
```

```
III.13 SUBROUTINE HOTSPT (I1,I2,KK,IZ,K,IS,TCLI,XL,S,EXPNUM,
     1SSPOT,XNSPOT,TCLO,NAP,XMCHEQ,SCH,SCHEQ,EXPCH)
C
C      SUBROUTINE FOR CHANNEL ANALYSIS
C
C      I1      =0 FOR COOLANT
C              1 FOR CLAD
C              2 FOR FUEL
C      I2      ICL,IFL (SEE LEGGI)
C      KK      KCLAD,KFUEL (SEE MAIN)
C      IZ      IZCL,IZFL (SEE INTERP.)
C      K,IS    ZONE,SUBZONE INDEX
C      TCLI    COOL.INLET TEMP
C      XL      SPOT LENGTH
C      S       TOTAL STAND.DEV
C      EXPNUM EXPECTED NUMBER OF HOT SPOTS IN THE CHANNEL
C      SSPOT   LOCAL STAND.DEV.   ( C )
C      XXNSPOT EQUIV.NUMB.OF SPOTS
C      TCLO    OUTLET COOL.TEMP.(ONLY FOR I1=0)
C      NAP     NUMBER OF PINS IN THE CHANNEL
C      XMCHEQ MEAN-CH-EQ
C      SCH     CHANNEL STAND.DEV.
C      SCHEQ SIGMA-CH-EQ
C      EXPCH   PROB.THAT THE CHANNEL HAS AT LEAST ONE HOT SPOT
C
      DIMENSION SX(300),G(300) ,TR(300)
      COMMON DUMM(1402),TICOOL(300),TICLA(300),TICLM(300),TICLI(300),TIF
     10(300),TIFI(300),ZI(300),CSDTC,CSDTA,CSDTCL,CSDTG,CSDTF,CSDP,CSDFT
     2,ZSDTC(30,5),ZSDTA(30,5),ZSDTCL(30,5),ZSDTG(30,5),ZSDTF(30,5),
     3 SSDTC(30,5),SSDTA(30,5),SSDTCL(30,5),SSDTG(30,5),SSDTF(30,5),
     4 PSDTC(30,5),PSDTA(30,5),PSDTCL(30,5),PSDTG(30,5),PSDTF(30,5),
     5 LSDTC(30,5),LSDTA(30,5),LSDTCL(30,5),LSDTG(30,5),LSDTF(30,5),
     6ZSDP(30,5),ZSDFT(30,5),SSDP(30,5),SSDFT(30,5),PSDP(30,5),PSDFT(30,
     75),LSDP(30,5),CRTF(30,5),CRSTF(30,5),CRTCL(30,5),CRSTCL(30,5),TC,
     1STC
      REAL LSDTC,LSDTCL,LSDTA,LSDTG,LSDTF,LSDP
      XLL=1./XL
      SQ=SQRT(XLL)
C
C      GROUPING OF THE UNCERTAINTIES
C
      SDCC=CSDTC**2+ZSDTC(K,IS)**2+SSDTC(K,IS)**2+PSDTC(K,IS)**2
      IF(I1.EQ.0 ) GO TO 2
      SDTA=SQRT(CSDTA**2+ZSDTA(K,IS)**2+SSDTA(K,IS)**2+PSDTA(K,IS)**2)
      SDTAL=SQRT(LSDTA(K,IS)**2+(HCLNT(1.+LSDTC(K,IS))-1.)**2)*SQ
      IF(I1.EQ.1.AND.I2.EQ.1) GO TO 2
      SDTCL=SQRT(CSDTCL**2+ZSDTCL(K,IS)**2+SSDTCL(K,IS)**2+PSDTCL(K,IS)*
     1*2)
      SDTCLL=LSDTCL(K,IS)*SQ
      IF(I1.EQ.1) GO TO 2
      SDTG=SQRT(CSDTG**2+ZSDTG(K,IS)**2+SSDTG(K,IS)**2+PSDTG(K,IS)**2)
      SDTGL=LSDTG(K,IS)*SQ
      IF(I2.EQ.1) GO TO 2
      SDTF=SQRT(CSDTF**2+ZSDTF(K,IS)**2+SSDTF(K,IS)**2+PSDTF(K,IS)**2)
```

```
      SDTFL=LSDTF(K,IS)*SQ
    2 SDP=SQRT(CSDP**2+ZSDP(K,IS)**2+SSDP(K,IS)**2+PSDP(K,IS)**2 )
      SDFT=CSDFT**2+ZSDFT(K,IS)**2+SSDFT(K,IS)**2+PSDFT(K,IS)**2
      IF(I1.NE.0) GO TO 13
C
C     COOLANT ANALYSIS
C
      SDTC=SQRT(SDCC+LSDTC(K,IS)**2*XLL)
      SDPL2=LSDP(K,IS)*SQ
      SDFT=SQRT(SDFT+STC**2)
      S=SIGMA(0,1,TCLI,TCLO,TCLO,T3,T4,T5,SDTC,0.,0.,0.,0.,SDFT,SDP,0.,
     1SDPL2)
      SSPOT=SIGMA(0,1,TCLI,TCLO,TCLO,T3,T4,T5,LSDTC(K,IS)*SQ       ,0.,
     10.,0.,0.,0.,0.,0.,SDPL2)
      XMCHEQ=0.
      SCH=SIGMA(0,1,TCLI,TCLO,TCLO,T3,T4,T5,PSDTC(K,IS),0.,0.,0.,0.,
     1PSDFT(K,IS),PSDP(K,IS),0.,0.)
      SCHEQ=SQRT(SSPOT**2+SCH**2)
      EXPCH=0.5-0.5*ERF((TC-TCLO)/(1.414232*S))
      RETURN
   13 IF(I1.EQ.1) GO TO 17
      SDFT=SQRT(SDFT+CRSTF(K,IS)**2)
      TICR=CRTF(K,IS)
      GO TO 18
   17 SDFT=SQRT(SDFT+CRSTCL(K,IS)**2)
      TICR=CRTCL(K,IS)
   18 INDEX=0
C
C     HOT SPOT EXPECTATION(EXPNUM)
C
      EXPNUM =0.
      XSPOT=0.
      SDPL1=LSDP(K,IS)*SQ
      I=IZ
      K1=IZ
      K2=IZ
      SDTC=SQRT(SDCC)
    9 AB=1./SQRT(ABS(ZI(I)-ZI(1)))
      SDTLC=LSDTC(K,IS)*AB
      SDPL2=LSDP(K,IS)*AB
      IF(I1.EQ.1.AND.I2.LE.2) TITI=TICLM(I)
      IF(I1.EQ.2.OR.I2.EQ.3) TITI=TICLI(I)
      G(I)=SIGMA(I1,I2,TCLI  ,TICOOL(I),TICLA(I),TITI,TIFO(I),TIFI(I),SD
     1TC,SDTA,SDTCL,SDTG,SDTF,SDFT,SDP,0.0,0.0 )
      SX(I)=SIGMA(I1,I2,TCLI,TICOOL(I ),TICLA(I ),TITI,TIFO(I ),TIFI(I )
     1,SDTLC,SDTAL,SDTCLL,SDTGL,SDTFL,0.0,0.,SDPL1,SDPL2)
      X=SQRT(G(I)**2+SX(I)**2)
      IF(I.NE.IZ) GO TO 4
      SCH=SIGMA(I1,I2,TCLI,TICOOL(IZ),TICLA(IZ),TITI,TIFO(IZ),TIFI(IZ),
     1PSDTC(K,IS),PSDTA(K,IS),PSDTCL(K,IS),PSDTG(K,IS),PSDTF(K,IS),PSDFT
     2(K,IS),PSDP(K,IS),0.,0.)
      S=X
      SSPOT=SX(I)
      Q=G(I)
```

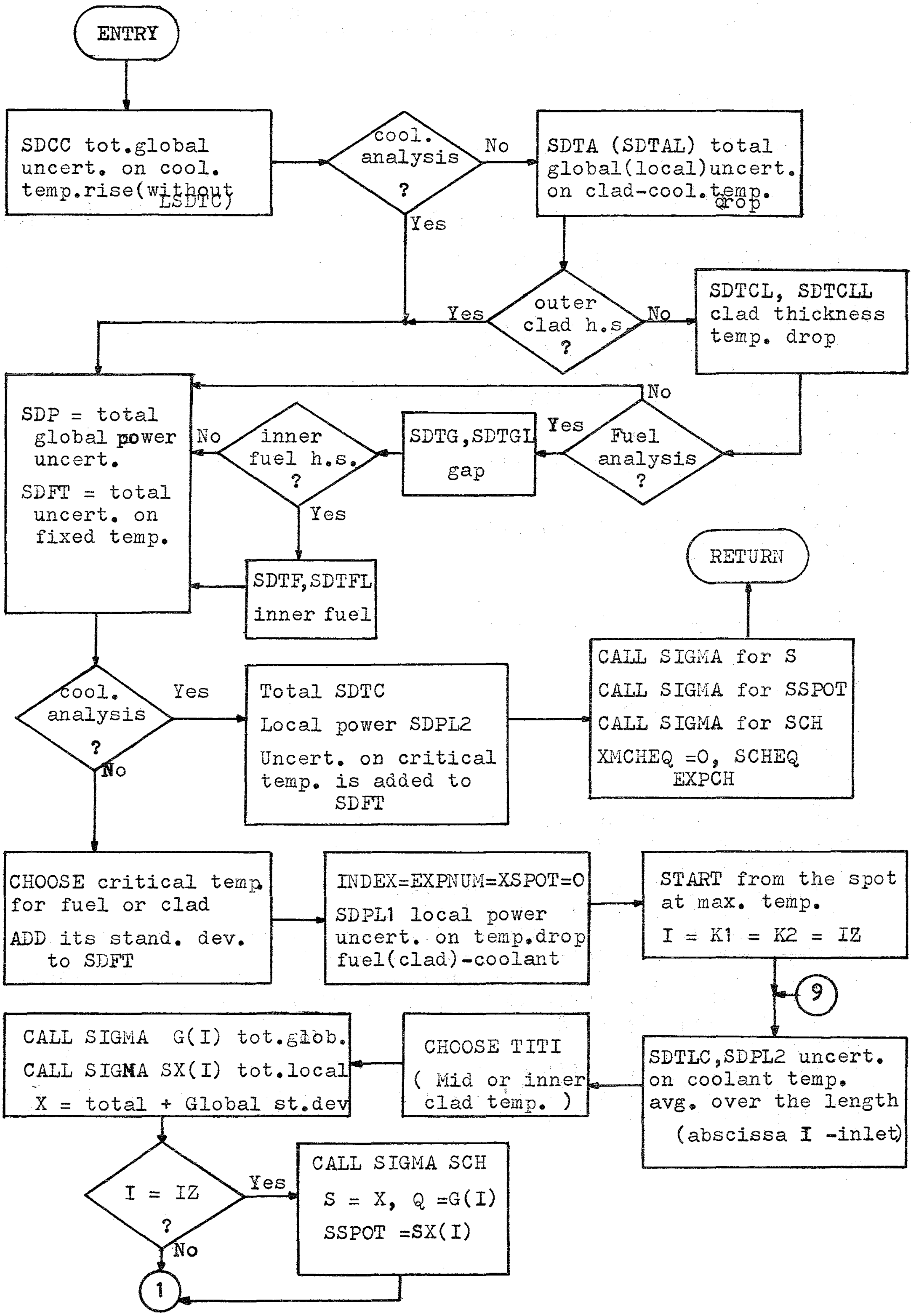

FIG.9a - Flow-Chart of HØTSPT - I

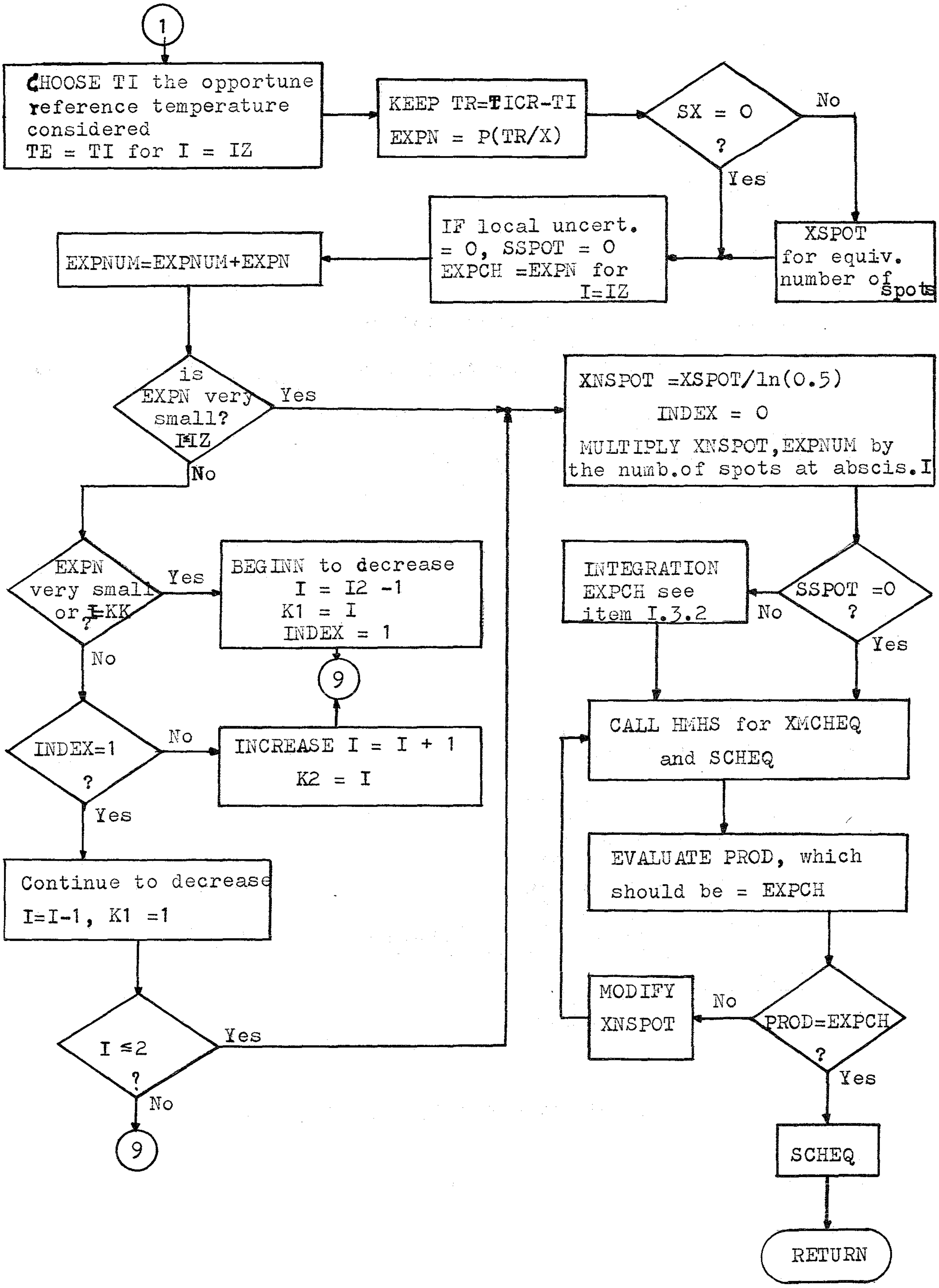

FIG.9b - HØTSPT - II

```
    4 IF(I1.EQ.2) GO TO 3
      GO TO (5,6,7),I2
    5 TI=TICLA(I)
      GO TO 10
    6 TI=TICLM(I)
      GO TO 10
    7 TI=TICLI(I)
      GO TO 10
    3 IF(I2.EQ.2) GO TO 8
      TI=TIFO(I)
      GO TO 10
    8 TI=TIFI(I)
   10 IF(I.EQ.IZ) TE=TI
      TR(I)=TICR-TI
      EXPN=0.5-0.5*ERF(TR(I) /(1.414232*X))
C     FIRST EVALUATION OF XNSPOT
      IF (SX(I).GT.0.) XSPOT=XSPOT+ALOG(0.5+0.5*ERF((TE-TI)/(1.414232*
     1SX(I)))  )
      IF(I.EQ.IZ.AND.SSPOT.LE.0.) EXPCH=EXPN
      EXPNUM=EXPNUM+EXPN
      IF(EXPN.LT.1.E-12.AND.I.LE.IZ) GO TO 100
      IF(EXPN.LT.1.E-12.OR.I.EQ.KK) GO TO 11
      IF(INDEX.EQ.1) GO TO 12
      I=I+1
      K2=I
      GO TO 9
   11 I=IZ-1
      K1=I
      INDEX=1
      GO TO 9
   12 I=I-1
      K1=I
      IF (I-2) 100,100,9
  100 XNSPOT=-XSPOT/0.69315
      INDEX=0
      IF (XNSPOT.EQ.0.) XNSPOT=1.
      XNSPOT=XNSPOT*FLOAT(NAP)
      EXPNUM=EXPNUM*FLOAT(NAP)
      IF(SSPOT.LE.0.) GO TO 201
      IF (EXPNUM.EQ.0.) GO TO 300
      AA=SQRT(ABS(ZI(K1)-ZI(1)))
      SCLOC=SIGMA(0,0,TCLI,TICOOL(K1),T3,T3,T4,T5,LSDTC(K,IS)/AA,0.,0.,
     10.,0.,0.,0.,0.,LSDP(K,IS)/AA)**2
      DO 101 I=K1,K2
      G(I)=SQRT(G(I)**2+SCLOC)
  101 SX(I)=SQRT(SX(I)**2-SCLOC )
      SUM1=0.
      N2=24
C
C     INTEGRATION FOR HOT CHANNEL EXPECTATION (EXPCH)
C
  230 SUM=0.
      N=N2-1
      TEMP=12./FLOAT(N2)
```

```
      DO 200 L=1,N
      X=FLOAT(L)*TEMP-6.
      Y=EXP(-0.5*X**2)
      PROD=1.
      ABC=0.5+0.5*ERF((      TR(IZ)-X*G(IZ))/(1.414232*SX(IZ)))
      IF (ABC.GE.1.) GO TO 200
      DO 250 I=K1,K2
      PROD=PROD*(0.5+0.5*ERF((      TR(I)-X*G(I))/(1.414232*SX(I))))
      IF (PROD.LE.1.E-5 ) GO TO 200
  250 CONTINUE
  200 SUM=SUM+Y*(1.-PROD**NAP)
      AREA=TEMP*SUM*0.398942
      IF(AREA.EQ.0.) GO TO 240
      BB=ABS(SUM1/AREA-1.)
      IF(BB.LE.0.01 ) GO TO 260
      SUM1=AREA
  240 N2=2*N2
      IF(N2.LT.2000) GO TO 230
      WRITE(6,1000)
 1000 FORMAT(1X,'PRECISION NOT OBTAINED')
  260 EXPCH=AREA
      IF (EXPCH.LE.EXPNUM) GO TO 201
      IF (EXPCH-EXPNUM-1.E-5) 300,300,301
  301 WRITE(6,1001) EXPCH
 1001 FORMAT(1X,'EXPCH.GT.EXPNUM.AND.EQ. ',E10.3)
  300 EXPCH=EXPNUM
C
C     FINAL EVALUATION OF XNSPOT,XMCHEQ,SCHEQ
C
  201 CALL HMHS(SSPOT,XNSPOT,XMCHEQ,SCHEQ)
      SCHEQ=SCHEQ**2
      X=SQRT(SCHEQ+Q**2)
      PROD=0.5-0.5*ERF((TR(IZ)-XMCHEQ)/(1.414232*X))
      IF (PROD-EXPCH) 310,311, 312
  310 XNSPOT=XNSPOT+1.
      INDEX=2
      GO TO 201
  312 IF(INDEX.EQ.2) GO TO 311
      XNSPOT=XNSPOT-5.
      IF (XNSPOT.GE.1.) GO TO 201
      XNSPOT=0.
      GO TO 310
  311 SCHEQ=SQRT(SCHEQ+SCH**2)
      RETURN
      END
```

```
III.14 SUBROUTINE HOTSA(N,I,M,REF,NZ,I2,TIN,SIGS,SIGZ,SIGC,TM,
     1EQCH,SEQCH,EXPSUB)
C
C     SUBROUTINE FOR SUBASSEMBLY ANALYSIS
C
C     N      NUMBER OF CHANNELS
C     NZ,IS  ZONE,SUBZONE INDEX
C     M      =0 FOR COOLANT
C      1 FOR CLAD
C      2 FOR FUEL
C     REF    REF.TEMP.
C     I2     ICL,IFL (SEE LEGGI)
C     TIN    COOL.INLET TEMP.
C     SIGS   SUBASS. STAND.DEV.   ( C )
C     SIGZ   ZONE    STAND.DEV.   ( C )
C     SIGC   CORE    STAND.DEV.   ( C )
C     TM     MEAN-S-EQ
C     EQCH   EQUIV.NUMBER OF CHANNELS
C     SEQCH  SIGMA-S-EQ
C     EXPNUM PROB.THAT AT LEAST ONE HOT SPOT OCCURS
C
      DIMENSION XNCH(546),RTMAX(3,5,546),TIC(2,5,546),TIA(2,5,546),TICL(
     15,546),TIG(5,546),EQSIG(3,5,546),EQMEAN(2,5,546),XXCH(546),SG(546)
      COMMON DUMM(1402),TICOOL(300),TICLA(300),TICLM(300),TICLI(300),TIF
     10(300),TIFI(300),ZI(300),CSDTC,CSDTA,CSDTCL,CSDTG,CSDTF,CSDP,CSDFT
     2,ZSDTC(30,5),ZSDTA(30,5),ZSDTCL(30,5),ZSDTG(30,5),ZSDTF(30,5),
     3 SSDTC(30,5),SSDTA(30,5),SSDTCL(30,5),SSDTG(30,5),SSDTF(30,5),
     4 PSDTC(30,5),PSDTA(30,5),PSDTCL(30,5),PSDTG(30,5),PSDTF(30,5),
     5 LSDTC(30,5),LSDTA(30,5),LSDTCL(30,5),LSDTG(30,5),LSDTF(30,5),
     6ZSDP(30,5),ZSDFT(30,5),SSDP(30,5),SSDFT(30,5),PSDP(30,5),PSDFT(30,
     75),LSDP(30,5),CRTF(30,5),CRSTF(30,5),CRTCL(30,5),CRSTCL(30,5),TC,
     1STC  ,EHCHC(30,5),EHCHCL(30,5),EHCHFL(30,5),XXCH,RTMAX,TIC,TIA,TICL
     2,TIG,EQSIG,EQMEAN ,DUMMA(81),TCC(30,5),TCA(30,5)
      XCH=0.
      K=M
      IF(M.EQ.0) K=3
C
C     THE CHANNELS ARE ORDERED ACCORDING TO DECREASING HOT SPOT PROB.
C
      DO 7 J=1,N
    7 XNCH(J)=XXCH(J)
      L1=N-1
      DO 2 II=1,L1
      L2=II+1
      DO 2 J=L2,N
      XNN=     RTMAX(K,I,II)-RTMAX(K,I,J)+3.*(EQSIG(K,I,II)-EQSIG(K,I,J))
      IF(K.NE.3) XNN=EQMEAN(K,I,II)-EQMEAN(K,I,J) +XNN
      IF (XNN.GE.0.) GO TO 2
      TEMP=RTMAX(K,I,II)
      RTMAX(K,I,II)=RTMAX(K,I,J)
       RTMAX(K,I,J)=TEMP
      TEMP=EQSIG(K,I,II)
      EQSIG(K,I,II)=EQSIG(K,I,J)
       EQSIG(K,I,J)=TEMP
```

```
      TEMP=XNCH(II)
      XNCH(II)=XNCH(J)
      XNCH(J)  =TEMP
      IF (K.EQ.3) GO TO 2
      TEMP=TIC(K,I,II)
        TIC(K,I,II)=  TIC(K,I,J)
         TIC(K,I,J)=TEMP
      TEMP=TIA(K,I,II)
        TIA(K,I,II)=  TIA(K,I,J)
         TIA(K,I,J)=TEMP
      TEMP=EQMEAN(K,I,II)
      EQMEAN(K,I,II)=EQMEAN(K,I,J)
      EQMEAN(K,I,J)=TEMP
      IF (K.EQ.1) GO TO 2
      TEMP=TICL(I,II)
      TICL(I,II)=TICL(I,J)
      TICL(I,J)=TEMP
      TEMP= TIG(I,II)
      TIG (I,II)=TIG (I,J)
       TIG(I,J)=TEMP
    2 CONTINUE
      TEMP=1.
      REF=RTMAX(K,I,1)
      IF (K.NE.1) GO TO 3
      TCC(NZ,I)=TIC(1,I,1)
      TCA(NZ,I)=TIA(1,I,1)
    3 DO 31 J=1,N
      GO TO (44,45,46),K
   44 T1=TIC(1,I,J)
      T2=TIA(1,I,J)
      T3=RTMAX(1,I,J)
      T=T3+EQMEAN(1,I,J)
      IF (J.GT.1) GO TO 11
      TM=EQMEAN(1,I,1 )
      XNN=EHCHCL(NZ,I)
      S=CRSTCL(NZ,I)
      TCR=CRTCL(NZ,I)
      GO TO 10
   45 T1=TIC(2,I,J)
      T2=TIA(2,I,J)
      T3=TICL(I,J)
      T4=TIG(I,J)
      T5=RTMAX(2,I,J)
      T=T5+EQMEAN(2,I,J)
      IF (J.GT.1) GO TO 11
      TM=EQMEAN(2,I,1)
      XNN=EHCHFL(NZ,I)
      S=CRSTF(NZ,I)
      TCR=CRTF(NZ,I)
      GO TO 10
   46 T1=RTMAX(3,I,J)
      T=T1
      IF (J.GT.1) GO TO 11
      TM=0.
```

```
      XNN=EHCHC (NZ,I)
      S=STC
      TCR=TC
C
C     GROUPING OF THE UNCERTAINTIES
C
   10 A=SQRT(SSDTC(NZ,I)**2+ZSDTC(NZ,I)**2+CSDTC**2)
      B=SQRT(SSDTA(NZ,I)**2+ZSDTA(NZ,I)**2+CSDTA**2)
      C=SQRT(SSDTCL(NZ,I)**2+ZSDTCL(NZ,I)**2+CSDTCL**2)
      D=SQRT(SSDTG(NZ,I)**2+ZSDTG(NZ,I)**2+CSDTG**2)
      E=SQRT(SSDTF(NZ,I)**2+ZSDTF(NZ,I)**2+CSDTF**2)
      F=SQRT(SSDFT(NZ,I)**2+ZSDFT(NZ,I)**2+CSDFT**2+S**2)
      P=SQRT(SSDP (NZ,I)**2+ZSDP (NZ,I)**2+CSDP**2)
      SIGS =SIGMA(M,I2,TIN,T1,T2,T3,T4,T5,SSDTC(NZ,I),SSDTA(NZ,I),SSDTCL
     1(NZ,I),SSDTG(NZ,I),SSDTF(NZ,I),SSDFT(NZ,I),SSDP(NZ,I),0.,0.)
      SIGZ =SIGMA(M,I2,TIN,T1,T2,T3,T4,T5,ZSDTC(NZ,I),ZSDTA(NZ,I),ZSDTCL
     1(NZ,I),ZSDTG(NZ,I),ZSDTF(NZ,I),ZSDFT(NZ,I),ZSDP(NZ,I),0.,0.)
      SIGC =SIGMA(M,I2,TIN,T1,T2,T3,T4,T5, CSDTC,CSDTA,CSDTCL,CSDTG,
     1CSDTF,CSDFT,CSDP,0.,0.)
      TT=REF+TM
      IF (EQSIG(K,I,1).EQ.0.0.OR.XNN.EQ.0.) GO TO 21
   11 SG(J)=SIGMA(M,I2,TIN,T1,T2,T3,T4,T5,A,B,C,D,E,F,P,0.,0.)
        IF(TEMP.EQ.0.0) GO TO 106
      TEMP=ALOG(0.5+0.5*ERF((TT-T)/(EQSIG(K,I,J)*1.414232)))
   31 XCH=XCH+XNCH(J)*TEMP
  106 EQCH=-XCH/0.69315
      GO TO 100
   21 EQCH=XNCH(1 )
      T=TCR-TM-REF
      CALL HMHS(EQSIG(K,I,1) ,EQCH,T1,SM)
      IF(EQSIG(K,I,1).EQ.0.)  EXPSUB=0.5-0.5*ERF(T/(1.414232*
     1SIGMA(M,I2,TIN,REF,T2,T3,T4,T5,A,B,C,D,E,F,P,0.,0.)))
      IF(XNN.EQ.0.) EXPSUB=0.
      GO TO 311
  100 INDEX=0
C
C     INTEGRATION FOR EVALUATION OF EXPSUB
C
      SUM1=0.
      N2=24
  230 SUM=0
      N1=N2-1
      TEMP=12./FLOAT(N2)
      DO 300 L=1,N1
      X=FLOAT(L)*TEMP-6.
      Y=EXP(-0.5*X**2)
      PROD=0.
      DO 250 J=1,N
      T=TCR-RTMAX(K,I,J)-X*SG(J)
      IF(K.NE.3) T=T-EQMEAN(K,I,J)
      ABC=0.5+0.5*ERF(T/(1.414232*EQSIG(K,I,J)))
      IF (ABC.GE.1.) GO TO 210
      IF(ABC.EQ.0.) GO TO 212
  250 PROD=PROD+ALOG(ABC)*XNCH(J)
```

```
  210 IF(PROD.GT.-100) GO TO 215
  212 PROD=0.
      GO TO 300
  215 PROD=EXP(PROD)
  300 SUM=SUM+Y*(1.-PROD)
      AREA=TEMP*SUM*0.398942
      IF (AREA.EQ.0.) GO TO 240
      IF(ABS(SUM1/AREA-1.).LE.0.01) GO TO 260
      SUM1=AREA
  240 N2=2*N2
      IF (N2.LT.2000) GO TO 230
      WRITE(6,1000) K
 1000 FORMAT(1X,'PRECISION NOT OBTAINED HOTSA K=',I2)
  260 EXPSUB=AREA
      IF(EXPSUB.LE.XNN) GO TO 200
      IF(EXPSUB.GT.XNN+1.E-4) WRITE(6,1001) EXPSUB,K
 1001 FORMAT(1X,'EXPSUB.GT.EXPCH.AND.EQ. ',E10.3,' K=',I2)
      EXPSUB=XNN
  200 T=TCR-TM-REF
C
C     EVALUATION OF EQCH,TM,SEQCH
C
  201 CALL HMHS(EQSIG(K,I,1) ,EQCH,T1,SM)
      ABC=SQRT(SG(1)**2+SM**2)
      AREA =0.5-0.5*ERF((T-T1)/(1.414232*ABC))
      IF(AREA-EXPSUB) 310,311,312
  310 EQCH=EQCH+1.
      INDEX=2
      GO TO 201
  312 IF (INDEX.EQ.2) GO TO 311
      EQCH=EQCH-10.
      IF(EQCH.GE.1.) GO TO 201
      EQCH=0.
      GO TO 310
  311 SEQCH=SQRT(SM**2+SIGS**2     )
      TM=TM+T1
      RETURN
      END
```

III.15 SUBROUTINE HOTCR(I1,IM,JM,ID,K1,K2,IT,PR,ILU)

```
C
C            SUBROUTINE FOR CORE ANALYSIS
C
C      I1     =1 FOR ACTIVE ZONE
C             =2 FOR RADIAL BLANKET
C             =3 IF HOTCR IS CALLED BY FLOPT
C      IM,JM  =ZONE,SUBZONE OF MAX.HOT SPOT PROB.
C      ID     IF.LT.0 ONLY THE HOT CORE EXPECT. IS EVALUATED
C      K1,K2  FIRST AND LAST ZONE IND. FOR ACTIVE ZONE OR BLANKET
C      IT     =1,2,3 FOR COOL.,CLAD,FUEL RESPECTIVELY
C      PR     =PREASSIGNED CONF.LEVEL
C      ILU    =1 IF THE HOT PIN EXPECTATION MUST BE EVALUATED
C
      DIMENSION TEMP(30,5),SIGCOR(30,5),CRTEMP(30,5),SIGCR(30,5)
     1,DT(30,5),SI(30,5)
      COMMON DUM0(82),NUSUZ(30),NSASUZ(30,5),RTCS(30,5),RTCLS(30,5),RTFL
     1S(30,5),DUMM(4747),SIGCC(30,5),SIGCCL(30,5),SIGCFL(30,5),DUM1(1650
     2),CRTF(30,5),CRSTF(30,5),CRTCL(30,5),CRSTCL(30,5),TC,STC,DUM2(450)
     3,XNCH(546),EQMEAN(3,5,546),DUM3(16380),EQSIG(3,5,546),DUM4(5460),
     4FLRT(30),TOUT(30) ,EXPE(2,10),TINL
      IF (I1.EQ.3) GO TO 200
      I2=2*IT
      IF(IT.NE.3) I2=I2-1
      EXPEC=EXPE(I1,I2)
      IF (EXPEC.EQ.0.AND.ID.LE.0) RETURN
      IF (IT.EQ.1) WRITE(6,1010)
      IF (IT.EQ.2) WRITE(6,1020)
      IF (IT.EQ.3) WRITE(6,1030)
C
C      CHOISE OF THE QUANTITIES FOR COOL.,CLAD,OR FUEL ANALYSIS
C
  200 DO 1 I=K1,K2
      NA=NUSUZ(I)
      DO 1 J=1,NA
      GO TO (2,3,4),IT
    2 TEMP(I,J)=RTCS (I,J)
      SIGCOR(I,J)=SIGCC (I,J)
      CRTEMP(I,J)=TC
      SIGCR(I,J)=STC
      GO TO 6
    3 TEMP(I,J)=RTCLS(I,J)
      SIGCR(I,J)=CRSTCL(I,J)
      CRTEMP(I,J)=CRTCL(I,J)
      SIGCOR(I,J)=SIGCCL(I,J)
      GO TO 6
    4 TEMP(I,J)=RTFLS(I,J)
      SIGCR(I,J)=CRSTF (I,J)
      CRTEMP(I,J)=CRTF (I,J)
      SIGCOR(I,J)=SIGCFL(I,J)
    6 SI(I,J)=SQRT(SIGCR(I,J)**2+SIGCOR(I,J)**2)
    1 DT(I,J)=CRTEMP(I,J)-TEMP(I,J)-EQMEAN(IT,J,I)
      IF (EXPEC.EQ.0.AND.I1.NE.3) GO TO 100
      IF (EQSIG(IT,JM,IM).EQ.0.) GO TO 17
```

```
C
C     INTEGRATION FOR CALCULATION OF PROB. OF AT LEAST ONE HOT SPOT
C
      SUM1=0.
      N2=24
   14 SUM=0.
      N=N2-1
      TEM =12./FLOAT(N2)
      DO 11 L=1,N
      X=FLOAT(L)*TEM -6.
      Y=EXP(-0.5*X**2)
      PROD=1.
      ABC=ERF((DT(IM,JM)-X*SI(IM,JM))/(1.414232*EQSIG(IT,JM,IM)))
      IF (ABC.EQ.1.) GO TO 11
      DO 12 I=K1,K2
      NA=NUSUZ(I)
      DO 12 J=1,NA
      PROD=PROD*(.5+.5*ERF((DT(I,J)-X*SI(I,J))/(1.414232*EQSIG(IT,J,I)))
     1)
      IF (PROD.LE.1.E-6) GO TO 11
   12 CONTINUE
   11 SUM=SUM+Y*(1.-PROD)
      AREA=TEM *SUM*0.398942
      IF(AREA.EQ.0.) GO TO 13
      IF (ABS(SUM1/AREA-1.).LE.0.01) GO TO 16
      SUM1=AREA
   13 N2=2*N2
      IF (N2.LT.2000) GO TO 14
      WRITE (6,1000)
   16 EXI=AREA
      GO TO 20
   17 EXI=0.5-0.5*ERF(DT(IM,JM)/(1.414232*SI(IM,JM)))
   20 IF(I1.NE.3) GO TO 21
      PR=EXI
      RETURN
C
C     FINAL HOT ELEMENT EXPECTATION
C
   21 IF(EXI.GT.EXPEC) EXI=EXPEC
      PROD=EXI*100.
      IF (IT.GT.1) GO TO 30
      X=EXPE(I1,1)/EXPE(I1,2)
      Y=EXPE(I1,2)/EXI
      WRITE(6,1001) EXI,PROD,Y,X
      GO TO 100
   30 N2= 3
      IF (IT.EQ.3) N2=6
      X=EXPE(I1,N2+2)/EXPE(I1,N2+1)
      Y=EXPE(I1,N2+1)/EXPE(I1,N2)
      ABC=EXPE(I1,N2)/EXI
      WRITE(6,1002) EXI,PROD,ABC,Y,X
      IF(ILU.NE.1) GO TO 100
      N3=9
      IF(IT.EQ.3) N3=10
```

```
      XX=X*Y
      Y=EXPE(I1,N3)/EXPE(I1,N2)
      X=XX/Y
      WRITE(6,1040) X,Y
  100 IF(ID.EQ.0) RETURN
C
C     EVALUATION OF MAX.TEMP. VS CONF.LEVEL
C
      EQN=0.
      IF (EQSIG(IT,JM,IM).EQ.0.) GO TO 102
      DO 101 I=K1,K2
      NA=NUSUZ(I)
      DO 101 J=1,NA
  101 EQN=EQN+ALOG(0.5+0.5*ERF((TEMP(IM,JM)+EQMEAN(IT,JM,IM)-TEMP(I,J)-
     1EQMEAN(IT,J,I))/(1.414232*EQSIG(IT,J,I)))))
      EQN=-EQN/0.69315
      GO TO 103
  102 EQN=1.
  103 CALL HMHS(EQSIG(IT,JM,IM),EQN,EQMC,SIGC)
      EQMC=EQMEAN(IT,JM,IM)+EQMC
      SIGC=SQRT(SIGC**2+SIGCOR(IM,JM)**2)
      WRITE(6,1003) EQN,EQMC,SIGC
      DO 104 I=1,9
      AB=0.5*FLOAT(I-1)
      PROB=0.5-0.5*ERF(AB/1.414232)
      CONF=1.-PROB
      TEM=TEMP(IM,JM)+EQMC+AB*SIGC
  104 WRITE(6,1004) PROB,AB,CONF,TEM
      WRITE(6,1005)
      IF (PR.LE.0.) RETURN
C
C     EVALUATION OF A HOT SPOT FACTOR FOR A NEW ITERATION
C
      SIGC=SQRT(SIGC**2+SIGCR(IM,JM)**2)
      DTMAX=TEMP(IM,JM)-TINL
      HSF=1.+(EQMC+PR*SIGC)/DTMAX
      HSF1=(CRTEMP(IM,JM)-TINL)/DTMAX
      IF(ABS(HSF/HSF1-1.).GT.0.002) GO TO 105
  106 WRITE(6,1006) HSF
      RETURN
  105 HS=HSF1/HSF
      WRITE (6,1007) HSF,HSF1
      IF(HS.LT.1.) GO TO 107
      WRITE(6,1008) DTMAX,HS
      RETURN
  107 HS=1./HS
      WRITE(6,1009) DTMAX,HS
C
C              FORMAT STATEMENTS
C
 1000 FORMAT(' PRECISION NOT OBTAINED')
 1001 FORMAT(' PROB. OF AT LEAST ONE HOT CHANNEL=', E14.6///' ON THE AVG
     1.',E10.3,' CORES OUT OF 100 ARE EXPECTED TO CONTAIN ',F10.2,
     2' SUBASS. HAVING ',F10.2,' HOT CHANNELS'///)
```

```
1002 FORMAT(' PROB. OF AT LEAST ONE HOT SPOT=', E14.6///' ON THE AVG.',
    1E10.3,' CORES OUT OF 100 ARE EXPECTED TO CONTAIN',F10.2,' SUBASS.
    2HAVING',F10.2,' CHANNELS WITH',F10.2,' HOT SPOTS'/13X,9(1H-),42X,
    39(1H-),16X,9(1H-),15X,9(1H-)///)
1003 FORMAT(' APPROX. EVALUATION OF EXPECTED MAX. TEMPERATURES'//' EQUI
    1V. NUMBER OF ZONES=',F8.2,10X,'M-C-EQ=',F8.2, 10X,'S-C-EQ=',F8.2//
    2' PROB. OF EXCEEDING',15X,'CONFIDENCE LEVEL',15X,'MAX.TEMP.'/1X,45
    3(2H--))
1004 FORMAT(8X,E10.2,10X,'(',F3.1,'SIGMA)',E14.6,11X,F10.2)
1005 FORMAT(1X,45(2H--)///)
1006 FORMAT(' THE REQUIRED HOT SPOT FACTOR',F10.4,' HAS BEEN ASSUMED IN
    1 THE DESIGN'///)
1007 FORMAT(' REQUIRED HOT SPOT FACTOR =',F10.4,10X,'ACTUAL HSF=',F10.4
    1/)
1008 FORMAT(' THE TEMP. DROP (REF.TEMP-INLET TEMP.=',  F10.2,') COULD B
    1E INCREASED BY A FACTOR=',F10.4///)
1009 FORMAT(' THE TEMP.DROP (REF. TEMP-INLET TEMP.=',F10.2, ') MUST BE
    1DECREASED BY A FACTOR=',F10.4///)
1010 FORMAT(1H1,40X,'HOT CHANNEL'///)
1020 FORMAT(1H1,40X,'CLAD HOT SPOT'///)
1030 FORMAT(1H1,40X,'FUEL HOT SPOT'///)
1040 FORMAT(' AVERAGE HOT SPOTS PER PIN=',F10.2,10X,'HOT PINS PER SUBAS
    1S.=',F10.2///)
     RETURN
     END
```

III.16 SUBROUTINE HMHS(S,X,HM,HS)

```
C
C     SUBROUTINE FOR EVALUATION OF THE MEAN (HM) AND STAND.DEV. (HS) OF
C           THE EQUIVALENT NORMAL DISTRIBUTION OF THE MAXIMUM IN X
C           SAMPLES FROM THE NORMAL DISTRIBUTION (0,S)
C
      Y=ALOG10(X)
      HM=(1.70694+0.54372*Y-1.70169*EXP(-0.81888*Y))*S
      HS=(0.62589-0.03584*Y+0.37230*EXP(-0.82554*Y))*S
      RETURN
      END
```

III.17 SUBROUTINE FLOPT(NZ)

```
C
C     SUBROUTINE FOR FLOW-RATE OPTIMIZATION
C
C     TCC     =REF.COOL.TEMP.
C     TCA     =REF.OUTER CLAD TEMP.
C     NSUB    =TOTAL NUMBER OF SUBASS. IN A ZONE
C     FL      TOTAL CORE FLOW-RATE
C     TEM     AVG.COOL.TEMP.AT CORE OUTLET
C
      DIMENSION JM(30),DX(30)
      COMMON EX,CO,DUMO(80),NUSUZ(30),NSASUZ(30,5),RTCS(30,5),
     1RTCLS(30,5),DUM1(300),SISCL(30,5),DUM2(2647),SEQSCL(30,5),DUM3(180
     20),SIGCCL(30,5),ABC(150),SIGZCL(30,5),DUM4(1050),EQMSCL(30,5),
     3DUM5(600),CRTCL(30,5),CRSTCL(30,5),DUM6(998),EQMEAN(3,5,546),
     5DUM7(16380),EQSIG(3,5,546),EQM8(5460),FLRT(30),TOUT(30),DUM9(20),
     5TH1Q,TCC(30,5),TCA(30,5),NSUB(30)
      EQUIVALENCE (DUM1(1),JM(1)),(DUM2(1),DX(1))
      WRITE(6,1000)
      FL=0.
      B=10000
      TEM=0.
C
C     EVALUATION OF THE MOST CRITICAL SUBZONES
C
      DO 1 I=1,NZ
      NA=NUSUZ(I)
      FL=FL+FLRT(I)*FLOAT(NSUB(I))
      TEM=TEM+FLRT(I)*TOUT(I)*FLOAT(NSUB(I))
      C=10000.
      DO 2 J=1,NA
      CALL HMHS(SEQSCL(I,J),FLOAT(NSASUZ(I,J)),E,D)
      EQMEAN(2,J,I)=E+EQMSCL(I,J)
      EQSIG (2,J,I)=D**2+SIGZCL(I,J)**2
      D=CRTCL(I,J)-(RTCLS(I,J)+EQMEAN(2,J,I)+3.*SQRT(EQSIG(2,J,I)+SIGCCL
     1(I,J)**2+CRSTCL(I,J)**2))
      EQSIG(2,J,I)=SQRT(EQSIG(2,J,I))
C     RTCS KEEPS THE INITIAL VALUE OF CLAD REF.TEMP.
      RTCS(I,J)=RTCLS(I,J)
      IF (D.GE.C) GO TO 2
      C=D
      JM(I)=J
      DX(I)=C
    2 CONTINUE
      NA=JM(I)
      IF(C.GE.B) GO TO 1
      IM=I
      B=C
    1 WRITE(6,1001) I,NSUB(I),FLRT(I),TOUT(I),JM(I),RTCLS(I,NA)
      TEM=TEM/FL
C     EVALUATION OF THE TOTAL HOT SPOT PROB.WHICH MUST BE A CONSTANT
      CALL HOTCR(3,IM,JM(IM),KCL,1,NZ,2,PR,IL)
      WRITE(6,1002) FL,TEM ,PR
C
```

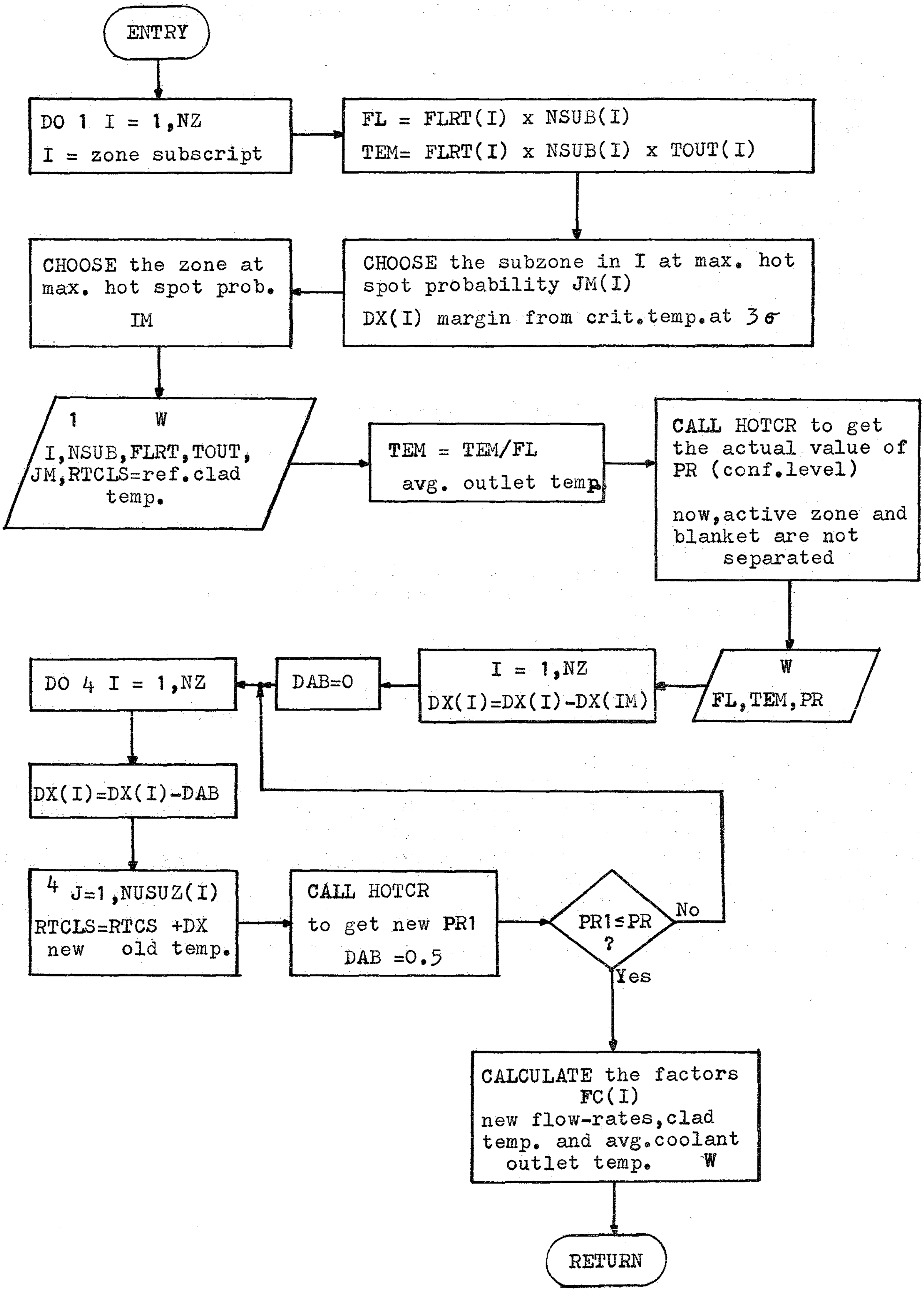

FIG. 10- Flow-Chart of FLØPT

```
C     EQUALIZATION OF THE HOT SPOT PROB.OF THE SUBASS.AND ITERATION
C
      DO 3 I=1,NZ
    3 DX(I)=DX(I)-DX(IM)
      DAB=0.
      FL=0.
      TEM=0.
      WRITE(6,1003)
    6 DO 4 I=1,NZ
      DX(I)=DX(I)-DAB
      NA=NUSUZ(I)
      DO 4 J=1,NA
    4 RTCLS(I,J)=RTCS(I,J)+DX(I)
      CALL HOTCR(3,IM,JM(IM),KCL,1,NZ,2,PR1,IL)
      DAB=0.5
      IF (PR1-PR) 10,10,6
C
C     EVALUATION OF THE NEW FLOW-RATES AND AVG.TEMP.
C
   10 DO 11 I=1,NZ
      NA=JM(I)
      DXA=0.
      DTCC=TCC(I,NA)-TH1Q
   12 FC=(DX(I)-DXA)/DTCC+1.
      DXA=(HCLNT(FC)-1.)*(TCA(I,NA)-TCC(I,NA))
      IF(ABS(DX(I)-DXA-(FC-1.)*DTCC).GT.0.5) GO TO 12
      FLRT(I)=FLRT(I)/FC
      TOUT(I)=(TOUT(I)-TH1Q)*FC +TH1Q
      FL=FL+FLRT(I)*FLOAT(NSUB(I))
      TEM=TEM+FLRT(I)*TOUT(I)*FLOAT(NSUB(I))
   11 WRITE(6,1004) I,DX(I),RTCLS(I,NA),FC    ,FLRT(I),TOUT(I)
      TEM=TEM/FL
      WRITE(6,1002) FL,TEM,PR1
 1000 FORMAT(1H1,40X,'FLOW-RATE OPTIMIZATION'///' INITIAL VALUES'//' ZON
     1E',10X,'NSUB',15X,'FLRT',15X,'TOUT',15X,'JMAX',15X,'RTCLS')
 1001 FORMAT(1X,I3,10X,I5,2(10X,F10.2),I15,10X,F10.2)
 1002 FORMAT(1X,55(2H--)///' TOTAL FLOW-RATE=',E14.6,15X,' AVG. OUTLET T
     1EMP.=',F8.2,15X,'PROB=',E10.3/////)
 1003 FORMAT(' FINAL VALUES'//' ZONE',17X,'DX',15X,'RTCLS',18X,'FC',15X,
     1'FLRT',17X,'TOUT')
 1004 FORMAT(1X,I4,2(10X,F10.2),10X,F10.4,2(10X,F10.2))
      RETURN
      END
```

IV. Application to the FR 3 reactor core

IV.1 General data

The FR 3 reactor [8] is a conceptual design of a sodium cooled fast test reactor. The principal thermal data are the following:

sodium inlet temperature	230 °C
max. linear power	526 W/cm
nominal max. clad temp. (constant in every subassembly)	557 °C
nominal max. fuel temp.	2350 °C
nominal max. coolant temp. rise	298 °C
critical clad temperature	700 °C (± 7)
fuel melting point	2750 °C (± 30)

The active zone was divided into 6 radial zones for the thermal nominal calculations. Each zone was further divided into 3 subzones, in order to take into account a stady-state burn-up situation. This is accomplished by assuming different systematic power factors (1, 0.96 and 0.92 respectively for a 3-zone burn-up fuel cycle). Other systematic factors were assumed for the coolant flow-rate in a subchannel and for the power due to deviations on flux profile, provoked by control rod position. For further details on systematic factors, statistical uncertainties and core design, see Ref. [8].

The hot spot was chosen at inner clad and inner fuel over a length of 1 cm and 2 cm, respectively.

A listing of the input cards is given below. As can be seen from the input cards, evaluation of the maximum temperatures vs the confidence level is required only for fuel and clad analysis; moreover, for fuel and clad hot spot a 2.4σ confidence level, and optimization of the flow-rate distribution is required. The intermediate quantities must be printed only for the channels in which the total hot spot probability is = 0.001.

IV.2 Listing of Input Cards

```
REACTOR FR3
    6    0    3    9    1    0    3    2    0    2    1    0    0
 0.0      2.4       2.4       0.001
    1    1              3    6    6    6
    2    2              3    4    4    4
    3    3              3    8    8    8
    4    4              3    7    7    7
    5    5              3   11   11   11
    6    6              3   12   12   12
 2.        1.        880.      0.        2750.     30.       700.      7.
    1    1    1
 1.14      1.        1.        1.        1.
    1    1    2
 1.14      1.        1.        1.        0.96
    1    1    3
 1.14      1.        1.        1.        0.92
    1    2    1
 1.14      1.        1.        1.        1.01
    1    2    2
 1.14      1.        1.        1.        0.97
    1    2    3
 1.14      1.        1.        1.        0.93
    4    3    1    4    1    5    1    6    1
 1.14      1.        1.        1.        1.02
    4    3    2    4    2    5    2    6    2
 1.14      1.        1.        1.        0.98
    4    3    3    4    3    5    3    6    3
 1.14      1.        1.        1.        0.94
  0.8      0.7
    1    4    0    0    1    0    1    1    1
    1    3          CLAD THERMAL CONDUCTIVITY                          0.01
    1    5          FUEL THERMAL CONDUCTIVITY                          0.028
    1    6          FLUX CONTROL                                       0.025
    1    7          SODIUM INLET TEMPERATURE                           1.
    3    1    1    1    2    1    3
    2    1    0    0    0    0    0    1    0
    2    6          FLUX CALCULATION                                   0.0
    3    5    2    0    0    0    0    3    0
    3    1          ORIFICE CALIBRATION                                0.015
    3    1          PIN DIAMETER(4.7+0.025 MM)                         0.0115
    3    6          FLUX (CONTROL ROD)                                 0.005
    3    6          ENRICHMENT                                         0.005
    3    6          SUBASSEMBLY DISPLACEMENT                           0.005
    4    3    2    0    0    0    0    1    0
    4    1          ACTIVE LENGTH (1/2 PELLET)                         0.004
```

```
 4   1        PITCH (5.7+0.025)MM                            0.009
 4   6        PIN DISPLACEMENT                                0.01
 5   9   1   1   1   1   1   4
 5   1        LOCAL PRESSURE DROP                            0.04
 5   2        H.T. CLAD-NA                                   0.03
 5   3        CLAD THICKNESS                                 0.01
 5   4        H.T. GAP                                       0.12
 5   5        FUEL THERMAL CONDUCTIVITY                       0.03
 5   6        DENSITY                                        0.018
 5   6        ENRICHMENT                                    0.005
 5   6        AXIAL FLUX                                     0.025
 5   6        CLAD FUEL ECCENTRICITY                         0.025
 3   2   1   2   2   2   3
 2   1   0   0   0   0   0   1   0
 2   6        FLUX CALCULATION                               0.01
 3   5   2   0   0   0   0   3   0
 3   1        ORIFICE CALIBRATION                            0.015
 3   1        PIN DIAMETER(4.7+0.025 MM)                     0.0115
 3   6        FLUX (CONTROL ROD)                             0.015
 3   6        ENRICHMENT                                     0.005
 3   6        SUBASSEMBLY DISPLACEMENT                       0.005
 4   3   2   0   0   0   0   1   0
 4   1        ACTIVE LENGTH (1/2 PELLET)                     0.004
 4   1        PITCH (5.7+0.025)MM                            0.009
 4   6        PIN DISPLACEMENT                                0.01
 5   9   1   1   1   1   1   4
 5   1        LOCAL PRESSURE DROP                            0.04
 5   2        H.T. CLAD-NA                                   0.03
 5   3        CLAD THICKNESS                                 0.01
 5   4        H.T. GAP                                       0.12
 5   5        FUEL THERMAL CONDUCTIVITY                       0.03
 5   6        DENSITY                                        0.018
 5   6        ENRICHMENT                                    0.005
 5   6        AXIAL FLUX                                     0.025
 5   6        CLAD FUEL ECCENTRICITY                         0.025
12   3   1   3   2   3   3   4   1   4   2   4   3   5   1   5
 2   5   3   6   1   6   2   6   3
 2   1   0   0   0   0   0   1   0
 2   6        FLUX CALCULATION                               0.02
 3   5   2   0   0   0   0   3   0
 3   1        ORIFICE CALIBRATION                            0.015
 3   1        PIN DIAMETER(4.7+0.025 MM)                     0.0115
 3   6        FLUX (CONTROL ROD)                             0.02
 3   6        ENRICHMENT                                     0.005
 3   6        SUBASSEMBLY DISPLACEMENT                       0.005
 4   3   2   0   0   0   0   1   0
 4   1        ACTIVE LENGTH (1/2 PELLET)                     0.004
 4   1        PITCH (5.7+0.025)MM                            0.009
 4   6        PIN DISPLACEMENT                                0.01
 5   9   1   1   1   1   1   4
 5   1        LOCAL PRESSURE DROP                            0.04
 5   2        H.T. CLAD-NA                                   0.03
 5   3        CLAD THICKNESS                                 0.01
 5   4        H.T. GAP                                       0.12
 5   5        FUEL THERMAL CONDUCTIVITY                       0.03
 5   6        DENSITY                                        0.018
 5   6        ENRICHMENT                                    0.005
 5   6        AXIAL FLUX                                     0.025
 5   6        CLAD FUEL ECCENTRICITY                         0.025
```

IV.3 Code outputs

IV.3.1 Output description

The outputs presented in the following item are described below. First, the general data, the critical temperatures and systematic factors are printed by the program. Successively, the uncertainty cards are printed as input documentation, (i. e., in the same form assigned to the inputs). Then the program prints the grouped relative standard deviations in each zone.

In our example, printing of the nominal temperatures was not required; therefore, the code prints- for the channels with a total hot spot expectation greater than 0.001 - the reference temperatures, the expected number of hot spots in the channel and the probability of the channel being hot (hot channel expectation), and some other quantities.

Then the code prints the results of the subassembly analysis. The reference temperatures now refer to the channel - in the subassembly - for which the hot spot probability is a maximum. This means that they are not necessarily the maximum temperatures in the subassembly. Moreover, the total hot spot and hot channels expectations in the subassembly are printed together with the probability of the subassembly being hot.

Then,(in our case all channels were calculated separately)the hot pin expectation per subassembly is printed: for instance, if a subassembly of the first subzone in the first zone has at least one hot spot, there is a 17 $^{o}/o$ probability that the pin (1,1) (see Fig. 4) has a hot spot.

When all zones have been examined, the code prints the total hot element expectation in the core.

Then the final fuel (clad) hot spot analysis is performed. As a result we obtain for the fuel that the probability that at least one hot spot occurs is 0,32.

If we have a population of 100 cores, we "expect" to find 32 cores in which an average of 3.5 subassemblies contain hot spots. Each hot subassembly has an average of 9 hot pins. Every hot pin is affected on the average by only one hot spot.

Then the maximum fuel temperature is printed vs the confidence level.

In our case (a total 2.4σ confidence level is required), the nominal temperature drop (inner fuel - inlet coolant) must be decreased by - 6 $^{o}/o$.

In the case of the clad, the temperature drop (inner clad - inlet coolant) could be increased by - 3 $^{o}/o$.

```
REACTOR FR3


NZ=NUMBER OF RADIAL ZONES=   6

(IB=  0         NBU=  3         NBF=  9         NBT=  1         ICB=  0         ICL=  3         IFL=  2
KCH=  0         KCL=  2         KFL=  1         NWRITE=  0     NX =  0
PRCH= 0.0            PRCL= 2.400          PRFL= 2.400          PRMIN= 0.100E-02 )


     ZONE INDEX    SUBZONE NUMBER        NSUB1          NSUB2          NSUB3          NSUB4          NSUB5

 1 (  1,  0,  0)          3                6              6              6
 2 (  2,  0,  0)          3                4              4              4
 3 (  3,  0,  0)          3                8              8              8
 4 (  4,  0,  0)          3                7              7              7
 5 (  5,  0,  0)          3               11             11             11
 6 (  6,  0,  0)          3               12             12             12
--------------------------------------------------------------------------------------------------------------------------------


                   SPOT LENGTH          CRITIC.TEMP.          ST.DEV.
                       CM                    C                   C

FUEL                  2.00              2750.00              30.00
CLAD                  1.00               700.00               7.00
COOLANT                                  880.00               0.0


SYSTEMATIC FACTORS             COOLANT FLOW RATE     CLAD-COOL. DT            GAP DT        INNER FUEL DT               POWER
ZONE INDEX  SUBZONE INDEX
     1            1                 1.1400            1.0000            1.0000            1.0000            1.0000
     1            2                 1.1400            1.0000            1.0000            1.0000            0.9600
     1            3                 1.1400            1.0000            1.0000            1.0000            0.9200
     2            1                 1.1400            1.0000            1.0000            1.0000            1.0100
     2            2                 1.1400            1.0000            1.0000            1.0000            0.9700
     2            3                 1.1400            1.0000            1.0000            1.0000            0.9300
     3            1                 1.1400            1.0000            1.0000            1.0000            1.0200
     3            2                 1.1400            1.0000            1.0000            1.0000            0.9800
     3            3                 1.1400            1.0000            1.0000            1.0000            0.9400
     4            1                 1.1400            1.0000            1.0000            1.0000            1.0200
     4            2                 1.1400            1.0000            1.0000            1.0000            0.9800
     4            3                 1.1400            1.0000            1.0000            1.0000            0.9400
     5            1                 1.1400            1.0000            1.0000            1.0000            1.0200
     5            2                 1.1400            1.0000            1.0000            1.0000            0.9800
     5            3                 1.1400            1.0000            1.0000            1.0000            0.9400
     6            1                 1.1400            1.0000            1.0000            1.0000            1.0200
     6            2                 1.1400            1.0000            1.0000            1.0000            0.9800
     6            3                 1.1400            1.0000            1.0000            1.0000            0.9400
--------------------------------------------------------------------------------------------------------------------------------


CORRELATION BETWEEN HEAT TRANSFER AND FLOW RATE=FA=FFR**EXP-CONST*EXP *(FFR-1)
EXP=     0.8000                      CONST=    0.7000
```

CORE UNCERTAINTIES

```
TYPE    3         CLAD THERMAL CONDUCTIVITY                          0.0100
TYPE    5         FUEL THERMAL CONDUCTIVITY                          0.0280
TYPE    6         FLUX CONTROL                                       0.0250
TYPE    7         SODIUM INLET TEMPERATURE                           1.0000
-------------------------------------------------------------------------------------------------------------------------


ST.DEV.                COOL.T.RISE   CLAD-COOL. DT   CLAD DT     FUEL-CLAD DT    INT.FUEL DT    POWER       FIXED TEMP.
                           R.V.           R.V.          R.V.          R.V.           R.V.         R.V.           C
ZONE        SUBZONE
                           0.0            0.0         0.0100         0.0           0.0280       0.0250        1.0000


UNCERTAINTIES FOR THE SUBZONES  1,1 - 1,2 - 1,3 -
-------------------------------------------------------------------------------------------------------------------------


ZONE UNCERTAINTIES


TYPE    6         FLUX CALCULATION                                   0.0
-------------------------------------------------------------------------------------------------------------------------


SUBASSEMBLY UNCERTAINTIES


TYPE    1         ORIFICE CALIBRATION                                0.0150
TYPE    1         PIN DIAMETER(4.7+0.025 MM)                         0.0115
TYPE    6         FLUX (CONTROL ROD)                                 0.0050
TYPE    6         ENRICHMENT                                         0.0050
TYPE    6         SUBASSEMBLY DISPLACEMENT                           0.0050
-------------------------------------------------------------------------------------------------------------------------


CHANNEL UNCERTAINTIES


TYPE    1         ACTIVE LENGTH (1/2 PELLET)                         0.0040
TYPE    1         PITCH (5.7+0.025)MM                                0.0090
TYPE    6         PIN DISPLACEMENT                                   0.0100
-------------------------------------------------------------------------------------------------------------------------


LOCAL UNCERTAINTIES


TYPE    1         LOCAL PRESSURE DROP                                0.0400
TYPE    2         H.T. CLAD-NA                                       0.0300
TYPE    3         CLAD THICKNESS                                     0.0100
TYPE    4         H.T. GAP                                           0.1200
TYPE    5         FUEL THERMAL CONDUCTIVITY                          0.0300
TYPE    6         DENSITY                                            0.0180
TYPE    6         ENRICHMENT                                         0.0050
TYPE    6         AXIAL FLUX                                         0.0250
TYPE    6         CLAD FUEL ECCENTRICITY                             0.0250
-------------------------------------------------------------------------------------------------------------------------
```

```
UNCERTAINTIES FOR THE SUBZONES  2,1 - 2,2 - 2,3 -
----------------------------------------------------------------------------------------------------------------------


ZONE UNCERTAINTIES


TYPE    6          FLUX CALCULATION                                  0.0100
----------------------------------------------------------------------------------------------------------------------


SUBASSEMBLY UNCERTAINTIES


TYPE    1          ORIFICE CALIBRATION                               0.0150
TYPE    1          PIN DIAMETER(4.7+0.025 MM)                        0.0115
TYPE    6          FLUX (CONTROL ROD)                                0.0150
TYPE    6          ENRICHMENT                                        0.0050
TYPE    6          SUBASSEMBLY DISPLACEMENT                          0.0050
----------------------------------------------------------------------------------------------------------------------


CHANNEL UNCERTAINTIES


TYPE    1          ACTIVE LENGTH (1/2 PELLET)                        0.0040
TYPE    1          PITCH (5.7+0.025)MM                               0.0090
TYPE    6          PIN DISPLACEMENT                                  0.0100
----------------------------------------------------------------------------------------------------------------------


LOCAL UNCERTAINTIES


TYPE    1          LOCAL PRESSURE DROP                               0.0400
TYPE    2          H.T. CLAD-NA                                      0.0300
TYPE    3          CLAD THICKNESS                                    0.0100
TYPE    4          H.T. GAP                                          0.1200
TYPE    5          FUEL THERMAL CONDUCTIVITY                         0.0300
TYPE    6          DENSITY                                           0.0180
TYPE    6          ENRICHMENT                                        0.0050
TYPE    6          AXIAL FLUX                                        0.0250
TYPE    6          CLAD FUEL ECCENTRICITY                            0.0250
----------------------------------------------------------------------------------------------------------------------
```

```
UNCERTAINTIES FOR THE SUBZONES  3,1 - 3,2 - 3,3 - 4,1 - 4,2 - 4,3 - 5,1 - 5,2 - 5,3 - 6,1 - 6,2 - 6,3 -
--------------------------------------------------------------------------------------------------------


ZONE UNCERTAINTIES


TYPE    6          FLUX CALCULATION                                           0.0200
--------------------------------------------------------------------------------------------------------


SUBASSEMBLY UNCERTAINTIES


TYPE    1          ORIFICE CALIBRATION                                        0.0150
TYPE    1          PIN DIAMETER(4.7+0.025 MM)                                 0.0115
TYPE    6          FLUX (CONTROL ROD)                                         0.0200
TYPE    6          ENRICHMENT                                                 0.0050
TYPE    6          SUBASSEMBLY DISPLACEMENT                                   0.0050
--------------------------------------------------------------------------------------------------------


CHANNEL UNCERTAINTIES


TYPE    1          ACTIVE LENGTH (1/2 PELLET)                                 0.0040
TYPE    1          PITCH (5.7+0.025)MM                                        0.0090
TYPE    6          PIN DISPLACEMENT                                           0.0100
--------------------------------------------------------------------------------------------------------


LOCAL UNCERTAINTIES


TYPE    1          LOCAL PRESSURE DROP                                        0.0400
TYPE    2          H.T. CLAD-NA                                               0.0300
TYPE    3          CLAD THICKNESS                                             0.0100
TYPE    4          H.T. GAP                                                   0.1200
TYPE    5          FUEL THERMAL CONDUCTIVITY                                  0.0300
TYPE    6          DENSITY                                                    0.0180
TYPE    6          ENRICHMENT                                                 0.0050
TYPE    6          AXIAL FLUX                                                 0.0250
TYPE    6          CLAD FUEL ECCENTRICITY                                     0.0250
--------------------------------------------------------------------------------------------------------
```

```
ZONE UNCERTAINTIES


ST.DEV.             COOL.T.RISE   CLAD-COOL. DT   CLAD DT      FUEL-CLAD DT   INT.FUEL DT   POWER      FIXED TEMP.
                         R.V.          R.V.          R.V.          R.V.          R.V.       R.V.             C
ZONE         SUBZONE
        1       1        0.0           0.0           0.0           0.0           0.0        0.0            0.0
        1       2        0.0           0.0           0.0           0.0           0.0        0.0            0.0
        1       3        0.0           0.0           0.0           0.0           0.0        0.0            0.0
        2       1        0.0           0.0           0.0           0.0           0.0        0.0100         0.0
        2       2        0.0           0.0           0.0           0.0           0.0        0.0100         0.0
        2       3        0.0           0.0           0.0           0.0           0.0        0.0100         0.0
        3       1        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        3       2        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        3       3        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        4       1        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        4       2        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        4       3        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        5       1        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        5       2        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        5       3        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        6       1        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        6       2        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
        6       3        0.0           0.0           0.0           0.0           0.0        0.0200         0.0
---------------------------------------------------------------------------------------------------------------------


SUBASSEMBLY UNCERTAINTIES


ST.DEV.             COOL.T.RISE   CLAD-COOL. DT   CLAD DT      FUEL-CLAD DT   INT.FUEL DT   POWER      FIXED TEMP.
                         R.V.          R.V.          R.V.          R.V.          R.V.       R.V.             C
ZONE         SUBZONE
        1       1        0.0189        0.0           0.0           0.0           0.0        0.0087         0.0
        1       2        0.0189        0.0           0.0           0.0           0.0        0.0087         0.0
        1       3        0.0189        0.0           0.0           0.0           0.0        0.0087         0.0
        2       1        0.0189        0.0           0.0           0.0           0.0        0.0166         0.0
        2       2        0.0189        0.0           0.0           0.0           0.0        0.0166         0.0
        2       3        0.0189        0.0           0.0           0.0           0.0        0.0166         0.0
        3       1        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        3       2        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        3       3        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        4       1        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        4       2        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        4       3        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        5       1        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        5       2        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        5       3        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        6       1        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        6       2        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
        6       3        0.0189        0.0           0.0           0.0           0.0        0.0212         0.0
---------------------------------------------------------------------------------------------------------------------
```

```
CHANNEL UNCERTAINTIES


ST.DEV.              COOL.T.RISE    CLAD-COOL. DT    CLAD DT      FUEL-CLAD DT    INT.FUEL DT     POWER       FIXED TEMP.
                         R.V.           R.V.           R.V.           R.V.           R.V.          R.V.            C
ZONE          SUBZONE
      1          1       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      1          2       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      1          3       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
~~    2          1       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0~~
      2          2       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      2          3       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      3          1       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      3          2       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      3          3       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      4          1       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      4          2       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      4          3       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      5          1       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      5          2       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      5          3       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      6          1       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      6          2       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
      6          3       0.0098         0.0            0.0            0.0            0.0          0.0100          0.0
----------------------------------------------------------------------------------------------------------------------------


LOCAL UNCERTAINTIES


ST.DEV.              COOL.T.RISE    CLAD-COOL. DT    CLAD DT      FUEL-CLAD DT    INT.FUEL DT     POWER       FIXED TEMP.
                         R.V.           R.V.           R.V.           R.V.           R.V.          R.V.            C
ZONE          SUBZONE
      1          1       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      1          2       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      1          3       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      2          1       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      2          2       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      2          3       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      3          1       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      3          2       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      3          3       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      4          1       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      4          2       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      4          3       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      5          1       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      5          2       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      5          3       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      6          1       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      6          2       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
      6          3       0.0400         0.0300         0.0100         0.1200         0.0300       0.0400
----------------------------------------------------------------------------------------------------------------------------
```

```
NOMINAL THERMAL DESIGN      DATE 07.05.71      TIME 18.51.49

INFO =   - F R 3 -          CHIMAX = 526. W/CM     REIHE 1 BIS 6

ALL TEMPERATURES AND STANDARD DEVIATIONS ARE EXPRESSED IN CENT. DEGREES

NOMINAL COOLANT INLET TEMP.=     230.00


HOT CHANNEL CONSIDERED AT OUTLET OF ACTIVE ZONE

HOT SPOT CONSIDERED ON THE CLAD INNER SURFACE

HOT SPOT CONSIDERED ON THE SURFACE OF THE FUEL INNER CHANNEL



                                         ZONE  1

FLOW RATE =  12587.62 GR/SEC                           AVER.COOLANT OUTLET TEMP.=     507.48

NUMBER OF SUBCHANNELS CALCULATED =  258                 TOTAL NUMBER OF PINS =  127


                 1.CHANNEL ANALYSIS


SUBCHANNEL      1 (  1,   1)          NUMBER OF IDENT. SUBCHAN.     1            NUMBER OF SPOTS  1(ASTAB=     0.17)
------------------------------------------------------------------------------------------------------------------------


                                         SUBZONE 1
                             COOLANT                        CLAD                           FUEL
REFERENCE TEMPERATURES          553.04                        590.94                         2422.28
AT HEIGHT  (CM)                 145.00                        144.50                          110.00
TOTAL STANDARD DEVIATIONS        11.67                         14.45                          109.06
EXPECTED NUMB.OF HOT SPOTS                               0.0                            0.878E-02
HOT CHANNEL EXPECTATION      0.0                         0.0                            0.694E-02
LOCAL STAND.DEVIATIONS            2.04                          2.61                           72.61
EQUIV.NUMBER OF HOT SPOTS                                       1.00                            4.88
CHANNEL STAND.DEVIATIONS          4.53                          4.82                           22.02
M-CH-EQ                          0.0                            0.01                           80.78
S-CH-EQ                           4.97                          5.48                           62.95

SUBCHANNEL      2 (  1,   2)          NUMBER OF IDENT. SUBCHAN.     1            NUMBER OF SPOTS  2(ASTAB=     0.53)
------------------------------------------------------------------------------------------------------------------------


                                         SUBZONE 1
                             COOLANT                        CLAD                           FUEL
REFERENCE TEMPERATURES          543.46                        584.02                         2401.45
AT HEIGHT  (CM)                 145.00                        144.50                          110.00
TOTAL STANDARD DEVIATIONS        11.32                         14.23                          108.82
EXPECTED NUMB.OF HOT SPOTS                               0.0                            0.868E-02
HOT CHANNEL EXPECTATION      0.0                         0.0                            0.634E-02
LOCAL STAND.DEVIATIONS            1.98                          2.64                           72.76
EQUIV.NUMBER OF HOT SPOTS                                       2.00                            8.73
CHANNEL STAND.DEVIATIONS          4.40                          4.71                           21.79
M-CH-EQ                          0.0                            1.43                          104.15
S-CH-EQ                           4.83                          5.28                           59.66
```

```
          2.SUBASSEMBLY ANALYSIS


                                      SUBZONE 1

                                       COOLANT                         CLAD                          FUEL

REFERENCE TEMPERATURES                  559.26                        600.22                        2407.68
SUBASS. STAND.DEVIATION                   6.85                          7.02                          19.20
ZONE STAND.DEVIATION                      0.0                           0.0                            0.0
CORE STAND.DEVIATION                      8.29                          9.32                          69.43
EQUIV.NUMBER OF CHANNELS                  1.00                          1.00                          51.76
M-S-EQ                                    0.03                          2.26                         247.73
S-S-EQ                                    8.51                          8.89                          42.27
HOT SPOT EXPECTATION IN A SUBASS.                                   0.0                          0.139E 01
HOT CHANNEL EXPECTATION IN A SUBASS.   0.0                          0.0                          0.972E 00
HOT SUBASS.EXPECTATION                 0.0                          0.0                          0.137E 00
-----------------------------------------------------------------------------------------------------------------------------


HOT PIN EXPECTATION PER SUBASS.
   I1   I2                          CLAD                          FUEL
    1    1                          0.0                           0.17
    1    2                          0.0                           0.16
    1    3                          0.0                           0.15
    1    4                          0.0                           0.14
    1    5                          0.0                           0.14
    1    6                          0.0                           0.14
    1    7                          0.0                           0.17
    2    1                          0.0                           0.12
    2    2                          0.0                           0.21
    2    3                          0.0                           0.21
    2    4                          0.0                           0.21
    2    5                          0.0                           0.21
    2    6                          0.0                           0.21
    2    7                          0.0                           0.21
    2    8                          0.0                           0.14
    3    1                          0.0                           0.10
    3    2                          0.0                           0.17
    3    3                          0.0                           0.18
    3    4                          0.0                           0.18
    3    5                          0.0                           0.18
    3    6                          0.0                           0.18
    3    7                          0.0                           0.18
    3    8                          0.0                           0.17
    3    9                          0.0                           0.10
    4    1                          0.0                           0.08
    4    2                          0.0                           0.13
    4    3                          0.0                           0.15
    4    4                          0.0                           0.15
    4    5                          0.0                           0.15
    4    6                          0.0                           0.15
    4    7                          0.0                           0.15
    4    8                          0.0                           0.15
    4    9                          0.0                           0.13
    4   10                          0.0                           0.08
    5    1                          0.0                           0.06
    5    2                          0.0                           0.11
    5    3                          0.0                           0.11
    5    4                          0.0                           0.12
    5    5                          0.0                           0.12
    5    6                          0.0                           0.12
    5    7                          0.0                           0.12
    5    8                          0.0                           0.12
    5    9                          0.0                           0.11
    5   10                          0.0                           0.10
```

```
                                        ACTIVE ZONE


SUMMARY OF HOT ELEMENT EXPECTATION
ZONE,SUBZ.           COOLANT                             CLAD                                       FUEL
             SUBASS.      CHANNEL          SUBASS.      CHANNEL      SPOT             SUBASS.      CHANNEL      SPOT

  1, 1     0.0          0.0              0.0          0.0          0.0              0.820E 00    0.583E 01    0.825E 01
                                                      0.0                                          0.822E 01               (PINS)
  1, 2     0.0          0.0              0.0          0.0          0.0              0.502E-01    0.135E 00    0.153E 00
                                                      0.0                                          0.153E 00               (PINS)
  1, 3     0.0          0.0              0.0          0.0          0.0              0.442E-03    0.581E-03    0.612E-03
                                                      0.0                                          0.611E-03               (PINS)
  2, 1     0.0          0.0              0.0          0.0          0.0              0.187E 00    0.107E 01    0.148E 01
                                                      0.0                                          0.147E 01               (PINS)
  2, 2     0.0          0.0              0.0          0.0          0.0              0.839E-02    0.219E-01    0.249E-01
                                                      0.0                                          0.249E-01               (PINS)
  2, 3     0.0          0.0              0.0          0.0          0.0              0.360E-04    0.360E-04    0.403E-04
                                                      0.0                                          0.401E-04               (PINS)
  3, 1     0.0          0.0              0.261E-04    0.787E-04    0.335E-03        0.643E-01    0.236E 00    0.326E 00
                                                      0.235E-03                                    0.324E 00               (PINS)
  3, 2     0.0          0.0              0.0          0.0          0.0              0.211E-02    0.435E-02    0.503E-02
                                                      0.0                                          0.501E-02               (PINS)
  3, 3     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
  4, 1     0.0          0.0              0.231E-04    0.638E-04    0.262E-03        0.117E-05    0.117E-05    0.125E-05
                                                      0.190E-03                                    0.117E-05               (PINS)
  4, 2     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
  4, 3     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
  5, 1     0.0          0.0              0.539E-04    0.193E-03    0.813E-03        0.0          0.0          0.0
                                                      0.575E-03                                    0.0                     (PINS)
  5, 2     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
  5, 3     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
  6, 1     0.0          0.0              0.122E-03    0.722E-03    0.313E-02        0.0          0.0          0.0
                                                      0.217E-02                                    0.0                     (PINS)
  6, 2     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
  6, 3     0.0          0.0              0.0          0.0          0.0              0.0          0.0          0.0
                                                      0.0                                          0.0                     (PINS)
----------------------------------------------------------------------------------------------------------------------------------
TOTAL      0.0          0.0              0.225E-03    0.106E-02    0.454E-02        0.113E 01    0.729E 01    0.102E 02


REFER.ZONE            6, 1                               6, 1                                        1, 1
REFER.TEMP.           580.41                             609.29                                     2407.68
CRIT.TEMP.            880.00                             700.00                                     2750.00
M-Z-EQ                 18.03                              32.10                                      299.73
S-Z-EQ                 10.92                              11.15                                       33.56
```

```
                                        FUEL HOT SPOT


PROB. OF AT LEAST ONE HOT SPOT=  0.323880E 00


ON THE AVG. 0.324E 02 CORES OUT OF 100 ARE EXPECTED TO CONTAIN      3.50 SUBASS. HAVING      6.44 CHANNELS WITH      1.40 HOT SPOTS
            ---------                                          ---------                ---------                   ---------


AVERAGE HOT SPOTS PER PIN=      1.00          HOT PINS PER SUBASS.=      9.00


APPROX. EVALUATION OF EXPECTED MAX. TEMPERATURES

EQUIV. NUMBER OF ZONES=    1.19          M-C-EQ=  304.66          S-C-EQ=   76.73

PROB. OF EXCEEDING                CONFIDENCE LEVEL              MAX.TEMP.
--------------------------------------------------------------------------------------
             0.50E 00          (0.0SIGMA)  0.500000E 00              2712.34
             0.31E 00          (0.5SIGMA)  0.691460E 00              2750.70
             0.16E 00          (1.0SIGMA)  0.841342E 00              2789.06
             0.67E-01          (1.5SIGMA)  0.933190E 00              2827.43
             0.23E-01          (2.0SIGMA)  0.977248E 00              2865.79
             0.62E-02          (2.5SIGMA)  0.993790E 00              2904.16
             0.14E-02          (3.0SIGMA)  0.998650E 00              2942.52
             0.23E-03          (3.5SIGMA)  0.999767E 00              2980.88
             0.32E-04          (4.0SIGMA)  0.999968E 00              3019.25
--------------------------------------------------------------------------------------


REQUIRED HOT SPOT FACTOR =    1.2307           ACTUAL HSF=    1.1572

THE TEMP.DROP (REF. TEMP-INLET TEMP.=   2177.68) MUST BE DECREASED BY A FACTOR=    1.0635
```

```
                                   CLAD HOT SPOT


PROB. OF AT LEAST ONE HOT SPOT=  0.224637E-03

ON THE AVG. 0.225E-01 CORES OUT OF 100 ARE EXPECTED TO CONTAIN       1.00 SUBASS. HAVING       4.71 CHANNELS WITH       4.29 HOT SPOTS
            ---------                                          ---------               ---------                 ---------


AVERAGE HOT SPOTS PER PIN=      1.43          HOT PINS PER SUBASS.=     14.09


APPROX. EVALUATION OF EXPECTED MAX. TEMPERATURES

EQUIV. NUMBER OF ZONES=     2.65          M-C-EQ=    40.29          S-C-EQ=    13.63

PROB. OF EXCEEDING                   CONFIDENCE LEVEL                   MAX.TEMP.
-----------------------------------------------------------------------------------------
          0.50E 00          (0.0SIGMA)  0.500000E 00                     649.58
          0.31E 00          (0.5SIGMA)  0.691460E 00                     656.39
          0.16E 00          (1.0SIGMA)  0.841342E 00                     663.21
          0.67E-01          (1.5SIGMA)  0.933190E 00                     670.02
          0.23E-01          (2.0SIGMA)  0.977248E 00                     676.83
          0.62E-02          (2.5SIGMA)  0.993790E 00                     683.65
          0.14E-02          (3.0SIGMA)  0.998650E 00                     690.46
          0.23E-03          (3.5SIGMA)  0.999767E 00                     697.27
          0.32E-04          (4.0SIGMA)  0.999968E 00                     704.09
-----------------------------------------------------------------------------------------


REQUIRED HOT SPOT FACTOR =     1.2031          ACTUAL HSF=     1.2391

THE TEMP. DROP (REF.TEMP-INLET TEMP.=     379.29) COULD BE INCREASED BY A FACTOR=     1.0299
```

```
                                  FLOW-RATE OPTIMIZATION

INITIAL VALUES

ZONE         NSUB         FLRT          TOUT          JMAX          RTCLS
  1           18        12587.62       507.48          1           600.22
  2           12        11885.64       509.74          1           604.31
  3           24        11032.67       508.65          1           608.41
  4           21         9836.70       509.23          1           608.82
  5           33         8604.16       517.14          1           609.17
  6           36         8244.79       522.59          1           609.29
-------------------------------------------------------------------------------------

TOTAL FLOW-RATE=  0.142131E 07          AVG. OUTLET TEMP.=  513.27          PROB= 0.291E-03


FINAL VALUES

ZONE            DX          RTCLS           FC            FLRT            TOUT
  1           31.36        631.59         1.0957        11488.55         534.02
  2           23.48        627.79         1.0703        11105.00         529.41
  3            1.48        609.90         1.0044        10984.78         509.87
  4            2.10        610.93         1.0061         9776.98         510.94
  5           -1.41        607.76         0.9960         8639.09         515.98
  6           -4.50        604.79         0.9871         8352.52         518.82
-------------------------------------------------------------------------------------

TOTAL FLOW-RATE=  0.139479E 07          AVG. OUTLET TEMP.=  518.65          PROB= 0.260E-03
```

At last, the data on flow-rate optimization are printed. In the FR 3-core it is possible to increase the outlet coolant nominal temperature from ~ 513 °C to 518 °C. Naturally, this is not important for a test reactor; it was calculated only as an example.

For the FR 3-core, the thermal design appears to be highly reliable as far as the clad is concerned. For the fuel, however there is a 32 °/o probability that hot spots occur in ~ 32 pins. Since hot spot occurrences in the fuel do not necessarily provoke pin failures, the failure expectation is even lower; therefore, such a design appears to be adequately reliable. (Other causes, such as pin fabrication defects, according to operation experiences cause larger failure rates).

V. Further Analysis

V.I Influence of the different groups of uncertainties

In order to assess the influence of the different groups of uncertainties on the hot element expectation, the THEDRA-code was applied to the FR 3 reactor core, considered at item IV.3, for 4 different cases:

- only local uncertainties are present
- only channel " " "
- only subassembly " " "
- only core " " "

In all cases, the following assumptions were made: for the power a 7 °/o standard deviation, as critical temperatures 2750 and 700 ° C for fuel and clad, respectively, and standard deviations of critical temperatures equal to zero.

The results are given in Table N. 1.

Table N. 1 Hot Element Expectations out of 100 Cores

Expect.	total number of hot spots	hot spots per pin	hot pins per subassy.	hot subassy. per core	hot cores	uncertainty type
Clad	---	---	---	---	---	local
	905	3.1	3.0	1.4	71.0	channel
	905	9.0	77.0	1.0	1.3	subassy.
	905	9.0	77.0	41.2	0.032	core
Expect.		hot spots per channel	hot channels per subassy.			
Fuel	30.300	1.1	13.2	21.3	100	local
	33.200	23	1.7	8.4	100	channel
	33.200	23	93.0	1.0	16.0	subassy.
	33.200	23	93.0	9.0	1.7	core

As already stated, the expected number of hot spots turns out to be always the same. (For the local uncertainties it must be considered that the local power uncertainty was averaged for the coolant temperature over the channel length: therefore, it is slightly lower than 7 °/o in reality for the fuel, where the most important temperature drop is that between inner fuel- and clad; and it is very little for the clad where the most important temperature drop is just the coolant temperature rise).
What is different is only the distribution of the hot spots among the several channels, subassemblies and cores. From Table N. 1 it turns out clear that a local uncertainty tends to provoke a few hot spots in many channels, subassemblies and cores. A channel uncertainty tends to provoke a few hot channels but with many hot spots, in many cores; and finally a core uncertainty will provoke many "hot subassemblies" in one core in an extremely improbable case. Moreover, the distribution of the hot spots within a subassembly should be the same, both if only a core uncertainty is present and if only a subassembly uncertainty is present, since both cases have the same effects as far as only a subassembly is considered.
As a consequence, local uncertainties provoke "small" failures more frequently, whereas global uncertainties provoke "total" failures in very rare cases.
(It should be noted that the in-core instrumentation can better measure global quantities, such as subassembly coolant outlet temperature or core outlet temperature, than local ones, such as channel temperatures. Therefore, during reactor operation "total" failures can be avoided for better than local ones by opportune actions of the safeguards system).

V.2 Pin failure expectation

The THEDRA-code already furnishes the expected number of pin failures in the two following cases:

a) the distribution of failures vs operating temperature is a normal one
b) the failure distribution is not normal, but its standard deviation is small with respect to the temperature uncertainties, so that the sum of both distribution is approximatively normal.

In both cases, in fact, it is sufficient to assign the critical temperatures as normal distributions by defining their nominal values and standard deviations. (CRTF, CRSTF etc. see item II.3). In the code it is possible to take into account different critical temperature distributions for each subzone.(They are assumed to be constant within a subassembly.) This allows the designer to take into account the actual operating conditions of the different subassemblies, e. g., burn-up, mechanical stresses, temperature fields etc.,and their effects on the failure temperature distribution.

However, even if conditions a) - b) are not satisfied, the THEDRA-code offers the designer the possibility to obtain the failure expectation as it will be shown by the following considerations.

By successive application of THEDRA it is possible to get the distribution of the number of pins exceeding a certain temperature vs this temperature. In this case, the standard deviations of the critical temperatures (CRSTF, CRSTCL, CRSTC) should be set equal to zero and the temperatures CRTF, CRTCL and CRTC have no longer the significance of "critical" temperatures but that of temperatures "exceeded".

For instance, Table N. 2 gives such a distribution in the case of the FR 3 reactor core, subjected to a power channel uncertainty of 7 °/o.

Table N. 2 Number of elements, whose clad temperature exceeds a certain value. (In 100 cores)

Temperature exceeded °C	Total number of hot spots	Total number of hot pins	Hot pins per subassy.	Hot subassy. per core	Hot cores
680	15,700	4,320	3.5	12.4	100
690	3,990	1,192	3.1	3.9	98
700	905	291	3	1.4	71
710	182	63	3	1	21
720	32	12	3	1	4
730	5	2	3	1	0.6

Let us assume that the clad failure distribution vs temperature Pf (ϑ) is constant for each subassembly.

It is clear that, if this condition is not satisfied, the analysis should

be repeated for each subzone, taking into account the data provided by THEDRA for the subzones.
Pf (ϑ) is assumed to be the probability that the clad fails if a spot - of the size assumed - is at a temperature $\geq \vartheta$, during its nominal operation time. This distribution should by obtained by suitable experiments.
In this example we assume that Pf(ϑ) is a rectangular distribution within the temperatures 680 and 730 °C (see Fig. 11).
From the Table N. 2, it is possible to obtain the number of spots and pins whose temperature falls within a given interval. This distribution is shown in Table N. 3.

Table N. 3 Number of hot spots and hot pins vs temperature

Temp. interval °C	Number of spots	Number of pins
680 - 690	11,710	3,128
690 - 700	3,085	901
700 - 710	713	238
710 - 720	150	51
720 - 730	27	10
730 -	5	2

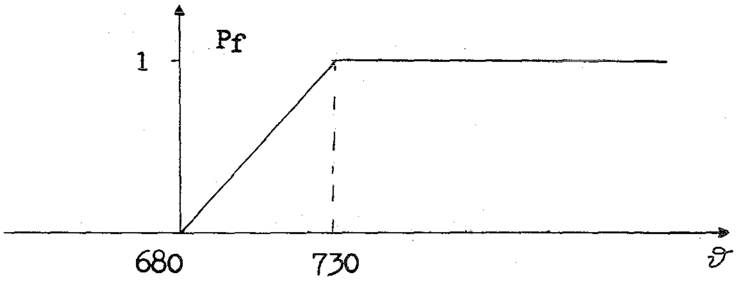

Fig. 11
$P_f(\vartheta)$ (Assumption)

Since in most practical cases, as we have shown at item V.1, the local uncertainties have a negligible influence for clad hot spot occurrences, a pin whose maximum temperature have exceeded 720 °C (for instance), must necessarily have some spots at temperature between 680 and 720 °C. The number of these spots can be easily calculated by dividing the number of spots at temperatures within 680 and 690 °C for the number of pins exceeding 680 °C (and so on). In our case

number of spots within 680 and 690 °C per pin = 11,710 / 4,320 = 2.7.

Analogously for the other temperature intervals, we get the average situation of Table N. 4.

Table N. 4 Average hot spot expectation

number of pins Np (j)	$n_s(i)$ avg. number of spots per pin in the temp. interv.					P_f'
	680 - 690	690 - 700	700 - 710	710 - 720	720 - 730	
3128	2.7	-	-	-	-	0.247
901	2.7	2.6	-	-	-	0.702
238	2.7	2.6	2.5	-	-	0.950
51	2.7	2.6	2.5	2.4	-	0.997
10	2.7	2.6	2.5	2.4	2.2	≃ 1
2	according with our assumption are with certainty failed					1

Since a failure can initiate in any spot, the failure probability for a pin is given by:

$$P_f'(j) = 1 - \prod_i \left[1 - P_f(\vartheta_i)\right]^{n_s(i)}$$

and the total pin failure expectation E is given by

$$E = \sum_j N_p(j) \quad P_f'(j).$$

Where i, j, Np, n_s are defined in Table N. 4 and P_f in Fig. 11. In our case, by substituting the numerical values we obtain E = 1696.

As it was shown, once $P_f(\vartheta)$ is given for every subassemblies according to their operating conditions, THEDRA allows the designer to get the pin failure expectation value, and therefore, to optimize the core thermal design according to the well known minimum global cost criteria. [See, for example, Ref. 9, 10].

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