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Institut für Neutronenphysik und Reaktortechnik
Projekt Schneller Brüter

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Abstract

A transfer function is a very convenient mathematical description of the dynamic behavior of a complex system because all pertinent parameters are contained within it. For this reason transfer functions are widely applied in the field of reactor dynamics. Only linear systems or linear approximations to nonlinear systems are amenable to analysis by methods of complex plane transformations. The thermal properties of a reactor (e.g. the specific heat capacity, the thermal conductivity of the fuel and the heat transfer coefficient of the gap between the fuel and the coolant) however are functions of the temperature, leading to nonlinearities in the system. As long as only relatively small oscillations are considered it seems reasonable to use constant values for these properties, corresponding to an average power and temperature level. It will be shown that this simple linearization process is only partially correct and may lead to considerable errors even for small temperature variations. Therefore a new linearization method has been developed by properly modifying the transfer functions and by introducing additional parameters which are functions of the steady state conditions. Temperature transients in nuclear reactors are usually treated by applying the "lumped model" which does not take into account any heat propagation effect. Because it has been shown that these effects are not always negligible /1,2/, space and time dependent equations for the heat transfer- and transport equations have been used. Reactor transfer functions which account for the space and time dependent heat transfer in a fuel element as well as for the temperature dependent heat transfer coefficients are considered. Numerical examples are given for the KNK and SEFOR reactors.

Übertragungsfunktionen für schnelle Reaktoren mit besonderer Berücksichtigung der Nichtlinearitäten und der räumlichen Abhängigkeit des Wärmeübergangsprozesses

Zusammenfassung

Übertragungsfunktionen bilden eine sehr bequeme mathematische Darstellungsweise des dynamischen Verhaltens komplexer Systeme, da sie alle einschlägigen Parameter enthalten. Aus diesem Grunde finden sie auch vielfache Anwendung auf dem Gebiet der Reaktordynamik. Aber nur lineare Systeme oder lineare Approximationen nichtlinearer Systeme können mit den Methoden der Funktionaltransformationen behandelt werden. Die thermodynamischen Eigenschaften eines Reaktors - z.B. die spezifische Wärmekapazität und thermische Leitfähigkeit des Brennstoffs und die Wärmeübergangszahl für den Spalt zwischen dem Brennstoff und der Brennstoffhülle - sind jedoch temperaturabhängig, was zu Nichtlinearitäten in dem System führt. Solange jedoch nur relativ kleine Oszillationen betrachtet werden, scheint es vernünftig, konstante Werte für diese Parameter zu benutzen, welche den entsprechenden Mittelwerten der Leistung und der Temperatur zuzuordnen sind. Es wird gezeigt, daß diese einfache Linearisierung nur teilweise zulässig ist und selbst bei kleinen Temperaturschwankungen zu beträchtlichen Fehlern führen kann. Deshalb wurde eine neue Linearisierungsmethode entwickelt, durch geeignete Modifikation der Übertragungsfunktionen und durch Einführung von zusätzlichen Parametern, welche von den stationären Bedingungen abhängen.

Normalerweise werden Temperaturtransienten in nuklearen Reaktoren mit Hilfe des sogenannten "lumped Modells" behandelt, welches keine Wärmeausbreitungseffekte berücksichtigt. Da gezeigt wurde /1,2/, daß diese Effekte nicht immer vernachlässigbar sind, wurden raum- und zeitabhängige Gleichungen für den Wärmeübergang und Wärmetransport benutzt.

Es wurden dann Übertragungsfunktionen berechnet, welche sowohl den raum- und zeitabhängigen Wärmeaustausch im Brennelement als auch die Temperaturabhängigkeit der Wärmeübergangsparameter berücksichtigen.

Numerische Beispiele werden für die Reaktoren KNK und SEFOR angegeben.

Table of Contents

I) Introduction

In the case of small deviations from the stationary operating conditions, the dynamic behaviour of a nuclear reactor can be described by a set of linear differential equations. This assumption enables one to analyse the system by using the transfer function method. A transfer function defines the system completely, because all pertinent parameters are contained in it. This function represents a very convenient mathematical description of the dynamic behaviour of complex systems in case of small periodic oscillations. For this reason transfer functions are widely applied in the field of reactor dynamics mainly with respect to stability considerations.

The assumption of small oscillations around the steady state values usually guarantees the validity of the transfer function method. In the following sections it will be shown that this approach may lead to considerable errors if the linearization process is not carried out correctly. The linearization of "non linear effects" can be taken into account by properly modifying the transfer functions and by introducing some additional parameters which are functions of the steady state values of the input variables.

Temperature transients in nuclear reactors are usually treated by using the well known lumped model, which does not take into account any heat propagation effect. Since it has been shown that these effects are not always negligible /1,2/, space and time dependent equations for heat transfer and transport equations have been used in this paper. The solutions of the space and time dependent heat transfer in a fuel element accounts also for temperature dependent heat transfer coefficients.
Numerical examples are given in the case of the KNK and of the Sefor reactors.

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II) Description of the model

1) Basic features of the model

We consider a delayed critical reactor, operating at steady state conditions at a certain power level. The operating conditions of this reactor can be varied by a multiple reactivity input system. For this input system, small oscillations compared to their mean values are assumed, so that in a first approximation the effects due to the higher harmonics can be neglected. With this assumption the mathematical model of the reactor can be reduced to a set of linear differential equations with constant coefficients and is therefore amenable to transfer function theory.

Fig. (1) shows a block diagram of the model with the three main components which determine the dynamic behaviour of the reactor namely: the input system, the zero power transfer function and the feedback effects. The model covers only the reactor: i.e. feedback effects through the coolant loops are not included.

The multiple reactivity input system is characterized by the following three parts: (A) direct reactivity input e.g. by control rod movement, (B) reactivity effects caused by oscillations of inlet coolant temperature "$\Delta\Theta_8$" through the transfer function "$R(\sigma)$" and (C) reactivity effects caused by oscillations of the coolant flow "$\frac{\Delta u}{u}$" through the transfer function "$M(\sigma)$".

$K(\sigma)$ denotes the well known /3/ zero power transfer function derived from the space independent neutron kinetic equations. This means that for the neutron kinetics the point reactor model has been used, which assumes that the spatial distribution of the neutron flux does not depend on the time. Therefore $K(\sigma)$ is only a function of the prompt neutron lifetime "l" and the delayed neutron parameters of the fissile materials. All feedback effects are classified in the two following cathegories: Power feedback effects at constant coolant temperatures (transfer function "$Q(\sigma)$") and reactivity power feedback effects through the variations of the coolant temperatures (transfer function "$S(\sigma)$").

2) Reactivity effects due to temperature oscillations

Each reactivity change (Fig. 1) for both internal feedback mechanisms as well as for external inputs (except for ΔK input) is calculated by multiplying the variation of the average temperature (upon which the reactivity change is dependent) by the associated reactivity/temperature coefficient. The oscillations of these temperatures are calculated (for given steady state conditions: i.e. for given values of the coolant inlet temperature θ_{80}, of the coolant outlet, of the coolant flow and of the power) from the oscillations of the power, of the coolant flow and of the inlet temperature.

The reactor has been devided into different zones as indicated in Fig. 2. Each zone is characterized by the material composition, the geometry, the thermodynamical parameters, the average temperatures, the reactivity coefficients and the heat sources. Fig. 2 shows a general concept of the model, which is applicable to different types of reactors e.g. the SNR 300, KNK, and SEFOR. Not all of these zones are always present in a reactor configuration. For example zone 7 is present in SEFOR but not in SNR 300 and KNK. The user of the program has to choose the zones which are necessary. The main coolant flow is the same for all reactor types. The coolant enters the reactor from the lateral and lower plenum (zones 8 and 5 respectively). From the lower plenum at the bottom of the reactor the coolant goes into the reactor in the vertical upright direction (through the lower axial blanket, the core and the upper axial blanket), and leaves the reactor from the mixing zone. The amount of power, produced in the different zones and in the various materials must be specified.

Most important is the heat flux from the fuel to the coolant in zone 1. It is described by considering an average fuel pin with associated coolant channel. The coolant channel is characterized by a coolant cross section S_1. The coolant flow is determined by the coolant inlet temperature, the coolant outlet temperature and the power with the assumption of an equal pressure drop in all channels, i.e. the mass flow distribution over the whole core cross-section is assumed to be flat.

Figs. 3a and 3b show a scheme of the cell with the corresponding temperature profiles. A model for the heat transfer from the fuel to the coolant in a simple geometry has been previously described /1,2/. It is based on the instationary heat balance equations with spatial variables which take into account the heat propagation inside a fuel element in the radial direction /1/ and the heat transport by the coolant in the axial direction /2/ with the following assumptions: (a) uniform heat production within the entire fuel pin volume and (b) no heat conduction in the axial direction inside the fuel pin. This model has been modified to account for the nonlinear effects due to the thermal parameters of the fuel and to the changes of the heat transfer coefficient of the gap between fuel and cladding.

Fuel is located only in the core (zone 1). The γ-ray absorption in the structure materials produces heat which is transferred from the structure materials to the coolant. Since these effects are of secondary importance, a simple lumped model has been used to describe the heat transfer process. This approximation is satisfactory because the temperature distribution within a structure material is flat and the fractional energy absorbed small. Adjacent zones are linked by means of boundary conditions of the coolant flow and of the coolant temperatures at the interface.

The dynamic heat exchange in the radial direction from the core and the lateral plenum to the static sodium between the core and the shroud is taken into account by using the static temperatures as input parameters. The static and dynamic heat propagation from the core and the lateral plenum to the radial blanket is neglected because in this region the dominating heat transport is due to the coolant which by-passes the core.

3) Non linearities in the time dependent heat transfer equations

The heat propagation calculations are complicated by the fact that the thermodynamic parameters such as the specific heat capacity "χ_{1A}" of the fuel; the fuel thermal conductivity "λ_{1A}" and the heat transfer coefficient of the gap between the fuel and the clad "h_{1A}" are temperature dependent. The influence of these effects at steady state is shown in the Figures 4a and 4b. Fig.4a shows the difference between the average fuel temperature T_{1AM} and the coolant temperature Θ_{1O} as a function of the power density PD_{1A}. Fig.4b shows the difference between T_{1AM} and the fuel surface temperature T_{1AS} as a function of PD_{1A}. These curves have been obtained with λ_{1A} and h_{1A} being analytical functions of T and

PD_{1A}. If λ_{1A} and h_{1A} are constant these temperature differences become linear functions of PD_{1A} (indicated in Figs. 4a and 4b by means of the dotted lines). The rather large deviations from linearity are due to the decrease of λ_{1A} with fuel temperatures and the increase of h_{1A} with reactor power. It is evident therefore that for steady state calculations the temperature dependence of λ and h_{1A} must be considered. In addition this dependence must also be considered in the case of the analysis of the oscillatory behaviour. If in fact constant values of λ_{1A} and h_{1A} are used, the oscillations would follow the dotted line instead of being tangent to the curve (Fig. 4a). Generally this makes a difference which should not be neglected. It is however difficult to find an analytical solution of the dynamic heat transfer equations with temperature dependent heat transfer parameters. Therefore the following approach was followed. First the steady state heat transfer equations were solved by assuming for λ_{1A}; h_{1A} and χ_{1A} the following equations

$$\lambda_{1A}(T) = \frac{1}{C}\,\frac{1}{T_{1AO}\,(T_A-T_{1AO})} \qquad \text{(II-1)}$$

$$h_{1A} = A_0+A_1\,(PD_{10})+A_2\,(PD_{10})^2+A_3\,(PD_{10})^3+B_1T_{1BO} \qquad \text{(II-2)}$$

$$\chi_{1A} = \frac{1}{R_1^2}\int_0^{R_1}\chi(T)\,2r\,dr \qquad \text{(II-3)}$$

with

$$\chi(T) = \chi_1+\chi_2T+\chi_3T^{-2} \qquad \text{(II-4)}$$

The parameters c, T_A; χ_1, χ_2 and χ_3 were obtained by fitting experimental results.

The coefficients A_0, A_1, A_2, A_3 and B_1 are also input data (see Appendix 2).

The time dependent heat transfer equations in the case of small temperatures oscillations about an average value are then solved with the following assumptions:

- The average value χ_{1A} according to eq. (II-3) was used instead of $\chi(T)$.
- A properly chosen effective value "λ_{eff}" is used for λ_{1A} (see chapter III).
- The change of the gap heat transfer coefficient "h_{1A}" has been supposed to be linearly dependent upon the changes of the linearly averaged temperature of the fuel and the cladding temperature.

4) Diagram of the feedback transfer functions

In Fig. 1 only a very schematic diagram of the feedback model and of the reactivity input system is shown. The overall transfer functions of this diagram are however obtained from many transfer functions describing the different physical effects in the different regions of the reactor.

Fig. 5a and 5b give a detailed schematic diagram of the model with all transfer functions and reactivity coefficients involved.
The following different cathegories of basic transfer functions are used in the model:

$F(\sigma)$ for material temperature changes due to power oscillations

$G(\sigma)$ for material temperature changes due to coolant temperature oscillations

$V(\sigma)$ for coolant temperature changes due to power oscillations

$U(\sigma)$ for coolant temperature changes due to coolant flow oscillations

$W(\sigma)$ for coolant temperature changes due to coolant temperature oscillations in a lower axial position

The nomenclature for the indices referring to the different zones and materials are given in Fig. 2 and Appendix 1.

All these transfer functions are normalized to 1 for $\sigma \to 0$ i.e. they become 1 in the limiting case of steady state conditions.

The reactivity coefficients C $(\frac{\text{¢}}{^{\circ}K})$ account for feedback reactivities which are associated to the average temperature changes of the various materials in the different zones. They are input data for the program.

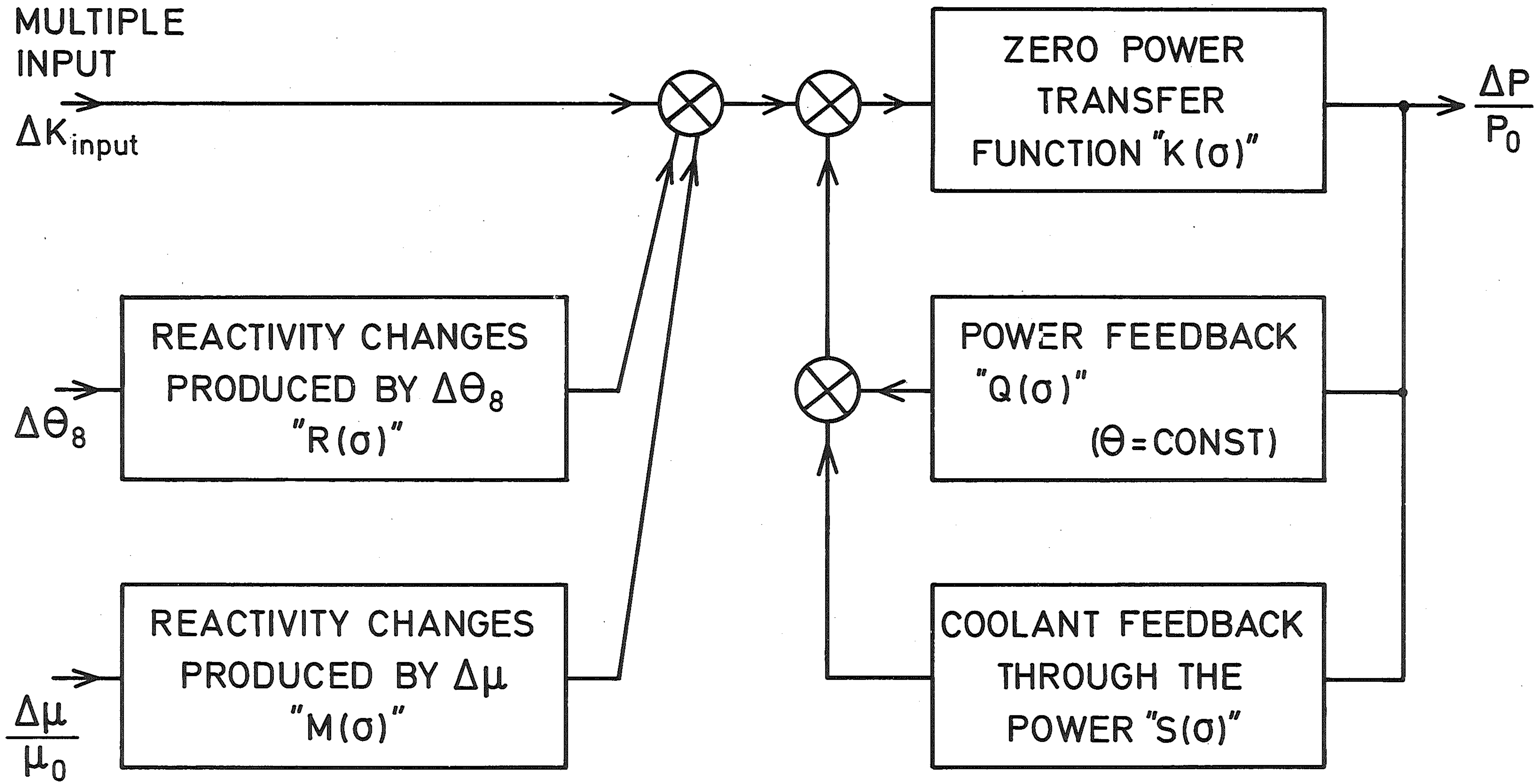
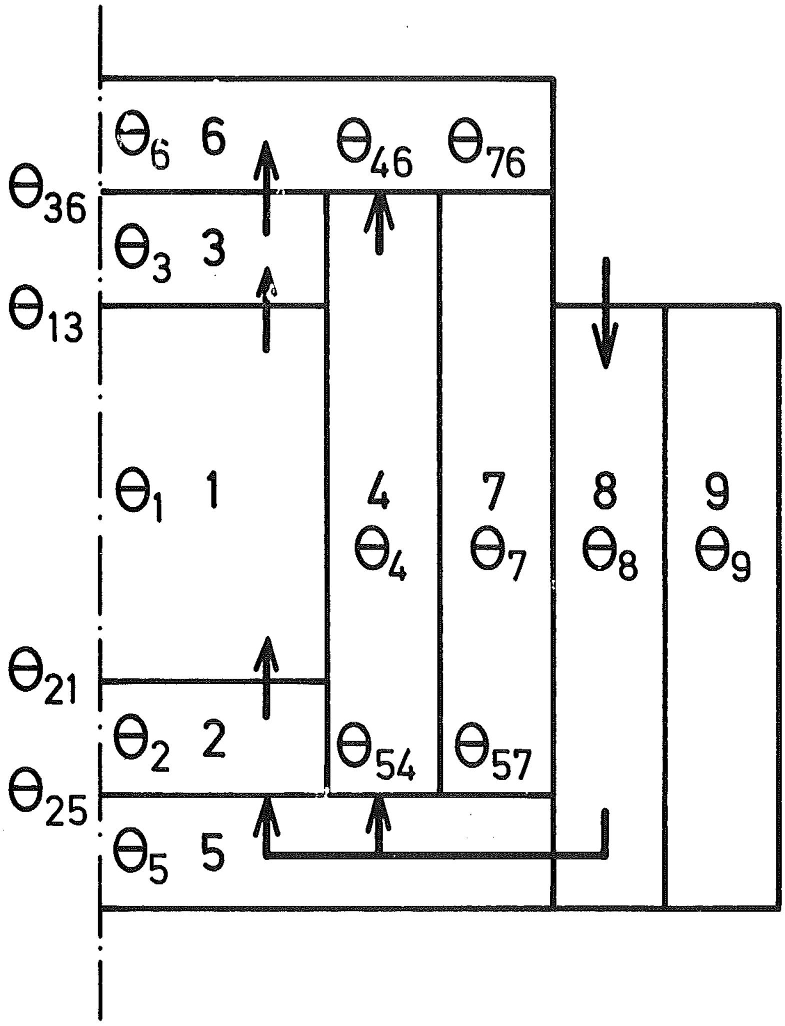


FIG. 1: BLOCK DIAGRAM OF THE ANALYTICAL MODEL FOR THE REACTIVITY INPUT SYSTEM AND FEEDBACK LOOPS

FIG. 2: SCHEMATIC DIAGRAM OF REACTOR ZONES



ZONE

1	CORE
2	LOWER AXIAL BLANKET
3	UPPER AXIAL BLANKET
4	RADIAL BLANKET
5	LOWER PLENUM
6	UPPER PLENUM
7	STATIC SODIUM BETWEEN CORE AND SHROUD
8	LATERAL PLENUM
9	RADIAL REFLECTOR

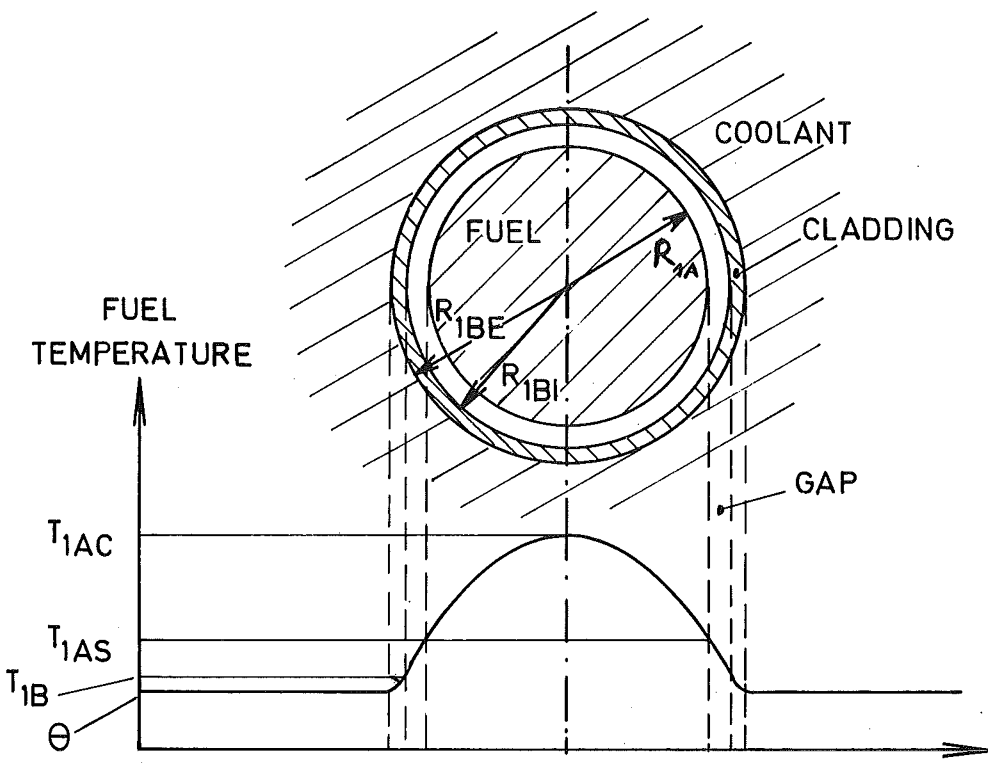


FIG. 3a: RADIAL TEMPERATURE PROFILES IN A FUEL PIN

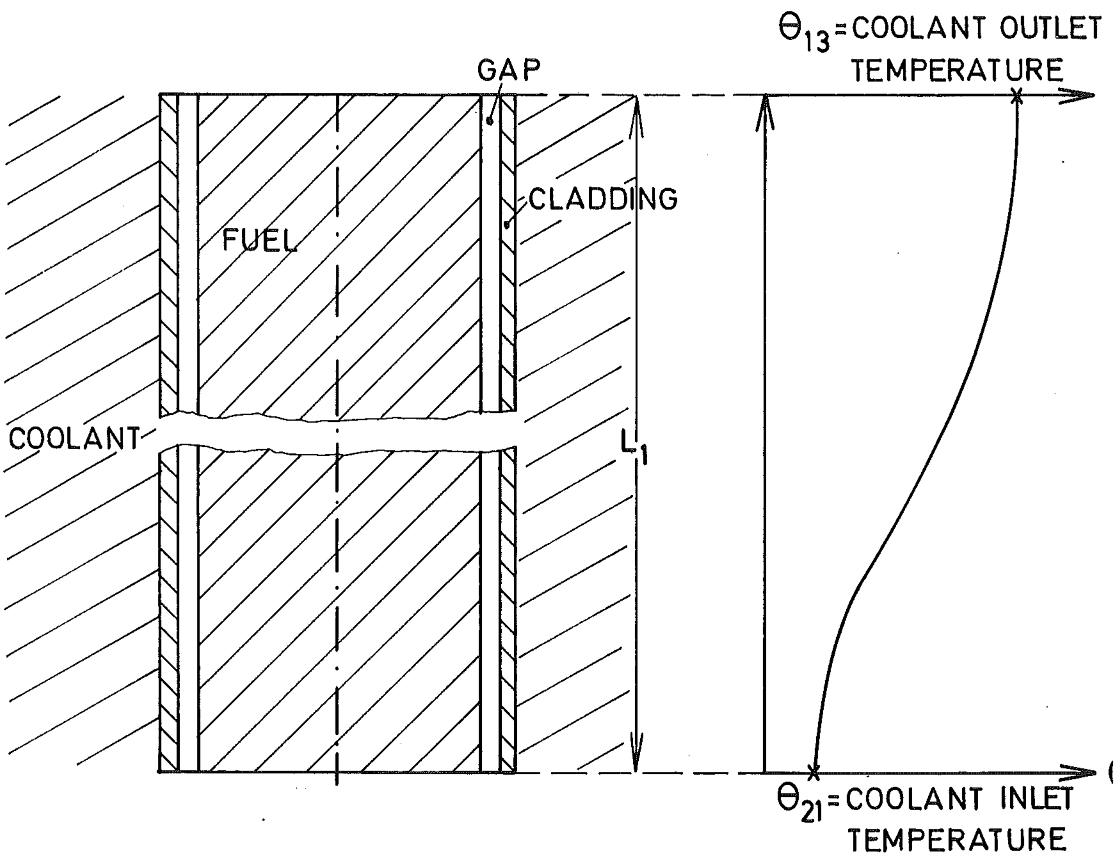


FIG. 3b: AXIAL TEMPERATURE PROFILE OF THE COOLANT

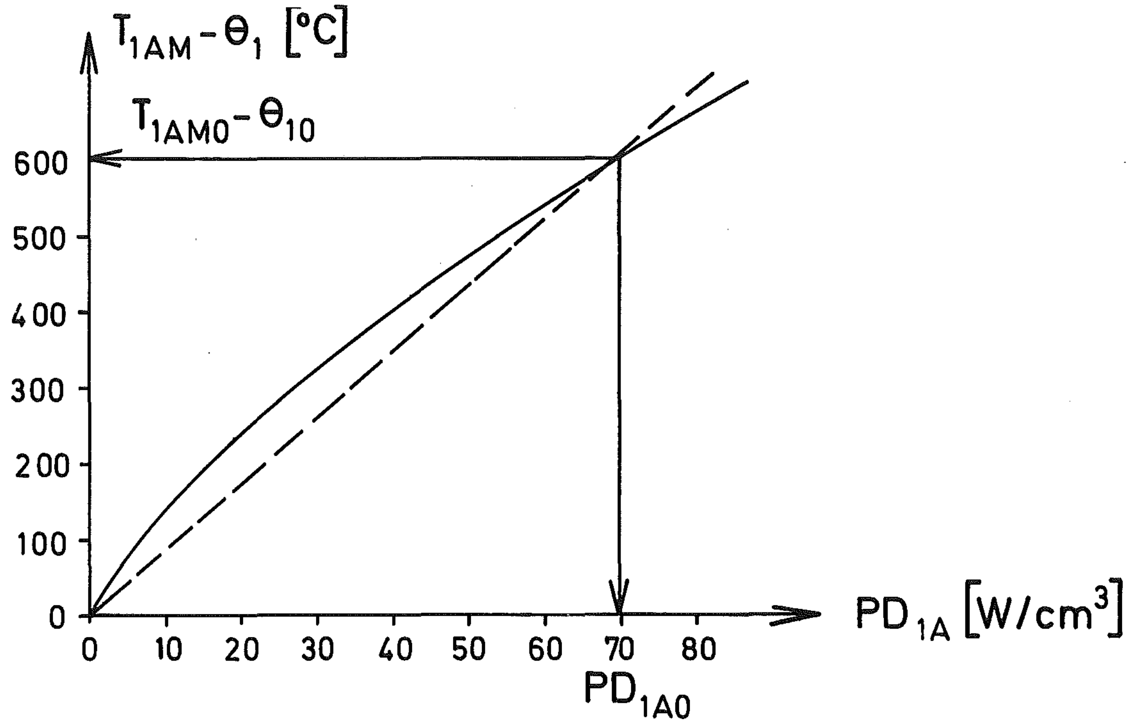


FIG. 4a: AVERAGE FUEL TEMPERATURE RISE ABOVE THE COOLANT TEMPERATURE VERSUS POWER DENSITY (SEFOR)

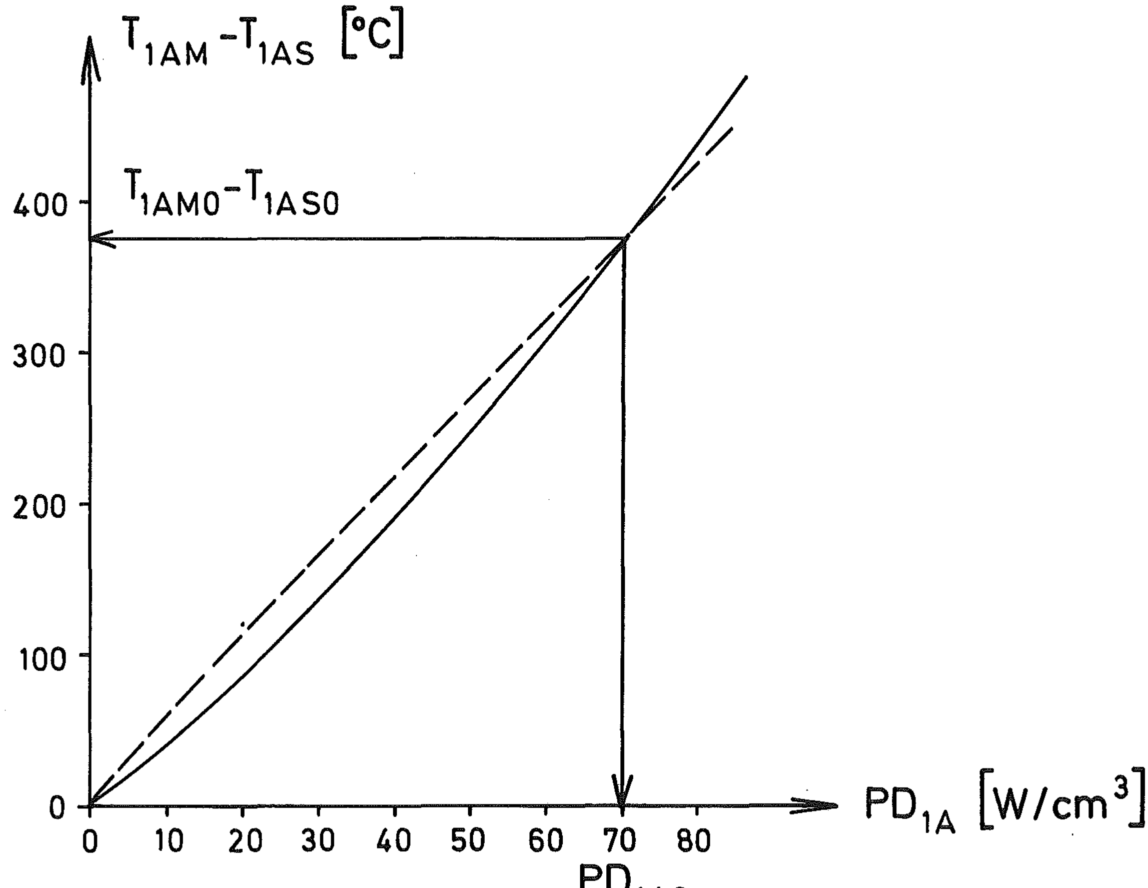


FIG. 4b: AVERAGE FUEL TEMPERATURE RISE ABOVE THE FUEL SURFACE TEMPERATURE VERSUS POWER DENSITY (SEFOR)

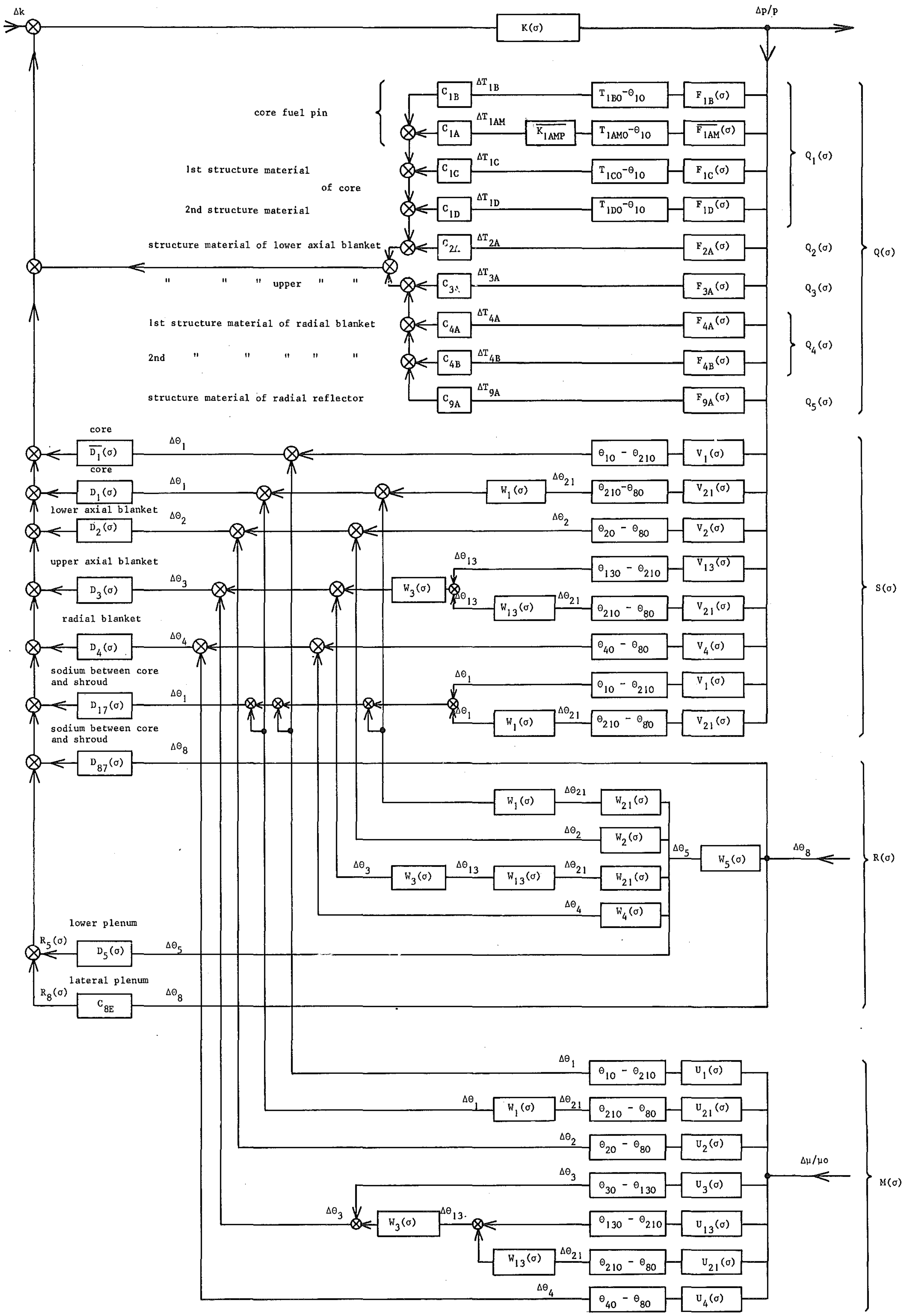


Fig. 5a Analytical model for all transfer function

ΔK(t) = Reactivity Power Feedback through the coolant temperatures

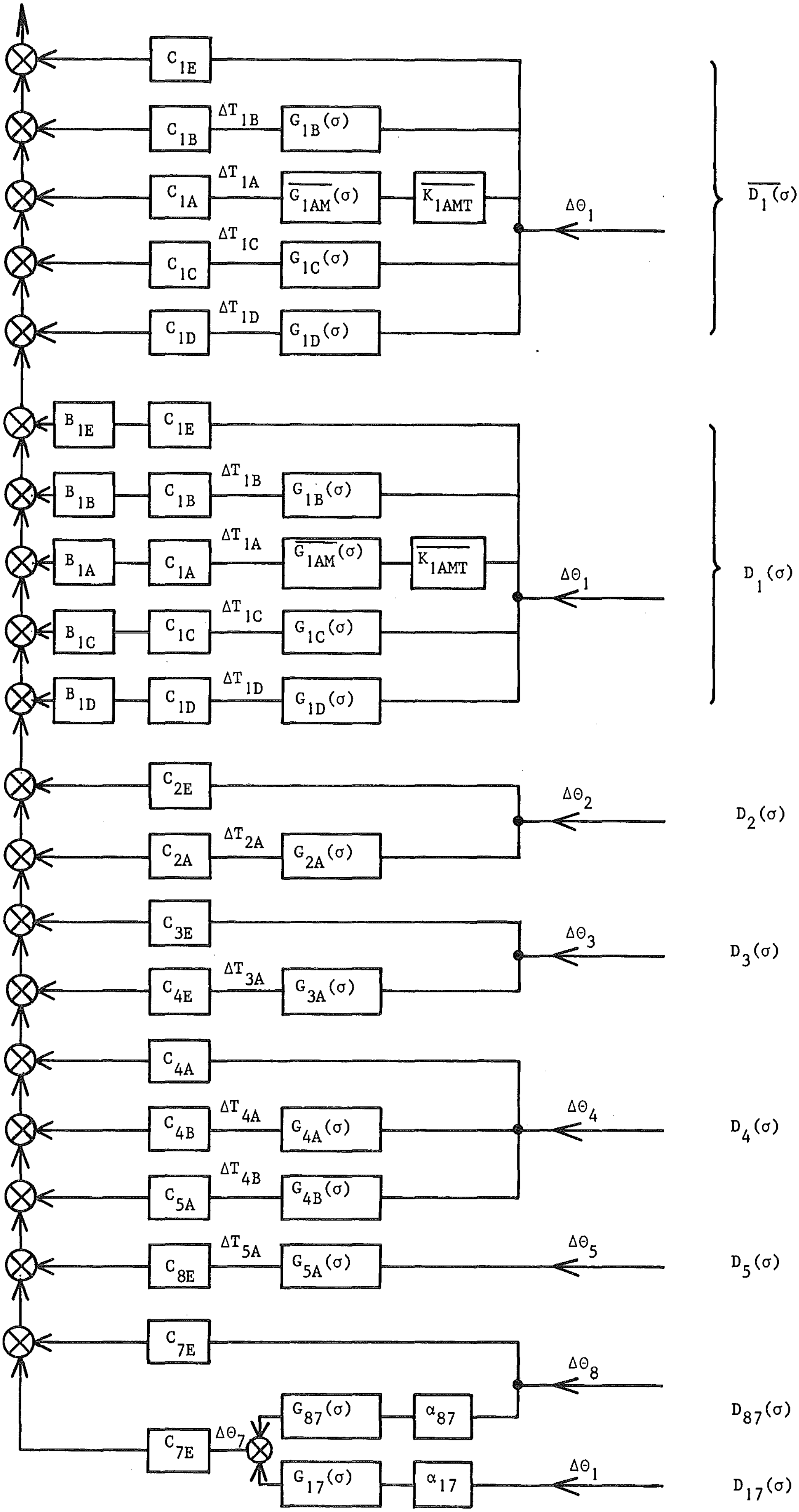


Fig. 5b Coolant temperature reactivity feedback functions

III) Mathematical Fundamentals*)

1) Heat Transfer from the Fuel to the Cladding in Radial Direction

a) Fundamental Equation

We consider the time dependent heat transfer parabolic equation for the heat transfer within the fuel

$$\mathrm{div}(\lambda_{1A} \mathrm{grad}\ T_{1A}) + PD_{1A} = \rho_{1A} \chi_{1A} \frac{\partial T_{1A}}{\partial t} \qquad \text{(III-1)}$$

Here the derivative of the enthalpy I with respect to the time is replaced by the product $\chi_{1A} \frac{\partial T_{1A}}{\partial t}$ where χ_{1A} denotes an average thermal capacity, as explained later.

In cylindrical geometry, by neglecting the heat transfer in the axial direction, eq.III-1 becomes

$$\frac{1}{r} \frac{\partial}{r} (\lambda_{1A} r \frac{\partial T_{1A}}{\partial r}) + PD_{10} = \rho_{1A}\ \chi_{1A} \frac{\partial T_{1A}}{\partial t} \qquad \text{(III-2)}$$

by introducing the dimensionless radius $y = \frac{r}{R_{1BI}}$, eq.III-2 becomes

$$\frac{1}{y} \frac{\partial}{\partial y} (\lambda_{1A}\, y \frac{\partial T_{1A}}{\partial y}) + R^2_{1BI}\ PD_{1A} = R^2_{1BI}\ \rho_{1A}\ \chi_{1A} \frac{\partial T_{1A}}{\partial t} \qquad \text{(III-3)}$$

b) Solution of eq.III-3 at Steady State Conditions

At steady state conditions eq.III-3 becomes

$$\frac{1}{y} \frac{d}{dy} (\lambda_{1AO}\, y \frac{dT_{1AO}}{dy}) + R^2_{1BI}\ PD_{1A} = 0 \qquad \text{(III-4)}$$

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*) All notations used in this paragraph are explained in Appendix 1.

were the subscript "O" indicates the steady state.
Integration of eq.III-4 gives

$$\lambda_{1AO} \frac{dT_{1AO}}{dy} = - \frac{y}{2} R_{1BI} PD_{1A} \qquad \text{(III-5)}$$

If the temperature dependence of λ_{1A} is described by the following function

$$\lambda_{1AO} = \frac{1}{C} \frac{1}{T_{1AO}(T_A - T_{1AO})} \quad \left[\frac{\text{Watt}}{\text{cm}\,^{\circ}\text{K}}\right] \qquad \text{(III-6)}$$

with C and T_A being constants,
one gets easily by integrating eq.(III-5)

$$T_{1AO}(y) = T_A \frac{\frac{T_{1ASO}}{T_A - T_{1ASO}} e^{\varphi PD_{1A}(1-y^2)}}{1 + \frac{T_{1ASO}}{T_A - T_{1ASO}} e^{\varphi PD_{1AO}(1-y^2)}} \quad [^{\circ}\text{K}] \qquad \text{(III-7)}$$

where T_{1ASO} is the surface temperature of the cylinder at steady state conditions and

$$\varphi = \frac{R_{1BI}^2 C T_A}{4} \quad \left[\frac{\text{cm}^3}{\text{Watt}}\right] \qquad \text{(III-8)}$$

The volume average temperature T_{1AMO} is given by

$$T_{1AMO} = \frac{1}{R_{1BI}^2 \pi} \int_0^{R_{1BI}} T_{1A0}\, 2r\pi dr = 2 \int_0^1 T_{1A0}\, y\, dy \quad [^{\circ}\text{K}] \qquad \text{(III-9)}$$

From eq.(III-7) and (III-9) one gets

$$T_{1AMO} = \frac{T_A}{\varphi PD_{1AO}} \ln\left\{ 1+\frac{T_{1ASO}}{T_A} (e^{\varphi PD_{1AO}}-1)\right\} \quad [{}^{o}K] \qquad \text{(III-10)}$$

The central fuel temperature T_{1ACO} results from eq.(III-7) for r=O, i.e. y=O

$$T_{1ACO} = \frac{T_A \dfrac{T_{1ASO}}{T_A - T_{1ASO}}}{1 + \dfrac{T_{1ASO}}{T_A - T_{1ASO}} e^{\varphi PD_{1AO}}} \quad [{}^{o}K] \qquad \text{(III-11)}$$

c) Non_stationary_case

Let us now consider the approximate solution of eq.(III-3) in case of small oscillations.
This solution is obtained by putting in eq.(III-3)

$$\lambda_{1A} = \lambda_{eff} = \text{const} \qquad \text{(III-12)}$$

The constant "λ_{eff}" denoting an effective thermal conductivity is chosen by imposing some conditions which are specified below.

The constant "χ_{1A}" denotes the specific thermal capacity averaged over the whole volume and is simply given by

$$\chi_{1A} = \frac{1}{R_{1B}^2 \pi} \cdot \int_0^R \chi(T_{1A}) 2r\pi dr = 2\int_0^1 \chi(T_{1A}) y \, dy \qquad \text{(III-13)}$$

From eq.(III-7) one gets easily

$$2y\,dy = -\frac{T_A}{\varphi PD_{1A}}\;\frac{1}{T_{1A}(T_A-T_{1A})}\;dT_{1A} \qquad \text{(III-14)}$$

Putting the relation (II-4) for $\chi(T_{1A})$ and eq.(III-14) in eq.(III-13) and integrating one gets finally

$$\chi_{1A} = \chi_1+\chi_2\,T_{1AMO}+\chi_3\left\{\frac{1}{T_A^2}+\frac{1}{\varphi PD_{1A}}\;\frac{T_{1ACO}-T_{1ASO}}{T_{1ACO}\cdot T_{1ASO}}\left[-\frac{1}{T_A}+\frac{T_{1ACO}+T_{1ASO}}{2T_{1ACO}T_{1ASO}}\right]\right.$$

$$\left[\frac{\text{Watt sec}}{\text{g }^{\circ}\text{K}}\right] \qquad \text{(III-15)}$$

We write now eq.(III-3) with λ_{eff}

$$\frac{\lambda_{eff}}{y}\,\frac{\partial}{\partial y}\left(y\,\frac{\partial T}{\partial y}\right) + R_{1BI}^2\;PD_{1A} = \rho_{1A}R_{1BI}^2\chi_{1A}\,\frac{\partial T}{\partial t} \qquad \text{(III-16)}$$

by introducing the radial time scale $t_{1A} = \dfrac{\rho_{1A}\chi_{1A}R_{1BI}^2}{\lambda_{eff}}$ (III-17)

and the dimensionless time $\tau = \dfrac{t}{t_{1A}}$ (III-18)

eq.(III-16) becomes

$$\frac{\partial^2 T_{1A}}{\partial y^2} + \frac{1}{y}\,\frac{\partial T_{1A}}{\partial y} + \frac{R_{1BI}^2}{\lambda_{eff}}\,PD_{10} - \frac{\partial T_{1A}}{\partial \tau} = 0 \qquad \text{(III-19)}$$

The boundary conditions associated to eq.(III-19) are

$$\left(\frac{\partial T_{1A}}{\partial y}\right)_{y=0} = 0 \qquad \text{(no heat flux in the center)} \qquad \text{(III-20)}$$

$$\frac{\lambda_{eff}}{R_{1BI}}\left(\frac{\partial T_{1A}}{\partial y}\right)_{y=1} = h_{1AB}(T_{1AS}-T_{1B}) \qquad \text{(III-21)}$$

(continuous heat flux between fuel surface and cladding)

Considering small variations ΔT_{1A}, ΔT_{1AS}, ΔT_{1B}, ΔPD_{1A}, Δh_{1AB} from the steady state conditions, eq.(III-19) and the associated boundary conditions (III-20) and (III-21) become respectively

$$\frac{\partial \Delta T_{1A}}{\partial y^2} + \frac{1}{y}\frac{\partial \Delta T_{1A}}{\partial y} + \frac{R_{1BI}^2}{\lambda_{eff}} \Delta PD_{1A} - \frac{\partial \Delta T_{1A}}{\partial \tau} = 0 \qquad \text{(III-22)}$$

$$\left(\frac{\partial \Delta T_{1A}}{\partial y}\right)_{y=0} = 0 \qquad \text{(III-23)}$$

$$\left(\frac{\partial \Delta T_{1A}}{\partial y}\right)_{y=1} \approx \frac{R_{1BI}}{\lambda_{eff}} \left[h_{1AB}(\Delta T_{1AS} - \Delta T_{1B}) + \Delta h_{1AB}(T_{1ASO} - T_{1BO}) \right] \qquad \text{(III-24)}$$

In the eqs.(III-22,23 and 24) the subscript "O" indicates the values of the variables at steady state conditions. Eq.(III-22) will be solved by means of the Laplace Transformation. In the Laplace domain eqs.(III-22,23 and 24) become respectively

$$\frac{d^2 \Delta T^*}{dy^2} + \frac{1}{y}\frac{d \Delta T^*}{dy} + \frac{R_{1BI}^2}{\lambda_{eff}} \Delta PD_{1A}^* - s\Delta T_{1A}^* = 0 \qquad \text{(III-25)}$$

$$\left(\frac{d\Delta T^*}{dy}\right)_{y=0} = 0 \qquad \text{(III-26)}$$

$$\left(\frac{d\Delta T^*}{dy}\right)_{y=1} = - \frac{R_{1BI}}{\lambda_{eff}} \left[h_{1AB}(\Delta T_{1AS}^* - \Delta T_{1B}^*) + \Delta h_{1AB}^*(T_{1ASO} - T_{1BO}) \right] \qquad \text{(III-27)}$$

where s denotes the independent variable in the Laplace domain and "*" indicates the operation of the Laplace transformation. The solution of eq.(III-25) with the associated boundary condition (III-26) is

$$\Delta T_{1A}^{*} = \frac{R_{1BI}^{2}}{s\lambda_{eff}} \Delta PD_{10}^{*} + A\ Jo(y\sqrt{-s}) \qquad \text{(III-28)}$$

The constant "A" is calculated by using the boundary condition (III-27). This gives

$$A = \frac{1}{\sqrt{-s}J_1(\sqrt{-s})} \frac{R_{1BI}}{\lambda_{eff}} \left[h_{1AB}(\Delta T_{1AS}^{*} - \Delta T_{1B}^{*}) + \Delta h_{1AB}^{*}(T_{1ASO} - T_{1BO}) \right]$$

(III-29)

From eq.(III-28 and 29) we get

$$\Delta T_{1A}^{*} = \frac{R_{1BI}}{s\lambda_{eff}} \Delta PD_{1A}^{*} + \frac{Jo(y\sqrt{-s})}{\sqrt{-s}J_1(\sqrt{-s})} \frac{R_{1BI}}{\lambda_{eff}} \left[h_{1AB}(\Delta T_{1AS}^{*} - \Delta T_{1B}^{*}) + \right.$$
$$\left. + \Delta h_{1AB}^{*}(T_{1ASO} - T_{1BO}) \right]$$

(III-30)

For y=1 eq.(III-30) gives

$$\Delta T_{1AS}^{*} = \frac{1}{1 + \frac{\gamma}{Z(s)}} \quad \Delta T_{1B}^{*} - \frac{\Delta h_{1AB}^{*}}{h_{1AB}}(T_{1ASO} - T_{1BO}) + \frac{1}{sZ(s)} \frac{R_{1BI}}{2h_{1AB}} \Delta PD_{1A}^{*}$$

(III-31)

where $Z(s) = - \frac{Jo(\sqrt{-s})}{2\sqrt{-s}J_1(\sqrt{-s})}$ (III-32)

$\gamma = \frac{\lambda eff}{2R_{1BI}\ h_{1AB}}$ (III-33)

With the two abbreviations

$G_s(s) = \frac{1}{1 + \frac{\gamma}{Z(s)}}$ (III-34)

$$F_s(s) = \frac{1/sZ(s)}{1+\gamma/Z(s)} = \frac{1}{\gamma s}\left[1-G_s(s)\right] \qquad \text{(III-35)}$$

eq.(III-31) becomes

$$\Delta T^*_{1AS} = G_s(s)\Delta T^*_{1B} - (T_{1ASO}-T_{1BO})G_s(s)\frac{\Delta h^*_{1AB}}{h_{1AB}} + \frac{R_{1BI}}{2h_{1AB}}F_s(s)\Delta PD^*_{1A} \qquad \text{(III-36)}$$

We calculate now ΔT^*_{1A} from eq.(III-28) by imposing the condition $\Delta T^*_{1A} = \Delta T^*_{1AS}$ for y=1. This gives

$$A = \frac{\Delta T^*_{1AS}}{Jo(\sqrt{-s})} - \frac{R^2}{s\lambda_{eff}Jo(\sqrt{-s})}\Delta PD^*_{1A} \qquad \text{(III-37)}$$

By putting eq.(III-37) into eq.(III-28), we get

$$\Delta T^*_{1A} = \frac{R^2_{1BI}}{s\lambda_{eff}}\left[1 - \frac{Jo(y\sqrt{-s})}{Jo(\sqrt{-s})}\right]\Delta PD^*_{1A} + \frac{Jo(y\sqrt{-s})}{Jo(\sqrt{-s})}\Delta T^*_{1AS} \qquad \text{(III-38)}$$

Let us now consider the two average temperatures:

$$\Delta T^*_{1AL} = 2\int_0^1 \Delta T^*_{1A}dy \qquad \text{linear average temperature} \qquad \text{(III-39)}$$

and

$$\Delta T^*_{1AM} = 2\int_0^1 \Delta T^*_{1A}y\,dy \qquad \text{volume average temperature} \qquad \text{(III-40)}$$

Taking into account eq.(III-38), the eqs.(III-39 and 40) become respectively

$$\Delta T^{*}_{1AL} = \frac{R^{2}_{1BI}}{s\lambda_{eff}} \frac{\pi}{2} \left[-\frac{H_o(\sqrt{-s})}{2\sqrt{-s}Z(s)} + H_1(\sqrt{-s}) \right] \Delta PD^{*}_{1A}$$

$$+ \quad 1 - \frac{\pi}{2} \left[-\frac{H_o(\sqrt{-s})}{2\sqrt{-s}Z(s)} + H_1(\sqrt{-s}) \right] \quad \Delta T^{*}_{1AS} \qquad \text{(III-41)}$$

$$\Delta T^{*}_{1AM} = \frac{R^{2}_{1BI}}{s\lambda_{eff}} \left[1 - \frac{1}{sZ(s)} \right] \Delta PD^{*}_{1A} + \frac{1}{sZ(s)} \Delta T^{*}_{1AS} \qquad \text{(III-42)}$$

In order to have the exact solution at steady state conditions ($s \to 0$) the two terms on the right side of each one of eqs. (III-41 and 42) must be multiplied by properly chosen coefficients β_L, α_L, β_M and α_M. By doing this eq.(III-41) and (III-42) become

$$\Delta T^{*}_{1AL} = \beta_L \frac{R^{2}_{1BI}}{s\lambda_{eff}} \frac{\pi}{2} \left[-\frac{H_o(\sqrt{-s})}{2\sqrt{-s}Z(s)} + H_1(\sqrt{-s}) \right] \Delta PD^{*}_{1A} + \alpha_L \left\{ 1 - \frac{\pi}{2} \left[-\frac{H_o(\sqrt{-s})}{2\sqrt{-s}Z(s)} + H_1(\sqrt{-s}) \right] \right\} \Delta T^{*}_{1AS} \qquad \text{(III-43)}$$

$$\Delta T^{*}_{1AM} = \beta_M \frac{R^{2}_{1BI}}{s\lambda_{eff}} \left[1 - \frac{1}{sZ(s)} \right] \Delta PD^{*}_{1A} + \alpha_M \frac{1}{sZ(s)} \Delta T^{*}_{1AS} \qquad \text{(III-44)}$$

Let us now substitute ΔT^{*}_{1AS} in eqs.(III-43 and 44) by means of eq.(III-36). We get (by using $\frac{\Delta PD^{*}_{1A}}{PD_{1A}} = \frac{\Delta P^{*}}{P_o}$)

$$\Delta T_{1AL} = \alpha_L G_L(s) \Delta T^{*}_{1B} - \alpha_L G_L(s) (T_{1ASO} - T_{1BO}) \frac{\Delta h^{*}_{1AB}}{h_{1AB}} +$$

$$+ (T_{1ASO} - T_{1BO}) \cdot \left(\alpha_L + \frac{\beta_L}{6\gamma}\right) F_L(s) \frac{\Delta P^{*}}{P_o} \qquad \text{(III-45)}$$

$$\Delta T^*_{1AM} = \alpha_M F_s(s)\Delta T^*_{1B} - \alpha_M (T_{1ASO} - T_{1BO}) F_s(s) \frac{\Delta h^*_{1AB}}{h_{1AB}} +$$

$$+ (T_{1ASO} - T_{1BO}) \cdot (\alpha_M + \frac{\beta_M}{8\gamma} F_M(s) \frac{\Delta P^*}{P_O} \qquad \text{(III-46)}$$

where

$$G_L(s) = G_s(s) \left\{ 1 - \frac{\pi}{2} \left[\frac{-H_O(\sqrt{-s})}{2\sqrt{-s}Z(s)} + H_1(\sqrt{-s}) \right] \right\} \qquad \text{(III-47)}$$

$$F_L(s) = \frac{6}{\beta_L + 6\alpha_L\gamma} \frac{1}{s} \left\{ \alpha_L \left[1 - G_L(s) \right] + (\beta_L - \alpha_L) \frac{\pi}{2} \left[\frac{-H_O(\sqrt{-s})}{2\sqrt{-s}Z(s)} + H_1(\sqrt{-s}) \right] \right\}$$

(III-48)

$$F_M(s) = \frac{8\gamma}{\beta_M + 8\gamma\alpha_M} \frac{1}{s} \left\{ \frac{\beta_M}{\gamma} \left[1 - \frac{1}{sZ(s)} \right] + \alpha_M \frac{1}{Z(s)} F_s(s) \right\} \qquad \text{(III-49)}$$

The width of the gap between the fuel and the cladding changes with the linear average fuel temperature T_{1AL} and with the cladding temperature T_{1B}. The resulting changes in the heat transfer coefficient h_{1AB} can therefore be expressed by

$$\frac{\Delta h^*_{1AB}}{h_{1AB}} = \varepsilon \frac{\Delta T^*_{1AL}}{(T_{1ASO} - T_{1BO})} - \eta \frac{\Delta T^*_{1B}}{(T_{1ASO} - T_{1BO})} \qquad \text{(III-50)}$$

The parameters "ε" and "η" are dimensionless coefficients, which will be determined by steady state calculations. Taking into account (III-50), eq.(III-45) becomes

$$\Delta T^*_{1AL} = K_{1ALT} G_{1AL}(s) \Delta T^*_{1B} + K_{1ALP} (T_{1ALO} - T_{1BO}) F_{1AL}(s) \frac{\Delta P^*}{P_O} \qquad \text{(III-51)}$$

$$F_{1AS}(s) = \frac{1}{1 - \frac{\varepsilon}{1+\varepsilon\alpha_L}(\alpha_L+\frac{\beta_L}{6\gamma})} \left[F_s(s) - \frac{\varepsilon}{1+\varepsilon\alpha_L}(\alpha_L+\frac{\beta_L}{6\gamma}) G_s(s) F_{1AL}(s) \right]$$

$$= F_s(s) \frac{1-\frac{\varepsilon}{6\gamma}\,\frac{\beta_L+6\gamma\alpha_L}{1+\varepsilon\alpha_L}\,\frac{G_s(s)F_{1AL}(s)}{F_s(s)}}{1-\frac{\varepsilon}{6\gamma}\,\frac{\beta_L+6\gamma\alpha_L}{1+\varepsilon\alpha_L}} \qquad \text{(III-61)}$$

$$K_{1AMT} = \left(\frac{\partial T_{1AMO}}{\partial T_{1BO}}\right)_{P=const} = \alpha_M\left[1+\eta-\varepsilon K_{1ALT}\right] = \alpha_M K_{1AST} \qquad \text{(III-62)}$$

$$K_{1AMP} = \left(\frac{\partial T_{AMO}}{\partial P_o}\right)_{T_{1B}=const} \cdot \frac{P_o}{T_{1AMO}-T_{1BO}} = \qquad \text{(III-62')}$$

$$= \frac{T_{1ASO}-T_{1BO}}{T_{1AMO}-T_{1BO}} \left[\alpha_M+\frac{\beta_M}{8\gamma} - \frac{\alpha_M\varepsilon}{1+\varepsilon\alpha_L}(\alpha_L+\frac{\beta_L}{6\gamma}\right] =$$

$$= \frac{T_{1ASO}-T_{1BO}}{T_{1AMO}-T_{1BO}} \left[-\frac{\beta_M}{8\gamma} + \alpha_M K_{1ASP}\right]$$

$$G_{1AM}(s) = F_s(s) \frac{G_{1AS}(s)}{G_s(s)} \qquad \text{(III-63)}$$

$$F_{1AM}(s) = \frac{1}{\alpha_M+\frac{\beta_M}{8\gamma}-\frac{\alpha_M\varepsilon}{1+\varepsilon\alpha_L}(\alpha_L+\frac{\beta_L}{6\gamma})} \left[(\alpha_M+\frac{\beta_M}{8\gamma} F_M(s) - \frac{\alpha_M\varepsilon}{1+\varepsilon\alpha_L}(\alpha_L+\frac{\beta_L}{6\gamma}) F_s(s) F_{1AL}(s)\right]$$

$$= F_M(s) \frac{1-\frac{4}{3}\,\frac{\alpha_M\varepsilon}{1+\varepsilon\alpha_L}\,\frac{\beta_L+6\gamma\alpha_L}{\beta_M+8\gamma\alpha_M}\,\frac{F_s(s)F_{1AL}(s)}{F_M(s)}}{1-\frac{4}{3}\,\frac{\alpha_M\varepsilon}{1+\varepsilon\alpha_L}\,\frac{\beta_L+6\gamma\alpha_L}{\beta_M+8\gamma\alpha_M}} \qquad \text{(III-64)}$$

The constant parameters K_{1AST}, K_{1ALT}, K_{1AMT}, K_{1ASP}, K_{1ALP}, K_{1AMP}, γ, ε, η, α_L, α_M, β_L, β_M can be calculated in principle from the steady state conditions. But they are not all independent.

Let us start from the following expressions:

$$K_{1AST} = 1 + \eta - \varepsilon K_{1ALT} \qquad \text{(III-58)}$$

$$K_{1ALT} = \alpha_L \frac{1+\eta}{1+\varepsilon\alpha_L} \qquad \text{(III-52)}$$

$$K_{1AMT} = \alpha_M K_{1AST} \qquad \text{(III-62)}$$

$$K_{1ASP} = 1 - \frac{\varepsilon}{1+\varepsilon\alpha_L} (\alpha_L + \frac{\beta_L}{6\gamma}) \qquad \text{(III-59)}$$

$$K_{1ALP} = \frac{1}{1+\varepsilon\alpha_L} (\alpha_L + \frac{\beta_L}{6\gamma}) \frac{T_{1ASO}-T_{1BO}}{T_{1ALO}-T_{1BO}} \qquad \text{(III-53)}$$

$$K_{1AMP} = \left[-\frac{\beta_M}{8\gamma} + \alpha_M K_{1ASP} \right] \frac{T_{1ASO}-T_{1BO}}{T_{1AMO}-T_{1BO}} \qquad \text{(III-62)}$$

From eqs. III-59 and III-53 we get

$$\varepsilon = \frac{1-K_{1ASP}}{K_{1ALP}} \frac{T_{1ASO}-T_{1BO}}{T_{1ALO}-T_{1BO}} \qquad \text{(III-65)}$$

From eq. III-58 we get

$$\eta = K_{1AST} - 1 + \varepsilon K_{1ALT} \qquad \text{(III-66)}$$

From eqs. III-58 and III-52

$$\alpha_L = \frac{K_{1ALT}}{1+\eta-\varepsilon K_{1ALT}} = \frac{K_{1ALT}}{K_{1AST}} \qquad \text{(III-67)}$$

and from eq. III-62 we get $\alpha_M = \frac{K_{1AMT}}{K_{1AST}}$ (III-68)

By combining eqs. III-53 and III.65, we get

$$\frac{\gamma}{\beta_L} = \frac{1}{6}\,\frac{T_{1ASO} - T_{1BO}}{K_{1ALP}(T_{1ALO}-T_{1BO})-\alpha_L K_{1ASP}(T_{1ASO}-T_{1BO})} \qquad \text{(III-69)}$$

Eq.(III-62') can be written as follows

$$\frac{\gamma}{\beta_M} = \frac{1}{8}\,\frac{T_{1ASO} - T_{1BO}}{K_{1AMP}(T_{1AMO}-T_{1BO})-\alpha_M K_{1ASP}(T_{1ASO}-T_{1BO})} \qquad \text{(III-70)}$$

Taking into account eq.III-69, eq.III-65 becomes

$$\varepsilon = \frac{1-K_{1ASP}}{\alpha_L K_{1ASP}+\frac{\beta_L}{6\gamma}} \qquad \text{(III-71)}$$

At this point we must decide how to choose "γ" (e.g. λ_{eff}). Since the reactivity effects depend upon the volume average temperature of the fuel T_{1AM}, it seems logical to determine this temperature most precisely. This means to impose the condition

$$\beta_M = 1 \qquad \text{(III-72)}$$

With this condition eq.III-70 becomes

$$\gamma = \frac{1}{8}\,\frac{T_{1ASO} - T_{1BO}}{K_{1AMP}(T_{1AMO}-T_{1BO})-\alpha_M K_{1ASP}(T_{1ASO}-T_{1BO})} \qquad \text{(III-73)}$$

Since analytical expressions for K_{1ALT} and K_{1ALP} are not available the following approximations will be used

$$K_{1ALT} \cong K_{1AMT} \qquad \text{(III-74)}$$

and

$$\beta_L \cong \beta_M = 1 \qquad \text{(III-75)}$$

From eqs.III-67, III-68 and III-74 it follows

$$\alpha_L \cong \alpha_M \qquad \text{(III-76)}$$

Taking into account eqs.III-75 and III-76, eq.III-71 becomes

$$\varepsilon = \frac{1-K_{1ASP}}{\alpha_M K_{1ASP}+\frac{1}{6\gamma}} \qquad \text{(III-77)}$$

2) Heat Transfer between Fuel and Coolant in Radial Direction

Fig.6 shows a block diagram of the electrical analogue for the heat flux in radial direction from the fuel to the coolant corresponding to the model of Fig.3a,b. The cladding is simulated by its heat capacity $\mathcal{C}_{1B}$.

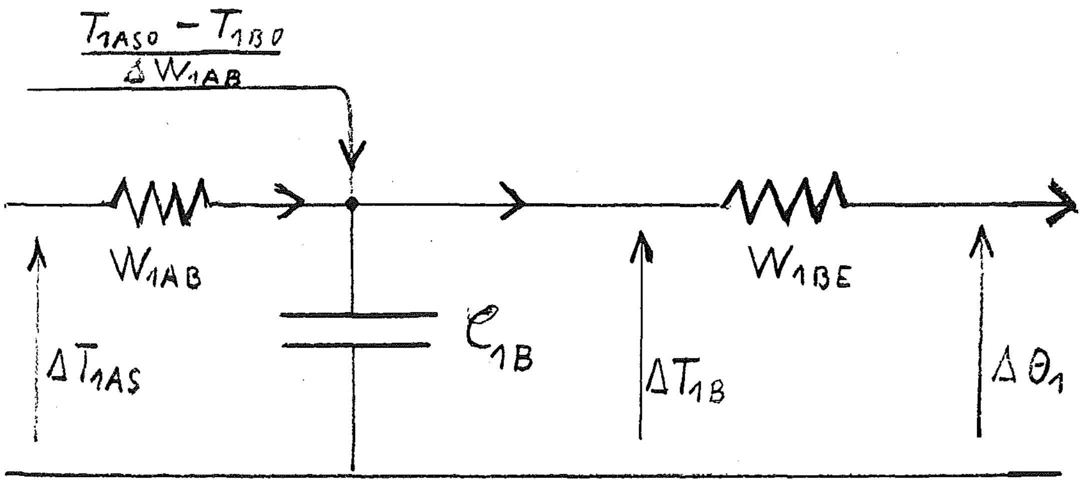


Fig.6 Model for the heat flow in radial direction from the fuel surface to the coolant

The thermal resistances between the fuel and the coolant are the thermal resistance of the cladding

$$W_{1B} = \frac{R_{1BE} - R_{1BI}}{\lambda_{1B} 2\pi \left(\frac{R_{1BE}+R_{1BI}}{2}\right)} \qquad \left[\frac{\text{cm } ^{\circ}\text{K}}{\text{Watt}}\right] \qquad \text{(III-78)}$$

the thermal resistance between fuel and cladding

$$W'_{1AB} = \frac{1}{h_{1A} 2\pi R_{1BI}} \quad \left[\frac{cm\ ^oK}{Watt} \right], \qquad \text{(III-78)}$$

and the thermal resistance between cladding and coolant

$$W'_{1BE} = \frac{1}{h_{1BE} 2\pi R_{1BE}} = \frac{1}{\pi Nu \lambda_{1E}} \quad \left[\frac{cm\ ^oK}{Watt} \right] \qquad \text{(III-79)}$$

with the cladding to sodium heat transfer coefficient

$$h_{1BE} = \frac{Nu\ \lambda_{1E}}{2\ R_{1BE}} \quad \left[\frac{Watt}{cm^2\ ^oK} \right] \qquad \text{(III-80)}$$

In this model we consider only the average cladding temperature because the heat transfer time constant for the cladding is small compared to those of the fuel, the coolant and the moderator.

In this case W_{1B} can be split into two equal parts, which are added to W'_{AB} and W'_{BC}:

$$W_{1AB} = \frac{1}{2\pi R_{1BI}} \left\{ \frac{1}{h_{1A}} + \frac{R_{1BE}-R_{1BI}}{R_{1BE}+R_{1BI}} \frac{R_{1BI}}{\lambda_{1B}} \right\} = \frac{1}{2\pi R_{1BI}} \frac{1}{h_{1AB}} \quad \left[\frac{cm\ ^oK}{Watt} \right]$$

(III-81)

$$W_{1BE} = \frac{1}{\pi} \left\{ \frac{1}{Nu\lambda_{1E}} + \frac{R_{1BE}-R_{1BI}}{R_{1BE}+R_{1BI}} \frac{1}{2\lambda_{1B}} \right\} \quad \left[\frac{cm\ ^oK}{Watt} \right] \qquad \text{(III-82)}$$

$$\text{with } h_{1AB} = \left\{ \frac{1}{h_{1A}} + \frac{R_{1BE}-R_{1BI}}{R_{1BE}+R_{1BI}} \frac{R_{1BI}}{\lambda_{1B}} \right\}^{-1} \quad \left[\frac{Watt}{cm^2\ ^oK} \right] \qquad \text{(III-83)}$$

a) Steady state case

With these resistances the average steady state fuel surface temperature T_{1ASO} is calculated from the average coolant temperature θ_{10} by the following equations:

$$T_{1ASO} = T_{1BO} + \frac{\alpha_{1A} P_o}{N_1 L_1} W_{1AB} \quad [{}^oK] \qquad \text{(III-84)}$$

with

$$T_{1BO} = \theta_{10} + \frac{\alpha_{1A} P_o}{N_1 L_1} W_{1BE} \quad [{}^oK] \qquad \text{(III-85)}$$

b) Non stationary Case

With reference to Fig.6 we can write the following equation in the Laplace domain:

$$\frac{\Delta T^*_{1AS} - \Delta T^*_{1B}}{W_{1AB}} + \frac{T_{1ASO} - T_{1BO}}{\Delta W^*_{1AB}} = \frac{\Delta T^*_{1B} - \Delta\theta^*_1}{W_{1BE}} + s \frac{\mathcal{C}_{1B}}{t_{1A}} \Delta T^*_{1B} \qquad \text{(III-86)}$$

Combing eq.III-86 with the relations for ΔT^*_{1AS}, Δh^*_{1AB} and ΔT^*_{1AL} namely the eqs.III-56, III-50 and III-51 and eliminating ΔT^*_{1AS}, Δh^*_{1AB} and ΔT^*_{1AL} from these equations, one gets

$$\Delta T^*_{1B} \left[\frac{s}{t_{1A}} \mathcal{C}_{1B} + \frac{1}{W_{1BE}} + \frac{1}{W_{1AB}} - \frac{\varepsilon K_{1ALT} G_{1AL}(s)}{W_{1AB}} + \frac{\eta}{W_{1AB}} - \frac{K_{1AST} G_{1AS}(s)}{W_{1AB}} \right]$$

$$= \frac{\Delta\theta^*_1}{W_{1BE}} + \left[-\frac{\varepsilon K_{1ALP} (T_{1ALO} - T_{1BO}) F_{1AL}(s)}{W_{1AB}} + \right.$$

$$\left. + \frac{(T_{1ASO} - T_{1BO}) K_{1ASP} F_{1AS}(s)}{W_{1AB}} \right] \frac{\Delta P^*}{P_o} \qquad \text{(III-87)}$$

Introducing the symbols

$$A = \frac{T_{1BO} - \theta_{10}}{T_{1ASO} - T_{1BO}} = \frac{W_{1BE}}{W_{1AB}} \qquad \text{(III-88)}$$

$$t_{1B} = \mathcal{T}_{1B} \cdot W_{1BE} \qquad [sec] \qquad \text{(III-89)}$$

eq.III-87 becomes

$$\Delta T^{*}_{1B} \left\{ 1 + s\frac{t_{1B}}{t_{1A}} + A \left[1 + \eta - \varepsilon K_{1ALT} G_{1AL}(s) - K_{1AST} G_{1AS}(s) \right] \right\}$$

$$= \Delta\theta^{*}_{1} + A \left[\varepsilon K_{1ALP} (T_{1ALO} - T_{1BO}) F_{1AL}(s) \right.$$

$$\left. + K_{1ASP} (T_{1ASO} - T_{1BO}) F_{1AS}(s) \right] \frac{\Delta P^{*}}{P_{O}} \qquad \text{(III-90)}$$

This can be written in the form

$$\Delta T^{*}_{1B} = G_{1B}(s)\ \Delta\theta^{*}_{1} + (T_{1BO} - \theta_{10}) F_{1B}(s)\ \frac{\Delta P^{*}}{P_{O}} \qquad \text{(III-91)}$$

where

$$G_{1B}(s) = \left\{ 1 + s\frac{t_{1B}}{t_{1A}} + A \left[1 + \eta - \varepsilon K_{1ALT} G_{1AL}(s) - K_{1AST} G_{1AS}(s) \right] \right\}^{-1}$$

$$= \left\{ 1 + s\frac{t_{1B}}{t_{1A}} + As\gamma F_{S}(s)(1+\eta) \left[1 + \frac{\alpha_{L}\varepsilon}{1+\alpha_{L}\varepsilon}\ G_{1AL}(s) \right] \right\}^{-1} \qquad \text{(III-92)}$$

$$F_{1B}(s) = A\ G_{1B}(s) \left[\varepsilon K_{1ALP} \frac{T_{1ALO} - T_{1BO}}{T_{1BO} - \theta_{10}} F_{1AL}(s) + K_{1ASP} \frac{T_{1ASO} - T_{1BO}}{T_{1BO} - \theta_{10}} F_{1AS}(s) \right]$$

$$= G_{1B}(s) \left[(1 - K_{1ASP}) F_{1AL}(s) + K_{1ASP} F_{1AS}(s) \right]$$

Inserting now ΔT^*_{1B} from eq.III-91 into eq.III-57, gives

$$\Delta T^*_{1AM} = \overline{K_{1AMT}}\,\overline{G_{1AM}(s)}\,\Delta\theta^*_1 + \overline{K_{1AMP}}(T_{1AMO}-\theta_{10})\overline{F_{1AM}(s)}\;\frac{\Delta P^*}{P_O} \qquad \text{(III-93)}$$

where

$$\overline{K_{1AMT}} = K_{1AMT} \qquad \text{(III-94)}$$

$$\overline{G_{1AM}(s)} = G_{1B}(s)\,G_{1AM}(s) \qquad \text{(III-95)}$$

$$\overline{K_{1AMP}} = K_{1AMP}\,\frac{T_{1AMO}-T_{1BO}}{T_{1AMO}-\theta_{10}} + K_{1AMT}\,\frac{T_{1BO}-\theta_{10}}{T_{1AMO}-\theta_{10}} \qquad \text{(III-96)}$$

$$\overline{F_{1AM}(s)} = \frac{K_{1AMP}(T_{1AMO}-T_{1BO})F_{1AM}(s)+K_{1AMT}(T_{1BO}-\theta_{10})\,G_{1AM}(s)F_{1B}(s)}{K_{1AMP}(T_{1AMO}-T_{1BO}) + K_{1AMT}(T_{1BO}-\theta_{10})} \qquad \text{(III-97)}$$

Taking into account eq.III-88 and III-63, eqs.III-96 and 97 can be written in the form

$$\overline{K_{1AMP}} = \left[\alpha_M K_{1ASP} + \frac{\beta_M}{8\gamma} + A\,K_{1AMT}\right]\frac{T_{1ASO}-T_{1BO}}{T_{1AMO}-\theta_{10}} \qquad \text{(III-98)}$$

$$\overline{F_{1AM}(s)} = \frac{\left[\alpha_M K_{1ASP}+\frac{\beta_M}{8\gamma}\right]F_{1AM}(s)+AK_{1AMT}G_{1AM}(s)F_{1B}(s)}{\alpha_M K_{1ASP} + \frac{\beta_M}{8\gamma} + A\,K_{1AMT}} \qquad \text{(III-99)}$$

3) Heat Transport by Means of the Coolant in Axial Direction

The heat transfer from the cladding to the coolant in radial direction and by the coolant in axial direction is basically treated in a similar way as described in /2/. The model underlying this report is however more general in so far as it takes into account also the heat exchange between the coolant and the structure materials. In addition all new results of the previous sections have to be incorporated in the heat balance for the coolant.

Assuming that the two structure materials (characterized by the indices "C" and "D") have the same length as the fuel rods and can be adequately associated to the coolant channel, the heat conduction equation for the coolant is

$$\frac{T_{1B}-\theta_1}{W_{1BE}} + \frac{T_{1C}-\theta_1}{W_{1CE}} + \frac{T_{1D}-\theta_1}{W_{1DE}} = \mathcal{S}_1 \, \rho_{1E} \, \chi_{1E} \left(\frac{\partial\theta_1}{\partial t} + v \frac{\partial\theta_1}{\partial Z}\right) \qquad \text{(III-100)}$$

with

$x = \frac{Z}{L_1} = \frac{\text{axial coordinate}}{\text{height of the cylinder}}$. This can be transformed into

$$\frac{T_{1B} - \theta_1}{W_{1BE}\mathcal{S}_1\rho_{1E}\chi_{1E}} + \frac{T_{1C} - \theta_1}{W_{1CE}\mathcal{S}_1\rho_{1E}\chi_{1E}} + \frac{T_{1D} - \theta_1}{W_{1DE}\mathcal{S}_1\rho_{1E}\chi_{1E}} = \frac{1}{t_{1A}} \frac{\partial\theta_1}{\partial\tau} + \frac{v}{L_1} \frac{\partial\theta_1}{\partial x}$$

(III-101)

If we set

$$\frac{m_{1A} \, l'}{A\gamma} = \frac{1}{\mathcal{S}_1\rho_{1E}\chi_{1E}} \, \frac{L_1}{v} \, \frac{1}{W_{1BE}} \qquad \text{(III-102)}$$

we get

$$\frac{m_{1A}l}{A\gamma}\ (T_{1B}-\theta_1)\ +\ \frac{}{v}\ \frac{(T_{1C}-\theta_1)}{W_{1CE}\,S_1\,\rho_{1E}X_{1E}}\ +\ \frac{}{v}\ (\frac{(T_{1D}-\theta_1)}{W_{1DE}\,S_1\,\rho_{1E}X_{1E}}\ =\ l\frac{\partial\theta_1}{\partial\tau}\ +\ \frac{\partial\theta_1}{\partial x}$$

$$\frac{m_{1A}}{A\gamma}(T_{1B}-\theta_1)\ +\ \frac{t_{1A}(T_{1C}-\theta_1)}{W_{1CE}\,S_1\,\rho_{1E}X_{1E}}\ +\ \frac{t_{1A}(T_{1D}-\theta_1)}{W_{1DE}\,S_1\,\rho_{1E}X_{1E}}\ =\ \frac{\partial\theta_1}{\partial\tau}\ +\ \frac{1}{l}\ \frac{\partial\theta_1}{\partial x} \qquad \text{(III-103)}$$

Considering the variation of the system from the stationary conditions,the following symbols are introduced

$$\left.\begin{array}{ll} \Delta T_{1B} = T_{1B} - T_{1BO} & \Delta\theta_1 = \theta_1 - \theta_{1O} \\ \Delta T_{1C} = T_{1C} - T_{1CO} & \Delta v = v - v_o \\ \Delta T_{1D} = T_{1D} - T_{1DO} & \end{array}\right\} \qquad \text{(III-104)}$$

The subscript "O" indicates the initial steady state condition and "Δ" indicates the variation from the steady state condition.

From $l' = \frac{L_{1/v}}{t_{1A}}$, $l'_o = \frac{L_{1/vo}}{t_{1A}}$ we get $\frac{l'}{l'_o} = \frac{v_o}{v}$; $\frac{\Delta v}{vo} = \frac{v}{v_o} - 1 = \frac{l'_o}{l'} - 1$

$$\frac{1}{l'} = \frac{1}{l'_o}(1+\frac{\Delta v}{vo})$$

With this relations eq.(III-103) becomes

$$\frac{m_{1A}l'_o}{A\gamma}\ (\Delta T_{1B}-\Delta\theta_1)\ +\frac{l'_o t_{1A}(\Delta T_{1C}-\Delta\theta_1)}{W_{1CE}\,S_1\,\rho_{1E}X_{1E}}\ +\frac{l'_o t_{1A}(\Delta T_{1D}-\Delta\theta_1)}{W_{1DE}\,S_1\,\rho_{E}X_{1E}}$$

$$=\ \frac{\Delta v}{vo}\ \frac{d\theta_{1O}}{dx}\ +\ (1+\frac{\Delta v}{v_O})\ \frac{d\Delta\theta_1}{\partial x}\ +\ l_o\ \frac{\partial\Delta\theta_1}{\partial\tau} \qquad \text{(III-105)}$$

Performing the Laplace transformation and neglecting the second order term $\frac{\Delta v}{vo}\cdot\frac{\partial\Delta\theta 1}{\partial x}$ one gets

$$\frac{\Delta v^*(s)}{v_o}\,\frac{d\theta_{10}}{dx} + \frac{d\Delta\theta_1^*(s)}{dx} + l_o' s\Delta\theta_1^*(s) = \frac{m_{1A}l_o'}{A\gamma}\left[\Delta T_{1B}^*(s)-\Delta\theta_1^*(s)\right]$$

$$+ \frac{L_1/v_o(\Delta T_{1C}^*-\Delta\theta_1^*)}{W_{1CE}S_1\rho_{1E}\chi_{1E}} + \frac{L_1/v_o(\Delta T_{1D}^*-\Delta\theta_1^*)}{W_{1DE}S_1\rho_{1E}\chi_{1E}} \qquad \text{(III-106)}$$

Using the eq.III-91 and corresponding equations for ΔT_{1C} and ΔT_{1D} and the relation $\frac{d\theta_o}{dx} = (\theta_{130}-\theta_{120})M(X)$ one gets

$$\frac{d\Delta\theta_1^*(s)}{dx} + \left[l_o's + \frac{m_{1A}l_o'}{A\gamma}(1-G_{1B}) + \frac{L_1/v_o(T_{1BO}-\theta_{10})}{W_{1BE}S_1\rho_{1E}\chi_{1E}}(1-G_{1B})\right]\Delta\theta_1^*(s) =$$

$$\left\{\frac{m_{1A}l_o'}{A\gamma}(T_{1BO}-\theta_{10})F_{1B}\frac{\Delta P^*}{P} + \frac{L_1/v_o(T_{1CO}-\theta_{10})F_{1C}}{W_{1CE}S_1\rho_{1E}\chi_1} + \frac{L_1/v_o(T_{1DO}-\theta_{10})F_{1D}}{W_{1DE}S_1\rho_{1E}\chi_{1E}}\right.$$

$$\left. - \frac{\Delta v^*(s)}{v_o}(\theta_{130}-\theta_{120})\right\} M(x) \qquad \text{(III-107)}$$

Using the relations

$$P_o\alpha_1 = N_1S_1\rho_{1E}\chi_{1E}v(\theta_{130}-\theta_{120}) \qquad \text{(III-108)}$$

$$P_o\alpha_{1A} = L_1N_1(PD_{10}R_{1BI}^2\pi) \qquad \text{(III-109)}$$

$$T_{1BO}-\theta_{10} = R_{1BI}^2\pi PD_{10}W_{1BE} \qquad \text{(III-110)}$$

$$T_{1CO}-\theta_{10} = \frac{P_o\alpha_{1C}}{N_1L_1}W_{1CE} \qquad \text{(III-111)}$$

$$T_{1DO}-\theta_{10} = \frac{P_o\alpha_{1D}}{N_1L_1}W_{1DE} \qquad \text{(III-112)}$$

$$\Delta v/v = \Delta\mu/\mu \;;\quad t_{1ax} = \frac{L_1}{v_o} \qquad \text{(III-113)}$$

and with respect to frequency analysis $s = j\omega t_{1A} = \sigma t_{1A}$ (i.e. $\sigma = j\omega$), the eq.III-107 can be transformed into

$$\frac{d\Delta\theta_1(\sigma)}{dx}+\left[\bar{t}_{1ax}\sigma\left(1+\frac{m_{1A}(1-G_{1B}(\sigma))}{A\gamma\sigma t_{1A}}\right)+t_{1ax}\sigma m_{1C}F_{1C}(\sigma)+t_{1ax}\sigma m_{1D}F_{1D}(\sigma)\right]\Delta\theta_1(\sigma)$$

$$=\left[\frac{-\Delta v(\sigma)}{v_o}+\frac{\alpha_{1A}}{\alpha_1}t_{1ax}F_{1B}(\sigma)+\frac{\alpha_{1C}}{\alpha_1}t_{1ax}F_{1C}(\sigma)+\frac{\alpha_{1D}}{\alpha_1}t_{1ax}F_{1D}(\sigma)\right](\theta_{130}-\theta_{120})$$

$$\cdot M(x)\frac{\Delta P}{P} \qquad \text{(III-114)}$$

Eq.(III-114) can be written as follows

$$\frac{d\Delta\theta_1(\sigma)}{dx} + y_1(\sigma)\Delta\theta_1(\sigma) = (\theta_{130}-\theta_{120})M(x)\left[-\frac{\Delta u}{u} + F_1(\sigma)\frac{\Delta P(\sigma)}{P}\right] \qquad \text{(III-115)}$$

with the following abbreviations

$$y_1(\sigma) = y_{1B}(\sigma) + y_{1C}(\sigma) + y_{1D}(\sigma) + \sigma t_{1ax} \qquad \text{(III-116)}$$

$$y_{1B}(\sigma) = \frac{m_{1A}(1-G_{1B}(\sigma))}{A\gamma\sigma t_{1A}}\, t_{1ax}\sigma \qquad \text{(III-117)}$$

$$y_{1C}(\sigma) = t_{1ax}\sigma m_{1C}F_{1C}(\sigma) \qquad \text{(III-118)}$$

$$y_{1D}(\sigma) = t_{1ax}\sigma m_{1D}F_{1D}(\sigma) \qquad \text{(III-119)}$$

$$F_1(\sigma) = \frac{\alpha_{1A}}{\alpha_1}F_{1B}(\sigma) + \frac{\alpha_{1C}}{\alpha_1}F_{1C}(\sigma) + \frac{\alpha_{1D}}{\alpha_1}F_{1D}(\sigma) \qquad \text{(III-120)}$$

The eq.(III-115) is valid for all coolant channels. The specific form of the functions $y(\sigma)$ and $F(\sigma)$ depends however on the composition of different materials in a specific coolant channel (see eqs. A-18 to A-21).

IV) Numerical Calculations

Numerical calculations for test purposes have been performed for the SEFOR-reactor /5/ because the oscillatory behaviour of this reactor has been previously analyzed in detail. In addition transfer functions have been calculated also for the test reactor KNK /6/.

The type of transfer function which is of most interest depends very much on the special objective of the analysis. Normally the overall closed loop transfer function $G_p(\omega)$ is required especially with regard to problems of reactor stability. However for special problems and experiments, e.g. noise measurements or oscillator measurements, other transfer function of this model have to be considered separately. Here only a few numerical results are given especially to demonstrate the influence of the nonlinearities on the results.

Differences between this model including the spatial dependence of the heat transfer process and the so called "lumped model" have been pointed out in /1/ and /2/ and will not be discussed here. All calculations referred to in this chapter take into account the spatial dependence of the heat transfer process.

As an example, in Fig.7 plots of the fuel surface temperature T_{1AS}, the average and the central fuel temperature (T_{1AM} and T_{1AC} respectively) in dependence of the reactor power are given for SEFOR. This plot suggests that for 19 MW reactor power the corrections for nonlinearities will become relatively large.Therefore the correction coefficients K_{1AMP} and K_{1ASP}, being equal 1 for a completely linear system, become relatively small ($K_{1AMP} = 0.81$, $K_{1ASP} = -0.076$). The extremely small value of K_{1ASP} is due to to the fact that the fuel surface temperature T_{1AS} is almost independent of the power level in this region (see FIg.7), because any temperature variation caused by a nonstationary reactor power is almost completely counterbalanced by a corresponding change of the fuel to cladding heat transfer coefficient h_{1A}. If this change would not be taken into account, T_{1AS} would increase with the reactor power as indicated in Fig.7 by the dotted line instead of slightly decreasing. Therefore it can be expected that non-linearities will have a big effect on the transfer function F_{1AS} between the fuel surface temperature and the reactor power as demonstrated in Fig.8. Here two calculations for the transfer function

$$\frac{\dfrac{\Delta T_{1AS}}{T_{1ASO} - T_{1BO}}}{\dfrac{\Delta P}{P_O}}$$

are compared one without taking into account the nonlinearities due to λ and h_{1A} and another one which corrects for these non-linearities as described in the previous sections. The small values at low frequencies for the latter one are in agreement with the flat curve of T_{1AS} in Fig.7. At higher frequencies the two additive components determining this transfer function, namely the temperature change caused directly by a power-variation and the additional temperature change caused by a power change through the gap coefficient, don't compensate as much as at lower frequencies, because of their different time constants and signs. This fact is the reason for the broad peak of the corrected transfer function at $\omega \approx 0.1\ sec^{-1}$. The influence of the non-linearities on the average fuel temperature T_{1AM} and the transfer function

$$\frac{\Delta T_{1AM}/(T_{1AMO} - T_{1BO})}{\Delta P/P_O}$$

is smaller because λ decreases and h_{1A} increases with increasing power so that both nonlinearity effects partially compensate each other. This fact is demonstrated in the Figures 7 and 9. The overall feedback term in the power-reactivity transfer function $Gp(\omega)$ depends very much on the average fuel temperature. Therefore the difference between two calculations of $Gp(\omega)$, one neglecting and one taking into account the nonlinearities is also not very large as shown in Fig.10a and b.

These conderations show that the importance for nonlinearity corrections depends very much on the kind of transfer function where $$K_{1ALT} = \left(\frac{\partial T_{1ALO}}{\partial T_{1BO}}\right)_{P=cost} = \alpha_L \frac{1+\eta}{1+\varepsilon\alpha_L} \qquad \text{(III-52)}$$

$$K_{1ALP} = \left(\frac{\partial T_{1ALO}}{\partial P_O}\right)_{T_{1B=const}} \cdot \frac{P_O}{T_{1ALO}-T_{1BO}} =$$

$$= \frac{1}{1+\varepsilon\alpha_L} \cdot \frac{T_{1ASO}-T_{1BO}}{T_{1ALO}-T_{1BO}} \left(\alpha_L + \frac{\beta_L}{6\gamma}\right) \qquad \text{(III-53)}$$

$$G_{1AL}(s) = (1+\varepsilon\alpha_L) \frac{G_L(s)}{1+\varepsilon\alpha_L G_L(s)} \qquad \text{(III-54)}$$

$$F_{1AL}(s) = (1+\varepsilon\alpha_L) \frac{F_L(s)}{1+\varepsilon\alpha_L G_L(s)} \qquad \text{(III-55)}$$

Taking into account eqs.(III-50) and (III-51), eqs.(III-36) and (III-46) become

$$\Delta T^*_{1AS} = K_{1AST} G_{1AS}(s) \Delta T^*_{1B} + K_{1ASP}(T_{1ASO}-T_{1BO}) F_{1AS}(s) \frac{\Delta P^*}{P_O} \qquad \text{(III-56)}$$

$$\Delta T^*_{1AM} = K_{1AMT} G_{1AM}(s) \Delta T^*_{1B} + K_{1AMP}(T_{1AMO}-T_{1BO}) F_{1AM}(s) \frac{\Delta P^*}{P_O} \qquad \text{(III-57)}$$

where

$$K_{1AST} = \left(\frac{\partial T_{1ASO}}{\partial T_{1BO}}\right)_{P=const} = 1+\eta-\varepsilon K_{1ALT} \qquad \text{(III-58)}$$

$$K_{1ASP} = \left(\frac{\partial T_{1ASO}}{\partial P_O}\right)_{T_{1B=const}} \cdot \frac{P_O}{T_{1ASO}-T_{1BO}} = 1 - \frac{\varepsilon}{1+\varepsilon\alpha_L}\left(\alpha_L + \frac{\beta_L}{6\gamma}\right) \qquad \text{(III-59)}$$

$$G_{1AS}(s) = G_s(s) \frac{1+\eta-\varepsilon K_{1ALT} G_{1AL}(s)}{1+\eta-\varepsilon K_{1ALT}} = G_s(s) \frac{1+\varepsilon\alpha_L}{1+\varepsilon\alpha_L G_L(s)} \qquad \text{(III-60)}$$

which one is interested in. Also it depends strongly on the design of the fuel pins i.e. on the ratio of the thermal resistance within the fuel to the thermal resistance between the fuel and the coolant /4/.

For the analysis of correlation measurements at the KNK, a variety of transfer functions have been calculated for this reactor.

The Figs. 11a and b show two calculations for $G\mu(\omega) = \frac{\Delta P/P}{\Delta\mu/u}$ one with and one without nonlinearity corrections. The difference between both calculations is about 30% at its maximum.

Also for KNK the transfer functions $W_1 = \frac{\Delta\theta_1}{\Delta\theta_{12}} = U_{13} = \frac{\Delta\theta_{13}/(\theta_{130}-\theta_{210})}{\Delta\mu/u}$ with nonlinearity corrections are plotted in Fig.12.
The sinks of this transfer functions appear at the expected frequencies $\omega_n \approx \frac{2\pi}{l_1/v} \cdot n$. Sinks of this type are typical for a model which accounts for heat transport in the axial direction and have been also predicted by other authors /7/.
This phenomenon becomes quite obvious when no heat is exchanged with the coolant. In this case the average coolant temperature oscillation will be zero for certain frequencies of $\Delta\theta_{12}$.

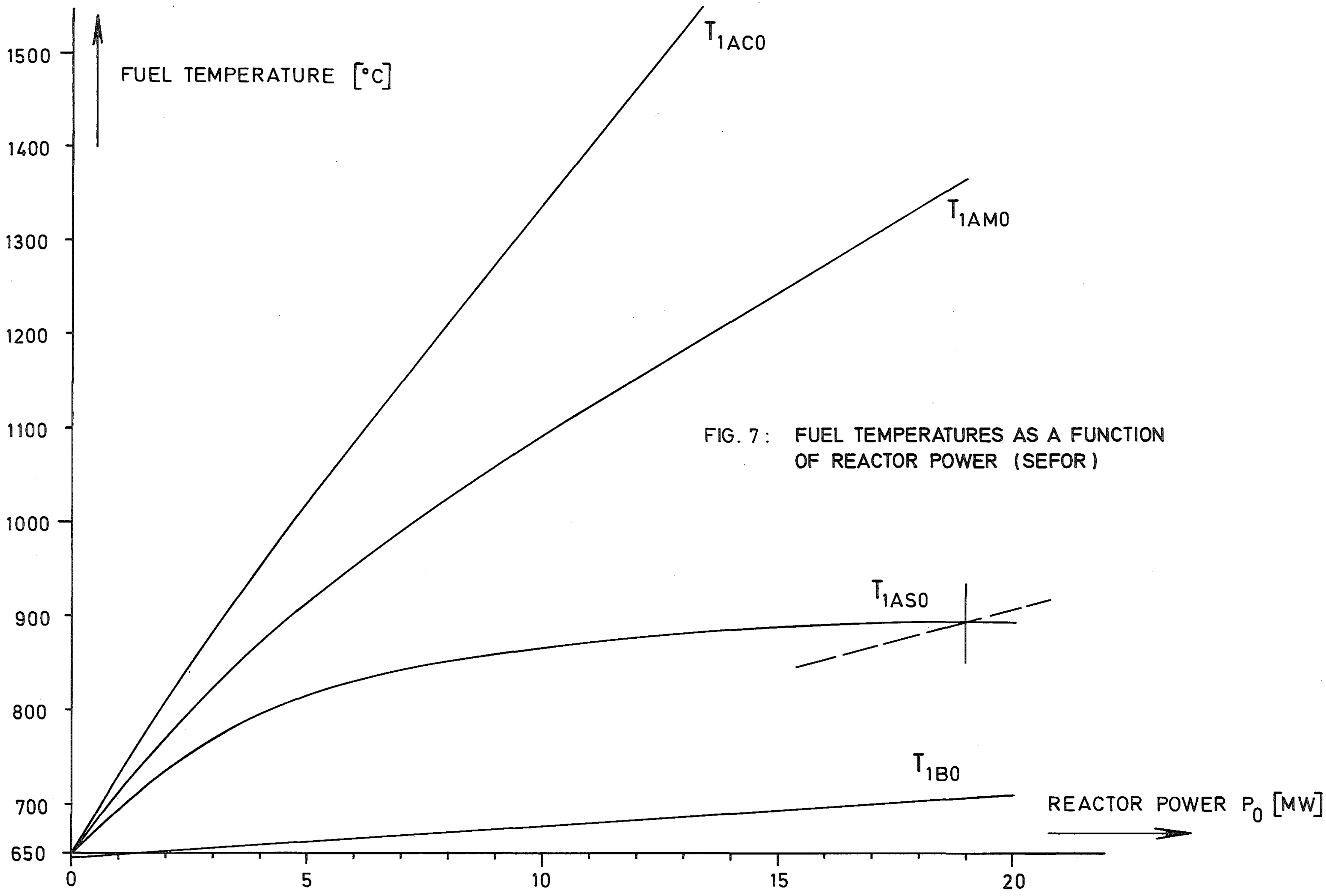


FIG. 7: FUEL TEMPERATURES AS A FUNCTION OF REACTOR POWER (SEFOR)

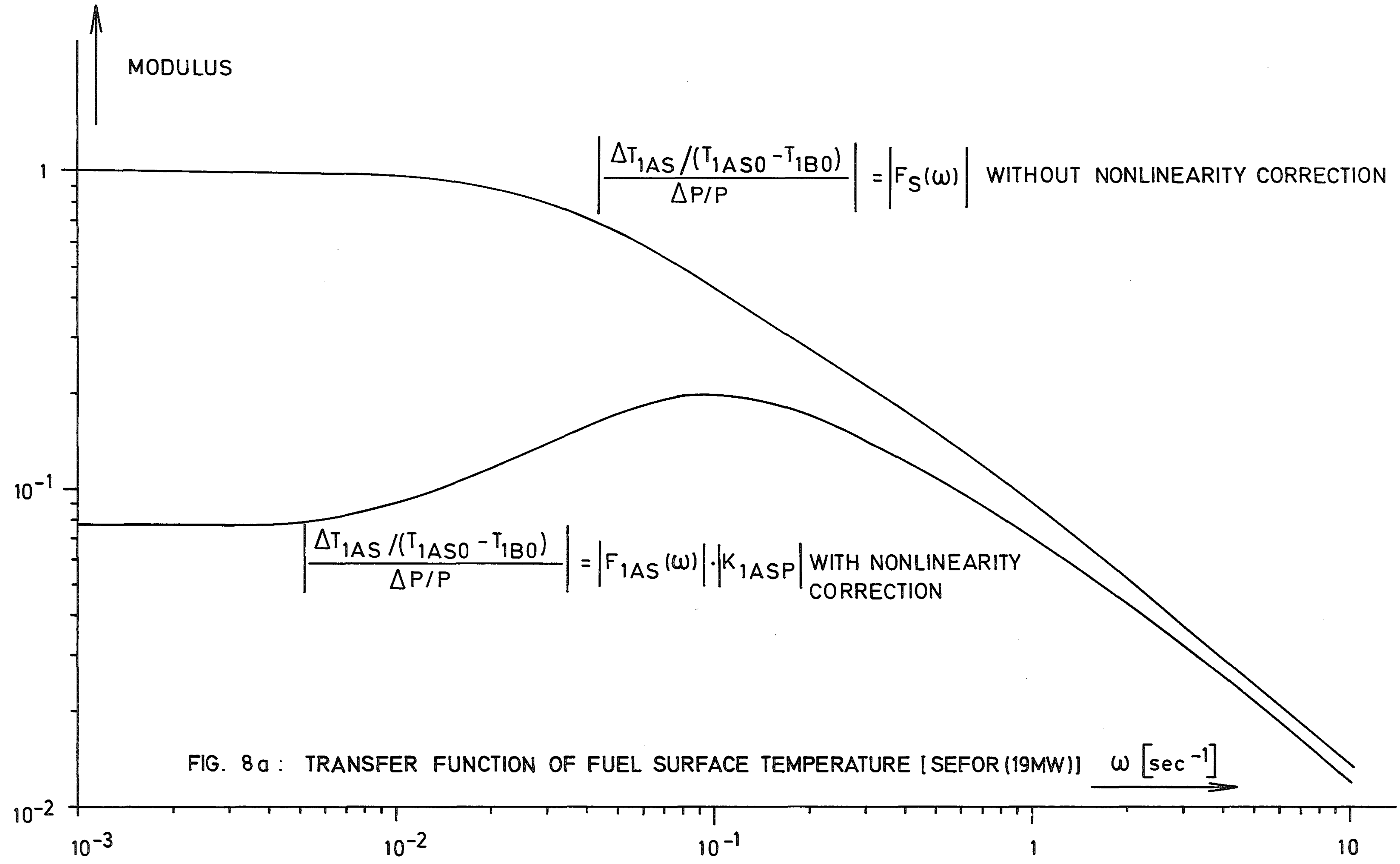


FIG. 8a : TRANSFER FUNCTION OF FUEL SURFACE TEMPERATURE [SEFOR (19MW)]

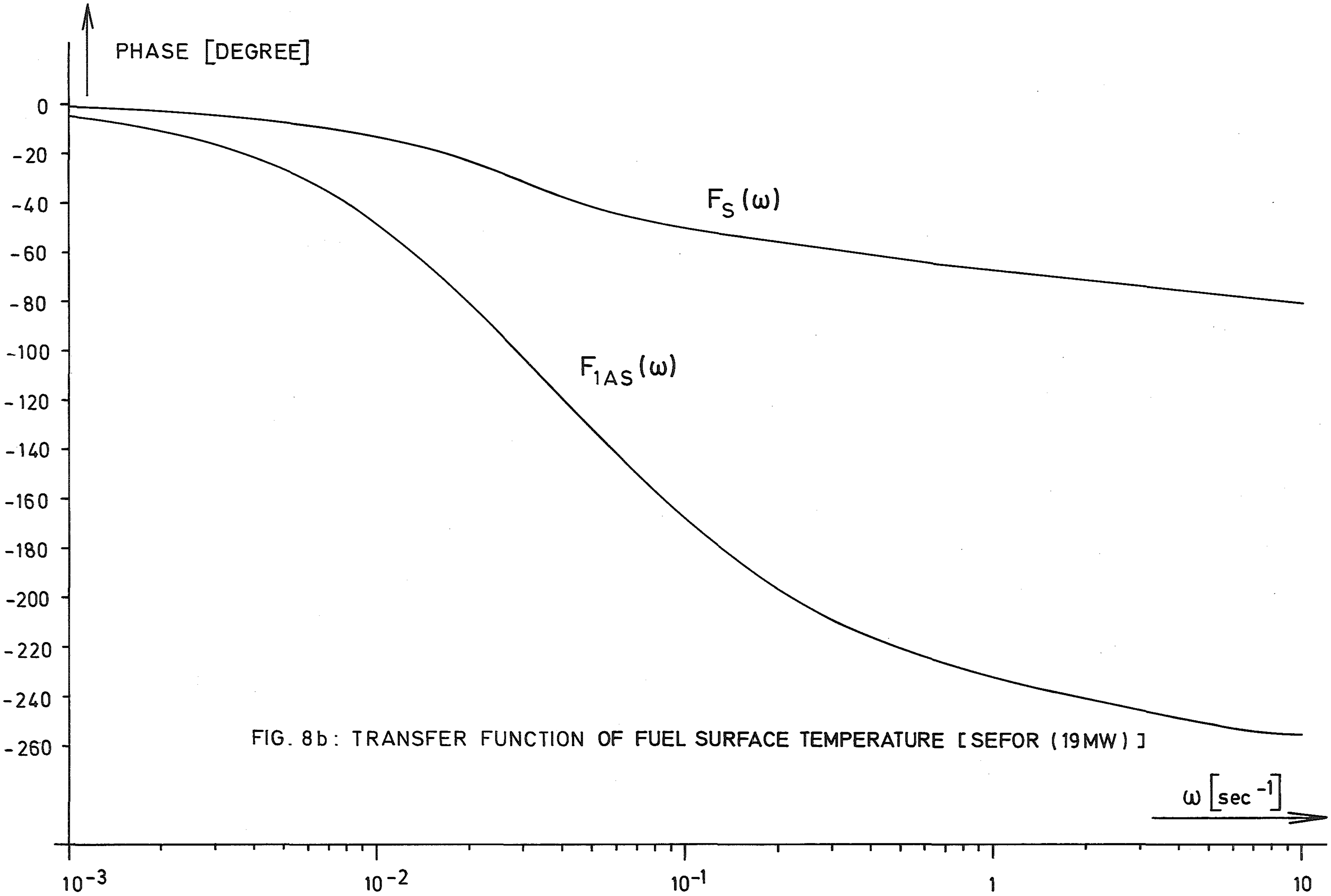


FIG. 8b: TRANSFER FUNCTION OF FUEL SURFACE TEMPERATURE [SEFOR (19MW)]

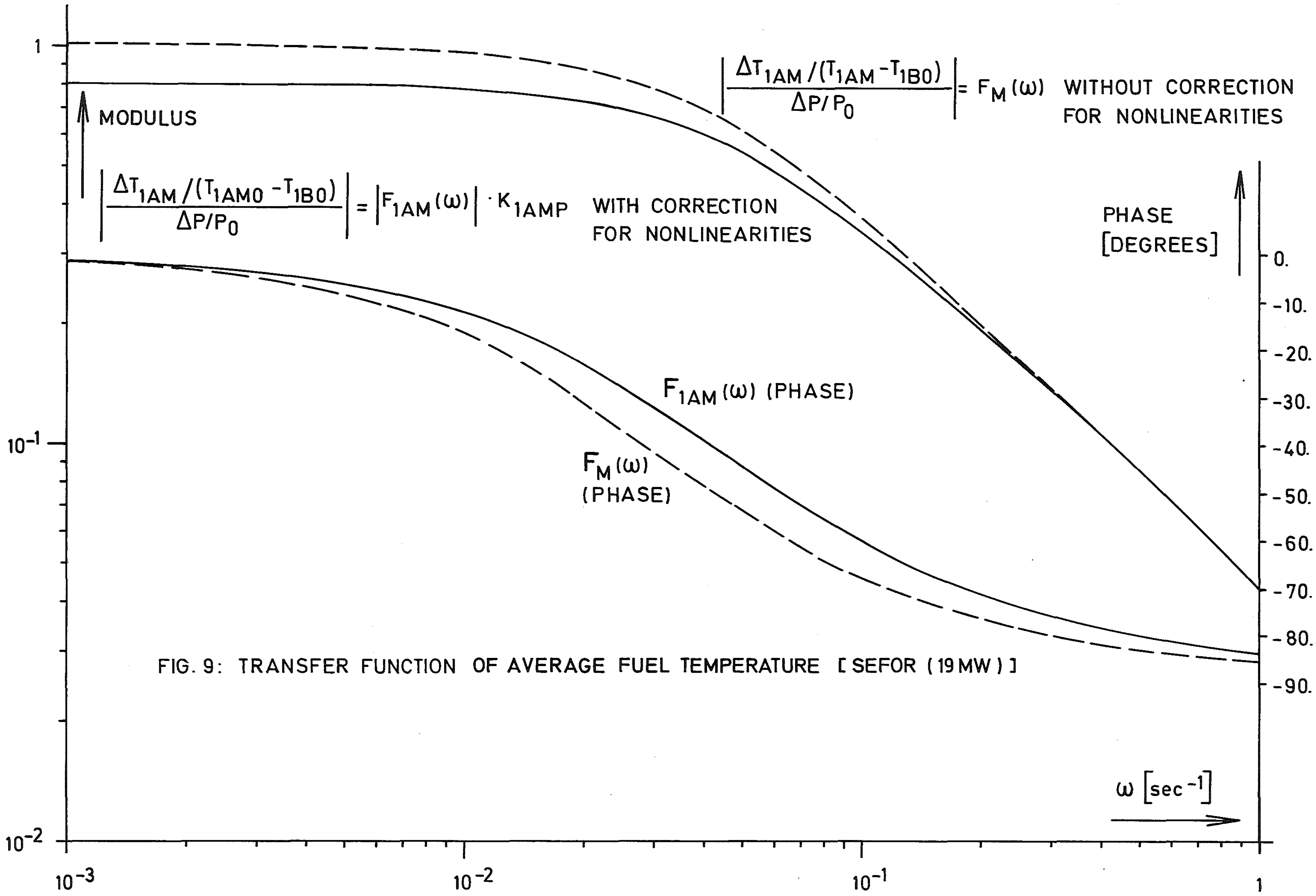


FIG. 9: TRANSFER FUNCTION OF AVERAGE FUEL TEMPERATURE [SEFOR (19 MW)]

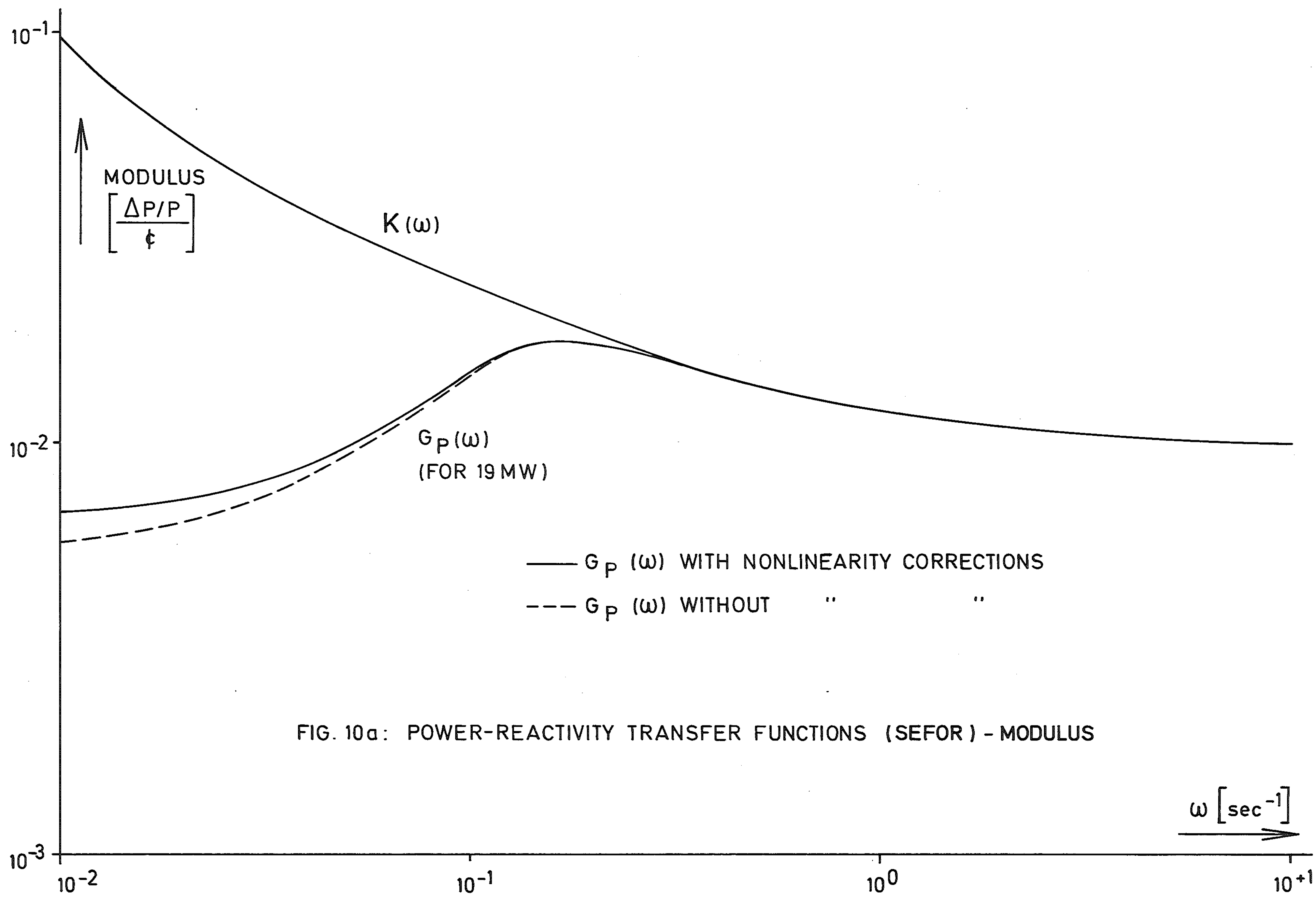


FIG. 10a: POWER-REACTIVITY TRANSFER FUNCTIONS (SEFOR) - MODULUS

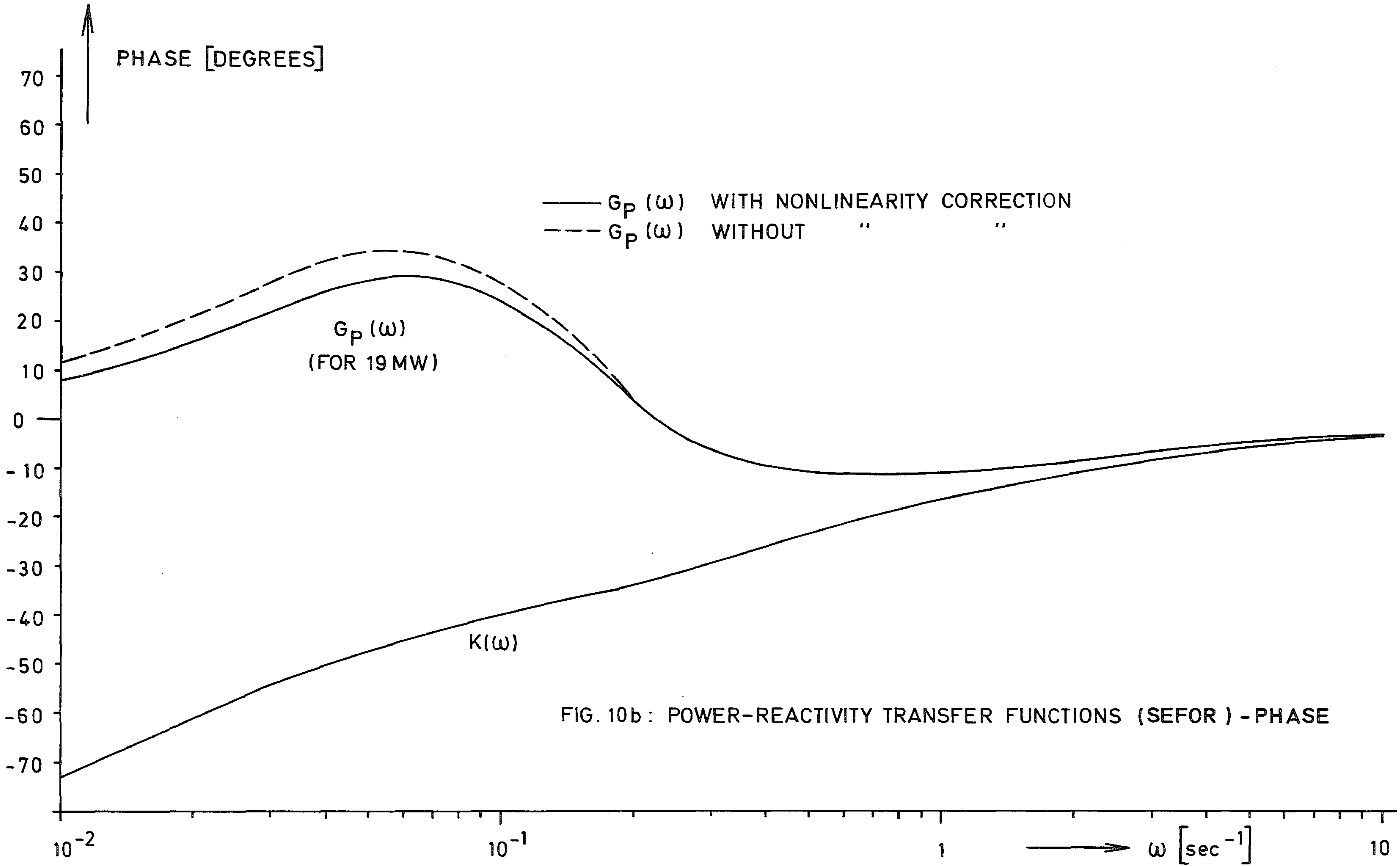


FIG. 10b: POWER-REACTIVITY TRANSFER FUNCTIONS (SEFOR) - PHASE

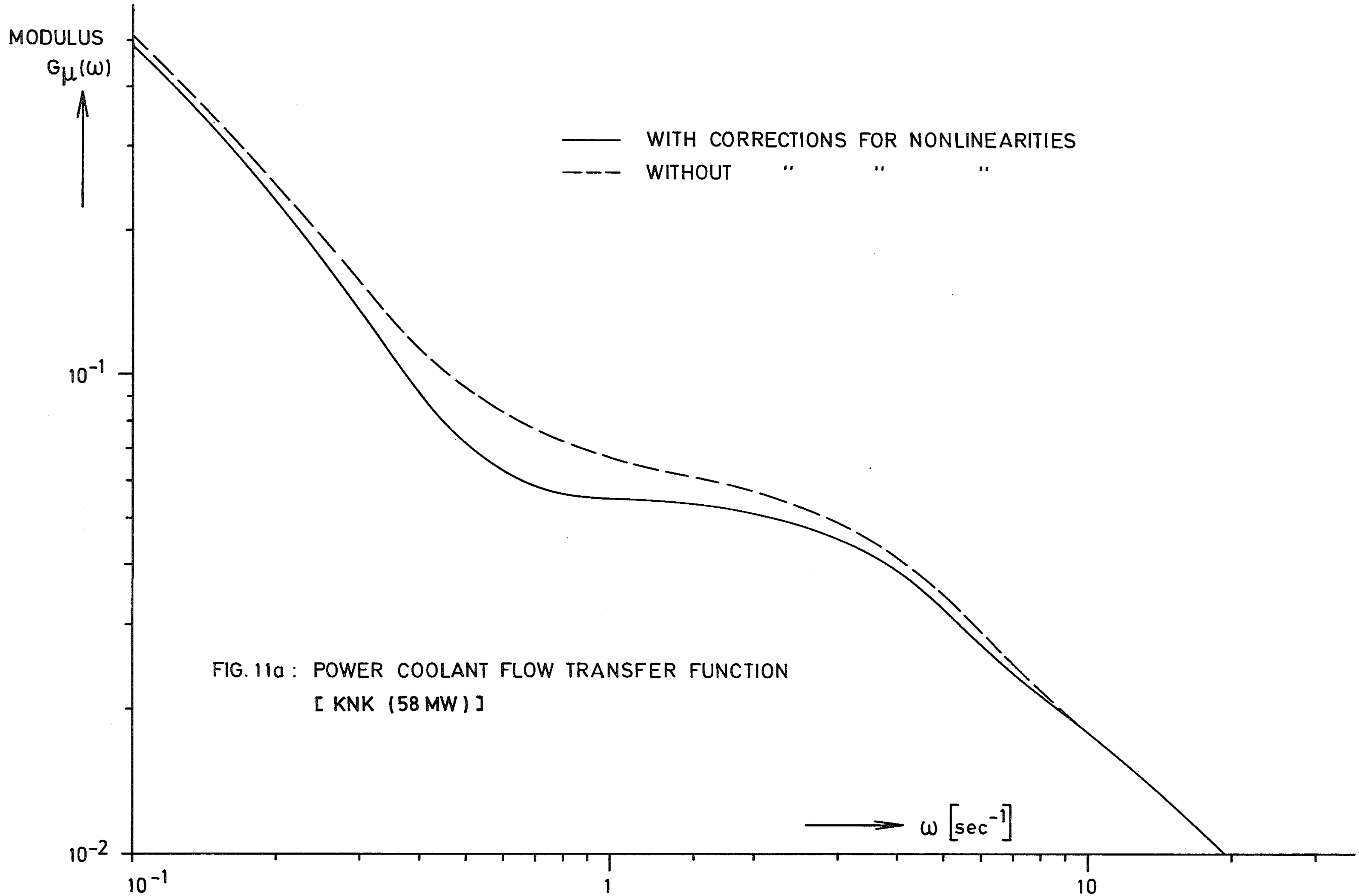


FIG. 11a : POWER COOLANT FLOW TRANSFER FUNCTION
[KNK (58 MW)]

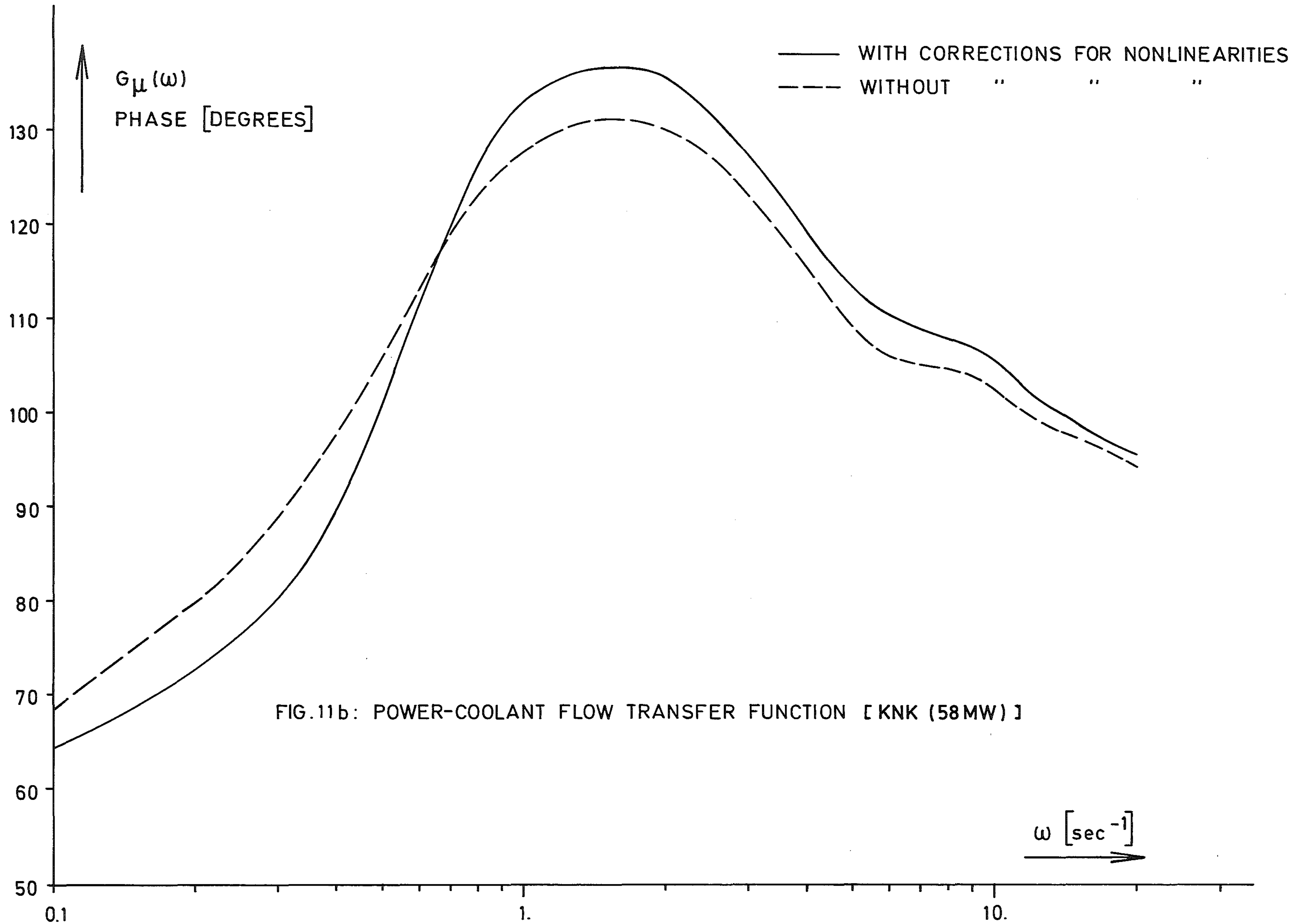


FIG.11b: POWER-COOLANT FLOW TRANSFER FUNCTION [KNK (58MW)]

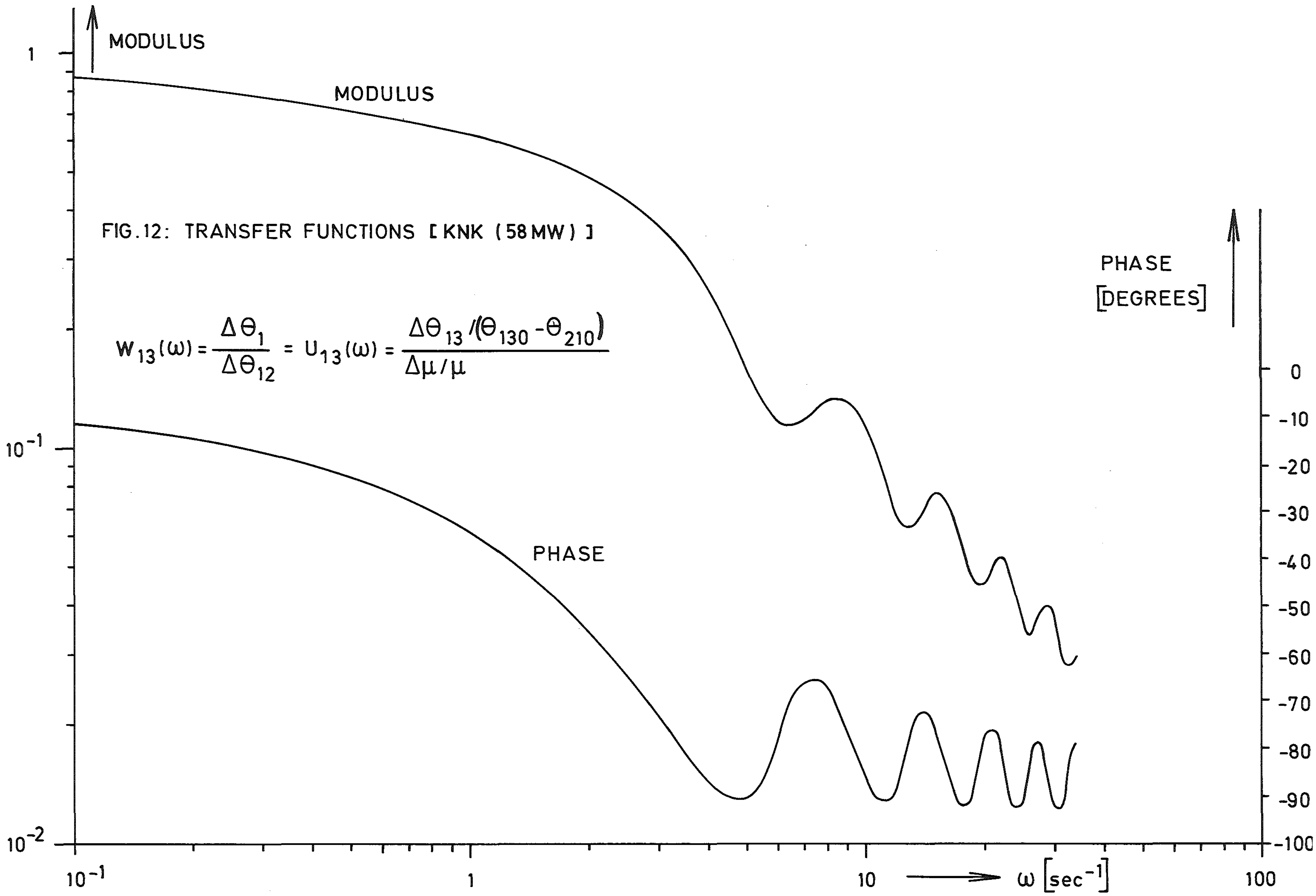


FIG. 12: TRANSFER FUNCTIONS [KNK (58 MW)]

$$W_{13}(\omega) = \frac{\Delta\Theta_1}{\Delta\Theta_{12}} = U_{13}(\omega) = \frac{\Delta\Theta_{13}/(\Theta_{130} - \Theta_{210})}{\Delta\mu/\mu}$$

V) Appendices

Appendix 1

Notations

a) Scheme of Indices

For the temperatures, time constants, delays and all transfer functions the following scheme of indices is used:

According to the list below, the first index is always a number and indicates the zone. Two numbers indicate the boundary of two zones. The subsequent capital letters refer to different materials of the parts in each zone:

Zone 1:	Core	A Fuel B Cladding C 1st structure material D 2nd " " E coolant
Zone 2:	Lower axial blanket	A structure material
Zone 3:	Upper axial blanket	E coolant
Zone 4:	Radial blanket	A 1st structure material B 2nd " " E coolant
Zone 5:	Lower plenum	A 1st structure material B 2nd " " E coolant 85 structure material between lateral (8) and lower plenum (5)
Zone 6:	Upper plenum	E coolant
Zone 7:	Static sodium between core and shroud	17 Material between core (1) and static sodium (7) 87 Material between zones 8 and 7 E coolant

Zone 8: Lateral plenum E coolant

Zone 9: Radial reflector A structure material

The subscript "O" at variable parameters indicates the initial steady state condition.

b) Notations

		units
$a_i = \frac{\beta_i}{\beta}$	delayed neutron fractions	-
$A = \frac{W_{1BE}}{W_{1AB}} = \frac{T_{1BO}-\theta_{1O}}{T_{1ASO}-T_{1BO}}$		
A_O	input parameters for the heat transfer coefficient h_{1A}	$\frac{Watt}{cm^2\ ^oK}$
A_1		$\frac{cm}{^oK}$
A_2		$\frac{cm^4}{Watt\ ^oK}$
A_3		$\frac{cm^7}{Watt^2\ ^oK}$
B_1		$\frac{Watt}{cm^2\ ^oK^2}$
$\overline{B_{1A}}$	reactivity correction coefficients	-
B_{1B}		-
B_{1C}		-
B_{1E}		
$\mathcal{C}$	thermal heat capacity (with index for the material and zone)	$\frac{Watt\ sec}{cm\ ^oK}$
C	constant input parameter for λ	$\frac{cm}{Watt\ ^oK}$
C_{1A}, C_{1B} etc.	reactivity coefficients	¢/^{o}K

		units
$D(\sigma)$	coolant temperature reactivity feedback function	$¢/^{o}K$
$F(\sigma)$	Transfer function between temperature and power	-
$G_o(\sigma), G_p(\sigma)$	Transfer function between power and reactivity	$\frac{\Delta P/P}{¢}$
$G(\sigma)$	Transfer function between material temperatures and coolant temperature	-
$G\mu(\sigma)$	Transfer function between power and coolant flow	-
$G_{\Theta}(\sigma)$	Transfer function between power and coolant inlet temperature	$\frac{\Delta P/P}{oK}$
H_o	Struve Function	-
H_1	" "	-
h_{1A}	heat transfer coefficient for the gap between the fuel surface and the cladding	$\frac{Watt}{cm^2\ oK}$
h_{1AB}	coefficient for the heat transfer from the fuel surface to the cladding	$\frac{Watt}{cm^2\ oK}$
$j = \sqrt{-1}$		-
J_o =	Bessel Function	-
J_1 =	" " 1st order	-

		units
$K_{1ALT} = \frac{\partial T_{1AL}}{\partial T_{1B}})_{P=const}$	correction coefficients for nonlinearity effects	-
$K_{1AMT} = \frac{\partial T_{1AM}}{\partial T_{1B}})_{P=const}$	correction coefficients for nonlinearity effects	-
$K_{1AST} = \frac{\partial T_{1AS}}{\partial T_{1B}})_{P=const}$	correction coefficients for nonlinearity effects	-
$K_{1ALP} = \frac{\partial T_{1AL}}{\partial P})_{T=const} \cdot \frac{P}{T_{1AL}-T_{1B}}$	correction coefficients for nonlinearity effects	-
$K_{1AMP} = \frac{\partial T_{1AM}}{\partial P})_{T=const} \cdot \frac{P}{T_{1AM}-T_{1B}}$	correction coefficients for nonlinearity effects	-
$K_{1ASP} = \frac{\partial T_{1AS}}{\partial P})_{T=const} \cdot \frac{P}{T_{1AS}-T_{1B}}$	correction coefficients for nonlinearity effects	-
$K(\sigma)$	zero power transfer function	-
L_1	core length	cm
l	prompt neutron lifetime	sec
l'	$\frac{L_1/v}{t_{1A}} = \frac{t_{1ax}}{t_{1A}}$	-
$M(\sigma)$	reactivity coolant flow transfer function	$\frac{¢}{\Delta\mu/u}$
m	ratio of material thermal capacity to coolant thermal capacity	-
N	number of pins associated to a coolant channel	-
N_u	Nusselt number	-

		units
N_{u1}, N_{u2}, N_{u3}	coefficients for Nusselt number	-
P	total reactor power	
PD_{1A}	fuel power density	$\frac{Watt}{cm^3}$
Pe	Peclet Number	-
$Q(\sigma)$	power feedback function at constant coolant temperature	¢
$R(\sigma)$	reactivity inlet temperature function	$\frac{¢}{^oK}$
R	radius of cladding	cm
r	radial coordinate within the fuel pin	cm
ROQ	change of reactivity caused by a power variation at constant coolant temperature	$\frac{¢}{^oK}$
ROS	change of reactivity caused by a power variation through the coolant temperature	$\frac{¢}{^oK}$
ROM	change of reactivity caused by coolant flow variation	$\frac{¢}{^oK}$
ROR	change of reactivity caused by inlet temperature variation	$\frac{¢}{^oK}$
$S(\sigma)$	reactivity power feedback through the coolant temperature	¢
S	cross section of a coolant channel	cm^2
s	Laplace variable (for frequency analysis $s = j\omega t_{1A} = \sigma t_{1A}$	-

		units
T	temperature of materials including the fuel	^oK
T_A	input parameter for the calculation of λ	^oK
t	variable time	sec
t_{1A}	radial time scale for the fuel	-
t_{1ax}	axial time constant	sec
t_{1B}	cladding time constant	sec
t_{85}	time delay between lower plenum and lateral plenum	sec
$U(\sigma)$	transfer function between coolant flow and temperature	-
$V(\sigma)$	transfer function between power and temperature	-
VOL	total fuel volume	cm^3
$W(\sigma)$	transfer function between temperatures	-
$X = \frac{Z}{L_1}$	dimensionless axial coordinate	-
$y(\sigma)$	transfer function	-
$\gamma = \frac{r}{R_{1BI}}$	dimensionless radial coordinate	-
Z	axial coordinate	cm

		units
α	percentage of power	-
β	total fraction of delayed neutrons	-
β_i	delayed neutron fraction of group i	-
$\gamma = \frac{\lambda_{eff}}{2\, h_{1AB} R_{1BI}}$		-
δ	percentage of coolant flow in a channel	-
α_L, α_M, β_L, β_M	correction coefficients for nonlinearity effects	-
ε	coefficient to calculate h_{1AB}	-
η	" " " h_{1AB}	-
θ	coolant temperature	^oK
λ, λ_{eff}	thermal heat conductivity	$\frac{Watt}{cm\ ^oK}$
λ_i	decay constant of delayed neutrons	$\frac{1}{sec}$
ρ	mass density	$\frac{g}{cm^3}$
$\sigma = j\omega = s/t_{1A}$		$\frac{1}{sec}$
$\tau = t/t_{1A}$	= dimensionless variable for the time	-
τ_{1F}, τ_{1G}	= time constants for bowing	
$\varphi = \frac{R_{1BI}^2 C T_A}{4}$		$\frac{cm^3}{Watt}$

		units
χ	specific heat capacity	$\frac{\text{Watt sec}}{\text{g }^{\circ}\text{K}}$
ω	radiant frequency	$\frac{1}{\text{sec}}$

Appendix 2

Calculation of the Constants

This section contains a summary of all equations used in the program to calculate different types of parameters which appear in the output. In cases they are not evident or have not been derived in sect.III, a short explanation is given.

1) Total percentage of delayed neutrons $\beta = \sum_{i=1}^{26} \beta_i$

2) Total percentages of power

Core	$\alpha_1 = \alpha_{1A}+\alpha_{1C}+\alpha_{1D}$
Lower axial blanket	$\alpha_2 = \alpha_{2A}$
Upper axial blanket	$\alpha_3 = \alpha_{3A}$
Radial blanket	$\alpha_4 = \alpha_{4A}+\alpha_{4B}$
Radial reflector	$\alpha_9 = \alpha_{9A}$
Total percentage	$\alpha = \alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_9$

3) Coolant flow $\mu_o = \frac{P_o}{\chi_E \rho_E (\theta_{60}-\theta_{80})} (\alpha_1+\alpha_2+\alpha_3+\alpha_4) \quad (\frac{cm^3}{sec})$

4) Coolant temperatures

Core: outlet temperature $\theta_{130}=\theta_{210}+(\theta_{360}-\theta_{80})\frac{\alpha_1}{\alpha_1+\alpha_2+\alpha_3}$ (^{o}

average temperature $\theta_{10} = \frac{1}{2} (\theta_{210}+\theta_{130}) \quad (^oK)$

upper axial blanket:

outlet temperature $\theta_{360}=\theta_{80}+(\theta_{60}-\theta_{80})\dfrac{\alpha_1+\alpha_2+\alpha_3}{\delta_1}$ (^{o}K)

average temperature $\theta_{30}=\theta_{130}+\frac{1}{2}\alpha_3(\theta_{360}-\theta_{80})$ (^{o}K)

lower axial blanket:

outlet temperature $\theta_{210}=\theta_{80}+(\theta_{360}-\theta_{80})\dfrac{\alpha_2}{\alpha_1+\alpha_2+\alpha_3}$ (^{o}K)

average temperature $\theta_{20}=\frac{1}{2}(\theta_{210}+\theta_{80})$ (^{o}K)

radial blanket:

outlet coolant temperature

$$\theta_{460}=\theta_{80}+(\theta_{60}-\theta_{80})\frac{\alpha_4}{1-\delta_1} \qquad (^{o}K)$$

average coolant temperature

$$\theta_{40}=\theta_{80}+\frac{1}{2}(\theta_{460}-\theta_{80}) \qquad (^{o}K)$$

$$\alpha_{87}=\frac{\theta_7-\theta_8}{\theta_{10}-\theta_8}=1-\alpha_{17}$$

5) <u>Parameters for the heat transfer calculations</u>

Total fuel volume $VOL = N_1 L_1 R_{1BI}^2 \pi$ (cm^3)

Fuel power density $PD_{10}=\dfrac{P_o}{VOL}\alpha_{1A}$ $\left(\dfrac{Watt}{cm^3}\right)$

$$A=\frac{T_{1BO}-\theta_{10}}{T_{1ASO}-T_{1BO}}$$

Peclet number $Pe=\dfrac{\mu_o\delta_1}{S_1N_1}\,2\,\dfrac{\chi_{1E}\rho_{1E}R_{1BE}}{\lambda_{1E}}$

Nusselt number $Nu = Nu_1 + Nu_2\, Pe^{Nu_3}$

The gap coefficient h_{1A} for the heat transfer from the fuel to the cladding depends primarily on the temperature of the gap filling gas /4/ which is determined by the temperatures of the fuel and the cladding. Therefore the heat transfer coefficient is calculated by means of the following relation

$$h_{1A} = A_o + A_1 PD_{10} + A_2 (PD_{10})^2 + A_3 (PD_{10})^3 + B_1 T_{1BO} \quad \left(\frac{Watt}{cm^2 {}^oK}\right)$$

The coefficients A_o, A_1, A_2, A_3 and B_1 are input data and have to be determined either on a theoretical basis /4/ or experimentally for instance by comparison of measured and calculated fuel temperatures.

$$h_{1AB} = \left(\frac{1}{h_{1A}} + \frac{R_{1BE} - R_{1BI}}{R_{1BE} + R_{1BI}} \frac{R_{1BI}}{\lambda_{1B}} \right)^{-1} \quad \left(\frac{Watt}{cm^2 {}^oK} \right)$$

$$X_{1A} = X_1 + \frac{X_3}{T_A^2} + X_2 T_{1AMO} + \frac{X_3}{\mathcal{J} \cdot PD_{10}} \frac{T_{1ACO} - T_{1ASO}}{T_{1ACO} \cdot T_{1ASO}} \left[-\frac{1}{T_A} + \frac{1}{2} \frac{T_{1ACO} + T_{1ASO}}{T_{1ACO} \cdot T_{1ASO}} \right]$$

$$\left[\frac{Watt\ sec}{g\ {}^oK} \right]$$

6) Fuel and structure material temperatures

Core:

Fuel temperatures

Fuel surface temperature $T_{1ASO} = T_{1BO} + \frac{\alpha_{1A} P_o}{N_1 L_1} \frac{1}{h_{1AB} 2\pi R_{1BI}}$

Average fuel temperature $T_{1AMO} = \frac{T_A}{\mathcal{J} \cdot PD_{10}} \ln \left\{ 1 + \frac{T_{1ASO}}{T_A} \left(e^{\mathcal{J} \cdot (PD_{10})} - 1 \right) \right\}$

$({}^oK)$

Average cladding temperature

$$T_{1BO} = \theta_{10} + \frac{\alpha_{1A} P_o}{\pi N_1 L_1} \left(\frac{R_{1BE} - R_{1BI}}{2\lambda_{1B} (R_{1BE} + R_{1BI})} + \frac{1}{\lambda_{1F} Nu} \right)$$

$({}^oK)$

1st structure material, average temperature: $T_{1CO} = \Theta_{10} + \frac{P_o}{P_{max}} (T_{1CO}-\Theta_{10})_{max}$ $({}^oK)$

2nd structure material, average temperature: $T_{1DO} = \Theta_{10} + \frac{P_o}{P_{max}} (T_{1DO}-\Theta_{10})_{max}$ $({}^oK)$

average temperatures for lower axial blanket: $T_{2AO} = \Theta_{20} + (T_{2AO}-\Theta_{20})_{max}\frac{P_o}{P_{max}}$ $({}^oK)$

upper axial blanket: $T_{3AO} = \Theta_{30} + (T_{3AO}-\Theta_{30})_{max}\frac{P_o}{P_{max}}$ $({}^oK)$

radial blanket: $T_{4AO} = \Theta_{40} + \frac{P_o}{P_{max}} (T_{4AO}-\Theta_{40})_{max}$ $({}^oK)$

structure material of the radial blanket: $T_{4Bo} = \Theta_{40} + \frac{P_o}{P_{max}} (T_{4BO}-\Theta_{40})_{max}$ $({}^oK)$

reflector: $T_{9AO} = \Theta_{90} + \frac{P_o}{P_{max}} (T_{9AO}-\Theta_{90})_{max}$ $({}^oK)$

7) Correction Coefficients for Nonlinearities in the Heat Transfer Process from the Fuel to the Coolant

The following coefficients for non linear effects are calculated from the derivatives of the steady state temperature relations. For the fuel surface temperature:

$$K_{1AST} = \left(\frac{\partial T_{1ASO}}{\partial T_{1BO}}\right)_{P=const} = \frac{\partial}{\partial T_{1B}}\left(T_{1BO}+\frac{\alpha_{1A}P_o}{N_1L_1}\,\frac{1}{h_{1AB}2\pi R_{1BI}}\right)$$

$$= 1 - \frac{PD_{10}}{2}\, R_{1BI}\, \frac{B_1}{h_{1A}^2}$$

$$K_{1ASP} = \left(\frac{\partial T_{1AS}}{\partial P}\right)_{T_{1B}=const} \frac{P}{T_{1ASO}-T_{1BO}} = 1-PD_{10}\frac{h_{1AB}}{h_{1A}^2}(A_1+2A_2(PD_{10})+3A_3(PD_{10})^2)$$

For the average temperature:

$$K_{1AMT} = \left(\frac{\partial T_{1AMO}}{\partial T_{1BO}}\right)_{P=const} = \frac{\partial}{\partial T_{1B}} \left\{ \frac{T_A}{\vartheta\cdot PD_{10}}\ \ln\left[1+\frac{T_{1ASO}}{T_A}\left(e^{\vartheta\cdot(PD_{10})}-1\right)\right]\right\}$$

$$= K_{1AST}\,\frac{e^{\vartheta\cdot(PD_{10})}-1}{\vartheta\cdot(PD_{10})}\,\frac{1}{1+\frac{T_{1ASO}}{T_A}\left(e^{\vartheta\cdot(PD_{10})}-1\right)}$$

$$K_{1AMP} = \left(\frac{\partial T_{1AMO}}{\partial P}\right)_{T_{1B}=const} \cdot \frac{P}{T_{1AMO}-T_{1BO}} =$$

$$= \frac{K_{1ASP}\,\frac{T_{1ASO}-T_{1BO}}{T_{1AMO}-T_{1BO}}\,\frac{e^{\mathcal{S}\cdot(PD_{10})}-1}{\mathcal{S}\cdot PD_{10}} + \frac{T_{1ASO}}{T_{1AMO}-T_{1BO}}\,e^{\mathcal{S}\cdot(PD_{10})}}{1 + \frac{T_{1ASO}}{T_A}\left(e^{\mathcal{S}\cdot PD_{10}}-1\right)}$$

$$- \frac{T_{1AMO}}{T_{1AMO}-T_{1BO}}$$

$$\overline{K_{1AMT}} = \left(\frac{\partial T_{1AMO}}{\partial \theta_{10}}\right)_{P=const} = K_{1AMT}$$

$$\overline{K_{1AMP}} = \left(\frac{\partial T_{1AMO}}{\partial P}\right)_{T_{1B}=const} \left(\frac{P}{T_{1AMO}-\theta_{10}}\right) = \frac{K_{1AMT}(T_{1BO}-\theta_{10})+K_{1AMP}(T_{1AMO}-T_{1BO})}{T_{1AMO}-\theta_{10}}$$

$$\alpha_M = \frac{K_{1AMT}}{K_{1AST}}$$

$$\alpha_L = \alpha_M$$

$$\gamma = \frac{\lambda_{eff}}{2h_{1AB}R_{1BI}} = \frac{1}{8}\,\frac{(T_{1ASO} - T_{1BO})}{K_{1AMP}(T_{1AMO}-T_{1BO})-\alpha_M K_{1ASP}(T_{1ASO}-T_{1BO})}$$

$$\varepsilon = 6\gamma\,\frac{1-K_{1ASP}}{1+6\gamma\alpha_L K_{1ASP}}$$

$$\eta = K_{1AST}(1+\alpha_L\varepsilon)-1$$

8) Ratios of material thermal capacities to coolant thermal capacities

(These parameters are used for the derivation of equ.A18-21)

Core:

Fuel $$m_{1A} = \frac{\chi_{1A} M_{1A}}{N_1 L_1 S_1 \rho_{1E} \chi_{1E}}$$

1st structure material $$m_{1C} = \frac{\chi_{1C} M_{1C}}{N_1 L_1 S_1 \rho_{1E} \chi_{1E}}$$

2nd structure material $$m_{1D} = \frac{\chi_{1D} M_{1D}}{N_1 L_1 S_1 \rho_{1E} \chi_{1E}}$$

lower axial blanket $$m_{2A} = \frac{\chi_{2A} M_{2A}}{N_1 L_1 S_1 \rho_{1E} \chi_{1E}}$$

upper axial blanket $$m_{3A} = \frac{\chi_{3A} M_{3A}}{N_1 L_1 S_1 \rho_{1E} \chi_{1E}}$$

radial blanket $$m_{4A} = \frac{\chi_{4A} M_{4A}}{N_4 L_4 S_4 \rho_{1E} \chi_{1E}}$$

$$m_{4B} = \frac{\chi_{4B} M_{4B}}{N_4 L_4 S_4 \rho_{1E} \chi_{1E}}$$

9) Time constants and delays

Core:

The fuel radial time scale t_{1A} is defined by

t_{1A} = 8 (thermal resistance of the fuel)(thermal capacity of the fuel)

$$= \frac{\rho_{1A} \chi_{1A} R_{1BI}^2}{\lambda_{eff}} = 8 M_{1A} \chi_{1A} \frac{K_{1AMP}(T_{1AMO} - T_{1BO}) - K_{1ASP}(T_{1ASO} - T_{1BO})}{\alpha_{1A} P_o}$$

[sec]

Cladding time constant = $t_{1B} = W_{1BE} \cdot \mathscr{C}_{1B}$

$$t_{1B} = \frac{T_{1BO}-\theta_{1O}}{\alpha_{1A}P_o} N_1 L_1 \pi (R_{1BE}^2 - R_{1BI}^2) \chi_{1B} \quad \text{(sec)}$$

Axial time delays of the coolant

In the core:

$$t_{1ax} = \frac{L_1}{\delta_1 \mu_o} S_1 N_1 \quad \text{(sec)}$$

In the lower axial blanket:

$$t_{2ax} = \frac{L_2}{\delta_1 \mu_o} S_1 N_1 \quad \text{(sec)}$$

In the upper axial blanket:

$$t_{3ax} = \frac{L_3}{\delta_1 \mu_o} S_1 N_1 \quad \text{(sec)}$$

In the radial blanket:

$$t_{4ax} = \frac{L_4}{(1-\delta_1)\mu_o} S_4 N_4 \quad \text{(sec)}$$

time delay between lower plenum and lateral plenum

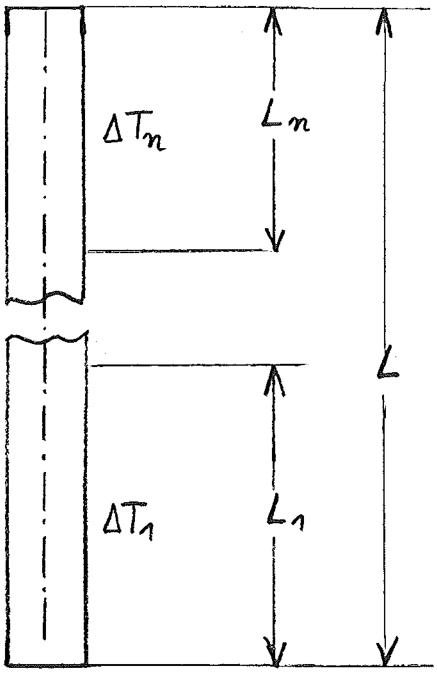
$$t_{85} = (t_{85})_{max} \frac{\mu_o}{\mu_{max}}$$

10) Reactivity correction coefficients

The reactivity correction coefficients account for non uniform temperature changes along the coolant channel. In this case the coolant channel is subdivided into smaller axial regions for which an uniform temperature change can still be assumed. This is demonstrated in Fig.13 with n axial regions, each of them being represented by an average temperature change $\overline{\Delta T_i}$ and by its own reactivity coefficient α_i (with $\sum_i \alpha_i = C_n$). The total reactivity change becomes then a sum of n terms

$$\Delta K = \alpha_1 \overline{\Delta T_1} + \ldots\ldots + \alpha_n \overline{\Delta T_n} = C_n \, B \, \overline{\Delta T}$$

In the program, this sum is presented by the term $C_n B\overline{\Delta T}$



$$\overline{\Delta T_1} = \frac{1}{L_1} \int_0^{L_1} \Delta T d2$$

$$\overline{\Delta T_n} = \frac{1}{L_n} \int_0^{L_n} \Delta T dz$$

$$\overline{\Delta T} = \frac{1}{L} \int_0^{L} \Delta T dz$$

$$L_1 + \ldots . L_n = L$$

Fig.13 Subdivision of the axial coolant channel for non uniform temperature changes along the channel.

which is the product of the overall average temperature change $\overline{\Delta T}$ and the reactivity coefficient for an uniform temperature change C_n and the correction factor

$$B = \frac{\alpha_1 \overline{\Delta T_1} + \alpha_2 \overline{\Delta T_2} + \alpha_3 \overline{\Delta T_3}}{C_n \overline{\Delta T}}$$

This factor is an input parameter and has to be calculated separately for each special case.

Of course for a uniform temperature change this correction is not necessary because in this case we have

$$\overline{\Delta T_1} = \ldots . \overline{\Delta T_n} = \overline{\Delta T} \text{ and } B = \frac{\alpha_1 + \ldots \alpha_n}{C_n} = 1$$

Appendix 3

Summary of important Equations and Transfer Functions

In this paragraph, the independent variable "s" in the Laplace domain is replaced by $s = jwt_{1A} = \sigma t_{1A}$, with "$\sigma$" becoming the independent variable.

a) Summary of Equations

Heat conduction equations for radial heat transfer from the fuel to the coolant:

$$\Delta T_{1A}(\sigma) = \frac{R_{1BI}^2}{\sigma t_{1A}\lambda_{eff}} \left[1 - \frac{J_o(y\sqrt{-\sigma})}{J_o(\sqrt{-\sigma})}\right] \Delta PD_{1A}(\sigma) + \frac{J_o(y\sqrt{-\sigma})}{J_o(\sqrt{-\sigma})} \Delta T_{1AS}(\sigma) \qquad (A-1)$$

$$\Delta T_{1AM}(\sigma) = \frac{1}{R_{1BI}^2 \pi} \int_0^R \Delta T_{1A}(\sigma) 2r\pi dr = 2 \int_{y=0}^{1} \Delta T_{1A}(\sigma) y dy \qquad (A-2)$$

$$\Delta T_{1AL}(\sigma) = \frac{1}{R} \int_0^R \Delta T_{1A}(\sigma) dr = \int_{y=1} \Delta T_{1A}(\sigma) dy \qquad (A-3)$$

$$\frac{\Delta h_{1AB}(\sigma)}{h_{1AB}} = \varepsilon \frac{\Delta T_{1AL}(\sigma)}{T_{1ASO}-T_{1BO}} - \eta \frac{\Delta T_{1B}(\sigma)}{T_{1ASO}-T_{1BO}} \qquad (A-4)$$

$$\Delta T_{1AM}(\sigma) = \alpha_M F_s(\sigma) \Delta T_{1B}(\sigma) + (T_{1ASO}-T_{1BO})(\alpha_M + \frac{\beta_M}{8\gamma}) F_M(\sigma) \frac{\Delta P(\sigma)}{P_O}$$

$$- \alpha_M (T_{1ASO}-T_{1BO}) Fs(\sigma) \frac{\Delta h_{1AB}(\sigma)}{h_{1AB}} \qquad (A-5)$$

$$\Delta T_{1AL}(\sigma)=\alpha_L G_L(\sigma)\Delta T_{1B}(\sigma)+(T_{1ASO}-T_{1BO})(\alpha_L+\frac{\beta_L}{6\gamma})F_L(\sigma)\frac{\Delta P(\sigma)}{P_O}$$

$$-\alpha_L(T_{1ASO}-T_{1BO})G_L(\sigma)\frac{\Delta h_{1AB}(\sigma)}{h_{1AB}} \qquad \text{(A-6)}$$

$$\Delta T_{1AS}(\sigma)=G_s(\sigma)\Delta T_{1B}(\sigma)+(T_{1ASO}-T_{1BO})F_s(\sigma)\frac{\Delta P(\sigma)}{\Delta P_O}$$

$$-(T_{1ASO}-T_{1BO})G_s(\sigma)\frac{\Delta h_{1AB}(\sigma)}{h_{1AB}} \qquad \text{(A-7)}$$

$$\Delta T_{1AM}(\sigma)=K_{1AMT}G_{1AM}(\sigma)\Delta T_{1B}+K_{1AMP}(T_{1AMO}-T_{1BO})F_{1AMO}(\sigma)\frac{\Delta P(\sigma)}{P_O} \qquad \text{(A-8)}$$

$$\Delta T_{1AL}(\sigma)=K_{1ALT}G_{1AL}(\sigma)\Delta T_{1B}+K_{1ALP}(T_{1ALO}-T_{1BO})F_{1AL}(\sigma)\frac{\Delta P(\sigma)}{P_O} \qquad \text{(A-9)}$$

$$\Delta T_{1AS}(\sigma)=K_{1AST}G_{1AS}(\sigma)\Delta T_{1B}+K_{1ASP}(T_{1ASO}-T_{1BO})F_{1AS}(\sigma)\frac{\Delta P(\sigma)}{P_O} \qquad \text{(A-10)}$$

$$\Delta T_{1AM}(\sigma)=\overline{K_{1AMT}}\,\overline{G_{1AM}}(\sigma)\Delta\Theta_1+\overline{K_{1AMP}}(T_{1AMO}-\Theta_{1O})\overline{F_{1AM}}(\sigma)\frac{\Delta P}{P_O} \qquad \text{(A-8')}$$

$$\Delta T_{1B}(\sigma)=G_{1B}(\sigma)\Delta\theta_1+(T_{1BO}-\theta_{1O})F_{1B}(\sigma)\frac{\Delta P}{P_o} \qquad \text{(A-11)}$$

$$\Delta T_{1C}(\sigma)=G_{1C}(\sigma)\Delta\theta_1+(T_{1CO}-\theta_{1O})F_{1C}(\sigma)\frac{\Delta P}{P_o} \qquad \text{(A-12)}$$

$$\Delta T_{1D}(\sigma)=G_{1D}(\sigma)\Delta\theta_1+(T_{1DO}-\theta_{1O})F_{1D}(\sigma)\frac{\Delta P}{P_o} \qquad \text{(A-13)}$$

$$\Delta T_{2A}(\sigma)=G_{2A}(\sigma)\Delta\theta_2+(T_{2AO}-\theta_{2O})F_{2A}(\sigma)\frac{\Delta P}{P_o} \qquad \text{(A-14)}$$

$$\Delta T_{3A}(\sigma) = G_{3A}(\sigma)\Delta\Theta_2+(T_{3A0}-\Theta_{30})F_{3A}(\sigma)\,\frac{\Delta P}{P_o} \qquad \text{(A-15)}$$

$$\Delta T_{4A}(\sigma) = G_{4A}(\sigma)\Delta\Theta_4+(T_{4A0}-\Theta_{40})F_{4A}(\sigma)\,\frac{\Delta P}{P_o} \qquad \text{(A-16)}$$

$$\Delta T_{4B}(\sigma) = G_{4B}(\sigma)\Delta\Theta_4+(T_{4B0}-\Theta_{40})F_{4B}(\sigma)\,\frac{\Delta P}{P_o} \qquad \text{(A-16')}$$

$$\Delta T_{5A}(\sigma) = G_{5A}(\sigma)\Delta\Theta_5$$

$$\Delta T_{9A}(\sigma) = (T_{9A}-\Theta_{90})F_{9A}(\sigma)\,\frac{\Delta P}{P_o} \qquad \text{(A-17)}$$

Heat balance equations for the coolant channel

$$\frac{d\Delta\theta(\sigma)}{dx} + y_1(\sigma)\Delta\theta = (\theta_{130}-\theta_{120})M(x)\left[-\frac{\Delta\mu}{\mu_o} + F_1(\sigma)\frac{\Delta P}{P_o}\right] \qquad \text{(A-18)}$$

$$\frac{d\Delta\theta(\sigma)}{dx} + y_2(\sigma)\Delta\theta = (\theta_{210}-\theta_{80})\left[-\frac{\Delta\mu}{\mu_o} + F_2(\sigma)\frac{\Delta P}{P_o}\right] \qquad \text{(A-19)}$$

$$\frac{d\Delta\theta(\sigma)}{dx} + y_3(\sigma)\Delta\theta = (\theta_{360}-\theta_{130})\left[-\frac{\Delta\mu}{\mu_o} + F_3(\sigma)\frac{\Delta P}{P_o}\right] \qquad \text{(A-20)}$$

$$\frac{d\Delta\theta(\sigma)}{dx} + y_4(\sigma)\Delta\theta = (\theta_{460}-\theta_{80})\left[-\frac{\Delta\mu}{\mu_o} + F_4(\sigma)\frac{\Delta P}{P_o}\right] \qquad \text{(A-21)}$$

The following equations for the coolant temperatures are solutions of the equat. A-18 to A-21 as demonstrated in /2/. Applying the notations of this paper they can be written in the form:

$$\Delta\theta_1 = W_1(\sigma)\Delta\theta_{12}-(\theta_{10}-\theta_{210})U_1(\sigma)\frac{\Delta\mu}{\mu} + (\theta_{10}-\theta_{210})V_1(\sigma)\frac{\Delta P}{P_o} \qquad \text{(A-22)}$$

$$\Delta\theta_{13} = W_{13}(\sigma)\Delta\theta_{21}-(\theta_{130}-\theta_{210})U_{13}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{130}-\theta_{210})V_{13}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-23)}$$

$$\Delta\theta_{21} = W_{21}(\sigma)\Delta\theta_{5} -(\theta_{210}-\theta_{80})U_{21}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{210}-\theta_{80})V_{21}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-24)}$$

$$\Delta\theta_{2} = W_{2}(\sigma)\Delta\theta_{5}-(\theta_{20}-\theta_{80})U_{2}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{20}-\theta_{80})V_{2}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-25)}$$

$$\Delta\theta_{36} = W_{36}(\sigma)\theta_{13}-(\theta_{360}-\theta_{130})U_{36}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{360}-\theta_{30})V_{36}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-26)}$$

$$\Delta\theta_{3} = W_{3}(\sigma)\Delta\theta_{13}-(\theta_{30}-\theta_{130})U_{3}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{30}-\theta_{130})V_{3}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-27)}$$

$$\Delta\theta_{46} = W_{46}(\sigma)\Delta\theta_{5}-(\theta_{460}-\theta_{80})U_{46}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{460}-\theta_{80})V_{46}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-28)}$$

$$\Delta\theta_{4} = W_{4}(\sigma)\Delta\theta_{5}-(\theta_{40}-\theta_{80})U_{4}(\sigma)\frac{\Delta\mu}{\mu} +(\theta_{40}-\theta_{80})V_{4}(\sigma)\frac{\Delta P}{P_o} \quad \text{(A-29)}$$

$$\Delta\theta_{7} = \alpha_{17}G_{17}(\sigma)\Delta\theta_{1}+\alpha_{87}G_{87}(\sigma)\Delta\theta_{8} \quad \text{(A-30)}$$

$$\Delta\theta_{5} = W_{5}(\sigma)\Delta\theta_{8} \quad \text{(A-31)}$$

<u>Equations for the Feedback</u>

Power Feedback will constant coolant temperatures

$$Q_{1A} = C_{1B}(T_{1BO}-\theta_{10})F_{1B}(\sigma)+C_{1A}\overline{K_{1AMP}}(T_{1AMO}-\theta_{10})\overline{F_{1AM}}(\sigma) \quad (\text{¢})$$

$$Q_{1C} = C_{1C}(T_{1CO}-\theta_{10})F_{1C}(\sigma) \quad (\text{¢})$$

$$Q_{1D} = C_{1D}(T_{1DO}-\theta_{1O})F_{1D}(\sigma) \qquad (¢)$$

$$Q_1 = Q_{1A} + Q_{1C} + Q_{1D} \qquad (¢)$$

$$Q_2 = C_{2A}(T_{2AO}-\theta_{2O})F_{2A}(\sigma) \qquad (¢)$$

$$Q_3 = C_{3A}(T_{3AO}-\theta_{3O})F_{3A}(\sigma) \qquad (¢)$$

$$Q_{4A} = C_{4A}(T_{4AO}-\theta_{4O})F_{4A}(\sigma) \qquad (¢)$$

$$Q_{4B} = C_{4B}(T_{4BO}-\theta_{4O})F_{4B}(\sigma) \qquad (¢)$$

$$Q_4 = Q_{4A}(\sigma) + Q_{4B}(\sigma) \qquad (¢)$$

$$Q_9 = C_{9A}(T_{9AO}-\theta_{9O})F_{9A}(\sigma) \qquad (¢)$$

$$Q(\sigma) = Q_1(\sigma)+Q_2(\sigma)+Q_3(\sigma)+Q_4(\sigma)+Q_9(\sigma) \qquad (¢)$$

Coolant temperature reactivity feedback functions

$$D_1 = C_{1E}+C_{1B}G_{1B}(\sigma)+C_{1A}\overline{G_{1AM}}(\sigma)\ \overline{K_{1AMT}}+C_{1C}G_{1C}(\sigma)+C_{1D}G_{1D}(\sigma) \qquad (¢/^{o}K)$$

$$\overline{D_1}=B_{1E}C_{1E}+B_{1B}C_{1B}G_{1B}(\sigma)+B_{1A}C_{1A}\overline{G_{1AM}}(\sigma)\overline{K_{1AMT}}+B_{1C}C_{1C}G_{1C}(\sigma)+B_{1D}C_{1D}G_{1D}(\sigma) \qquad (¢/^{o}K)$$

$$D1_{BOF} = \frac{C_{1F}}{1+s\tau_{1F}} \left(\frac{¢}{^oK}\right) \qquad D1_{BOG} = \frac{C_{1G}}{1+s\cdot\tau_{1G}} \qquad (¢/^oK)$$

$$D_2 = C_{2E} + C_{2A}G_{2A}(\sigma) \qquad (¢/^oK)$$

$$D_3 = C_{3E} + C_{3A}G_{3A}(\sigma) \qquad (¢/^oK)$$

$$D_4 = C_{4E} + C_{4A}G_{4A}(\sigma) + C_{4B}G_{4B}(\sigma) \qquad (¢/^oK)$$

$$D_5 = C_{5A}G_{5A}(\sigma) \qquad (¢/^oK)$$

$$D_{17} = C_{7E}\alpha_{17}G_{17}(\sigma) \qquad (¢/^oK)$$

$$D_{18} = C_{7E}\alpha_{87}G_{87}(\sigma) \qquad (¢/^oK)$$

Reactivity Power Feedback through the coolant temperature

$$S_1 = \overline{D_1}(\sigma)(\theta_{10} - \theta_{210})V_1(\sigma) + (\theta_{210} - \theta_{80})V_{21}(\sigma)W_1(\sigma)D_1(\sigma)$$
$$+ D1_{BOF}(\theta_{210} - \theta_{80})V_{21}(\sigma) + D_{1BOG}\Big\{(\theta_{130} - \theta_{210})V_{13}(\sigma)$$
$$+ (W_{13}(\sigma) - 1)(\theta_{210} - \theta_{80})V_{21}(\sigma)\Big\} \qquad (¢)$$

$$S_2 = D_2(\sigma)(\theta_{20} - \theta_{80})V_2(\sigma)$$

$$S_3 = D_3(\sigma)\Big\{(\theta_{130} - \theta_{130})V_3(\sigma) + \big[(\theta_{130} - \theta_{210})V_{13}(\sigma) +$$
$$+ (\theta_{210} - \theta_{80})V_{21}(\sigma)W_{13}(\sigma)\big]W_3(\sigma)\Big\} \qquad (¢)$$

$$S_4 = (\theta_{4O}-\theta_{8O})V_4(\sigma)D_4(\sigma) \qquad (\not{c})$$

$$S_7 = D_{17}(\sigma)\left\{(\theta_{1O}-\theta_{21O})V_1(\sigma)+(\theta_{21O}-\theta_{8O})V_{21}(\sigma)W_1(\sigma)\right\} \qquad (\not{c})$$

$$S(\sigma) = S_1(\sigma)+S_2(\sigma)+S_3(\sigma)+S_4(\sigma)+S_7(\sigma) \qquad (\not{c})$$

Steady State Equations for the Feedback

For steady state condition ($\sigma \to 0$) the equations for the feedback can be simplified because in this case all transfer functions are equal to 1. They assume the following form:

Power Feedback with constant coolant temperatures

$$Q_{1A}^{(\sigma=0)} = C_{1B}(T_{1BO}-\theta_{1O})+C_{1A}\overline{K_{1AMP}}(T_{1AMO}-\theta_{1O}) \qquad (\not{c})$$

$$Q_{1C}^{(\sigma=0)} = C_{1C}(T_{1CO}-\theta_{1O}) \qquad (\not{c})$$

$$Q_{1D}^{(\sigma=0)} = C_{1D}(T_{1DO}-\theta_{1O}) \qquad (\not{c})$$

$$Q_1^{(\sigma=0)} = Q_{1A}+Q_{1C}+Q_{1B} \qquad (\not{c})$$

$$Q_2^{(\sigma=0)} = C_{2A}(T_{2AO}-\theta_{2O}) \qquad (\not{c})$$

$$Q_3^{(\sigma=0)} = C_{3A}(T_{3AO}-\theta_{3O}) \qquad (\not{c})$$

$$Q_{4A}^{(\sigma=0)} = C_{4A}(T_{4AO}-\theta_{4O}) \qquad (\not{c})$$

$$Q_{4B}^{(\sigma=0)} = C_{4B}(T_{4BO}-\theta_{4O}) \qquad (\not{c})$$

$$Q_4^{(\sigma=0)} = Q_{4A} + Q_{4B} \qquad (\not{c})$$

Coolant Temperature-Reactivity Feedback

$$D_1(\sigma=0) = C_{1E} + C_{1B} + C_{1A}K_{1AMT} + C_{1C} + C_{1D} \qquad (¢/^{o}K)$$

$$\overline{D_1}(\sigma=0) = B_{1E}C_{1E} + B_{1B}C_{1B} + B_{1A}C_{1A}\overline{K_{1AMT}} + B_{1C}C_{1C} + B_{1D}C_{1D} \qquad (¢/^{o}K)$$

$$D_{1BOF}^{(\sigma=0)} = C_{1F} \qquad D_{1BOG}^{(\sigma=0)} \; C_{1G} \qquad (¢/^{o}K$$

$$D_2(\sigma=0) = C_{2E} + C_{2A} \qquad "$$

$$D_3(\sigma=0) = C_{3E} + C_{3A} \qquad "$$

$$D_4(\sigma=0) = C_{4E} + C_{4A} + C_{4B} \qquad "$$

$$D_5(\sigma=0) = C_{5A} \qquad "$$

$$D_{17}(\sigma=0) = C_{7E}\alpha_{17} \qquad "$$

$$D_{87}(\sigma=0) = C_{7E}\alpha_{87} \qquad "$$

Reactivity-Power Feedback through the Coolant Temperature

$$S_1(\sigma=0) = \overline{D_1}(\theta_{10}-\theta_{210}) + D_1(D_{210}-\theta_{80}) + D_{1BOF}(\theta_{210}-\theta_{80})$$

$$+ D_{1BOG}(\theta_{130}-\theta_{210}) \qquad (¢)$$

$$S_2(\sigma=0) = D_2(\theta_{20}-\theta_{80}) \qquad (¢)$$

$$S_3(\sigma=0) = D_3(\theta_{30}-\theta_{80}) \qquad (¢)$$

$$S_4(\sigma=0) = D_4(\theta_{40}-\theta_{80}) \qquad (¢)$$

$$S_7(\sigma=0) = D_{17}(\theta_{10}-\theta_{80}) \qquad (¢)$$

$$S(\sigma=0) = S_1(\sigma=0) + S_2(\sigma=0) + S_3(\sigma=0) + S_4(\sigma=0) + S_7(\sigma=0) \qquad (¢)$$

Reactivity-Coolant Flow Functions

$$M_1(\sigma=0) = -\overline{D_1(\sigma=0)}(\theta_{10}-\theta_{210})+D_1(\sigma=0)(\theta_{210}-\theta_{80})+D1_{BOF}(\theta_{210}-\theta_{80})$$

$$+ D1_{BOG}(\theta_{130}-\theta_{210}) \qquad ¢/\Delta\mu/\mu$$

$$M_2(\sigma=0) = -D_2(\sigma=0) \quad (\theta_{20}-\theta_{80}) \qquad (\frac{¢}{\Delta\mu/\mu})$$

$$M_3(\sigma=0) = -D_3(\sigma=0) \quad (\theta_{30}-\theta_{80}) \qquad "$$

$$M_4(\sigma=0) = -D_4(\sigma=0) \quad (\theta_{40}-\theta_{80}) \qquad "$$

$$M_7(\sigma=0) = -D_{17}(\sigma=0) \quad (\theta_{10}-\theta_{80}) \qquad "$$

$$M(\sigma=0) = M_1(\sigma=0)+M_2(\sigma=0)+M_3(\sigma=0)+M_4(\sigma=0)+M_7(\sigma=0) \qquad (\frac{¢}{\Delta\mu/\mu})$$

Reactivity-Inlet Temperature Functions

$$R_1(\sigma=0) = D_1(\sigma=0) + D1_{BOG}(\sigma=0) \qquad (\frac{¢}{^oK})$$

$$R_2(\sigma=0) = D_2(\sigma=0) \qquad "$$

$$R_3(\sigma=0) = D_3(\sigma=0) \qquad "$$

$$R_4(\sigma=0) = D_4(\sigma=0) \qquad "$$

$$R_5(\sigma=0) = D_5(\sigma=0) \qquad "$$

$$R_7(\sigma=0) = D_{87}(\sigma=0) + D_{17}(\sigma=0) \qquad "$$

$$R_8(\sigma=0) = C_{8E}$$

$$R = R_1+R_2+R_3+R_4+R_5+R_7+R_8 \qquad "$$

Equations for Steady State Reactivity Changes

The steady state reactivity changes caused by changes either of the power, the coolant temperature, the coolant flow or the coolant inlet temperature with reference to a steady state level denoted by N=1 are calculated according to the following relations.*)

Power induced reactivity changes with constant coolant temperature

$$ROQ1A_N = Q_{1A}(\sigma=0)]_N - Q_{1A}(\sigma=0)]_1 \qquad (¢)$$

$$ROQ1C_N = Q_{1C}(\sigma=0)]_N - Q_{1C}(\sigma=0)]_1 \qquad (¢)$$

$$ROQ1D_N = Q_{1D}(\sigma=0)]_N - Q_{1D}(\sigma=0)]_1 \qquad (¢)$$

$$ROQ2_N = Q_2(\sigma=0)]_N - Q_2(\sigma=0)]_1 \qquad (¢)$$

$$ROQ3_N = Q_3(\sigma=0)]_N - Q_3(\sigma=0)]_1 \qquad (¢)$$

$$ROQ4A_N = Q_{4A}(\sigma=0)]_N - Q_{4A}(\sigma=0)]_1 \qquad (¢)$$

$$ROQ4B_N = Q_{4B}(\sigma=0)]_N - Q_{4B}(\sigma=0)]_1 \qquad (¢)$$

$$ROQ4_N = ROQ4A_N + ROQ4B_N \qquad (¢)$$

$$ROQ9_N = Q_9(\sigma=0)]_N - Q_9(\sigma=0)]_1 \qquad (¢)$$

$$ROQ_N = Q_N(\sigma=0)]_N - Q(\sigma=0)]_1 \qquad (¢)$$

---

*) These equations do however not account for changes of the reactivity-coefficients when the power or the temperatures changes.

Reactivity changes caused by changes of the reactor power through the coolant temperature

$ROS1_N$	=	$S_1(\sigma=0)]_N$	$- S_1(\sigma=0)]_1$	(¢)
$ROS2_N$	=	$S_2(\sigma=0)]_N$	$- S_2(\sigma=0)]_1$	(¢)
$ROS3_N$	=	$S_3(\sigma=0)]_N$	$- S_3(\sigma=0)]_1$	(¢)
$ROS4_N$	=	$S_4(\sigma=0)]_N$	$- S_4(\sigma=0)]_1$	(¢)
$ROS7_N$	=	$S_7(\sigma=0)]_N$	$- S_7(\sigma=0)]_1$	(¢)
ROS_N	=	$S(\sigma=0)]_N$	$- S(\sigma=0)]_1$	(¢)

Reactivity changes caused by changes of the coolant flow

$ROM1_N$	=	$M_1(\sigma=0)]_N$	$- M_1(\sigma=0)]_1$	(¢)
$ROM2_N$	=	$M_2(\sigma=0)]_N$	$- M_2(\sigma=0)]_1$	(¢)
$ROM4_N$	=	$M_4(\sigma=0)]_N$	$- M_4(\sigma=0)]_1$	(¢)
$ROM7_N$	=	$M_7(\sigma=0)]_N$	$- M_7(\sigma=0)]_1$	(¢)
ROM_N	=	$M(\sigma=0)]_N$	$- M(\sigma=0)]_1$	(¢)

Inlet temperature reactivities

ROR_1	=	$D_1(\sigma=0)]_N \; \theta 8_N$	$- D_1(\sigma=0)]_1 \; \theta 8_1$	(¢)
ROR_2	=	$D_2(\sigma=0)]_N \; \theta 8_N$	$- D_2(\sigma=0)]_1 \; \theta 8_1$	(¢)
ROR_3	=	$D_3(\sigma=0)]_N \; \theta 8_N$	$- D_3(\sigma=0)]_1 \; \theta 8_1$	(¢)

$$ROR_4 = D_4(\sigma=0)]_N \; \Theta 8_N - D_4(\sigma=0)]_1 \; \Theta 8_1 \qquad (¢)$$

$$ROR_5 = D_5(\sigma=0)]_N \; \Theta 8_N - D_5(\sigma=0)]_1 \; \Theta 8_1 \qquad (¢)$$

$$ROR_7 = [\bar{D}_{87}(\sigma=0) + D_{17}(\sigma=0)]_N \Theta 8_N - [\bar{D}_{87}(\sigma=0) + D_{17}(\sigma=0)]_1 \Theta 8_1 \qquad (¢)$$

$$ROR_8 = C8_E(\Theta 8_N - \Theta 8_1) \qquad (¢)$$

$$ROR = R(\sigma=0)]_N \; \Theta 8_N - R(\sigma=0)]_1 \; \Theta 8_1 \qquad (¢)$$

b) <u>Summary of Important Transfer Functions</u>

Reactivity power transfer function without feedback for point reactor kinetics /3/

$$K(\sigma) = \frac{\Delta P/P}{\rho} = \frac{1}{\sigma} \left[\frac{1}{\beta} + \sum_{i=1}^{24} \frac{a_i}{\sigma + \lambda_i} \right]^{-1} \frac{1}{100} \left[\frac{\%\,Power}{cent} \right]$$

<u>Thermodynamic Basic Functions</u>

$$Z(\sigma) = - \frac{J_0\left(\sqrt{\sigma t_{1A}}\right)}{2\sqrt{-\sigma t_{1A}}\; J_1\left(\sqrt{-\sigma t_{1A}}\right)}$$

$$G_s(\sigma) = \frac{1}{1 + \frac{\gamma}{Z(\sigma)}}$$

$$F_s(\sigma) = \frac{1/t_{1A}\sigma Z(\sigma)}{1 + \gamma / Z(\sigma)} = \frac{G_s(\sigma)}{\sigma t_{1A} Z(\sigma)}$$

$$G_L(\sigma) = G_s(\sigma) \left\{ 1 - \frac{\pi}{2} \left[\frac{H_0\left(\sqrt{-\sigma t_{1A}}\right)}{2\sqrt{-\sigma t_{1A}}\, Z(\sigma)} + H_1\left(\sqrt{-\sigma t_{1A}}\right) \right] \right\}$$

$$F_L(\sigma) = \frac{6}{1 + 6\gamma\alpha_L} \frac{\alpha_L}{\sigma t_{1A}} \left\{ 1 - G_L(\sigma) - \frac{\alpha_L - 1}{\alpha_L} \frac{\pi}{2} \left[\frac{H_0}{2\sqrt{-\sigma t_{1A}}\, Z(\sigma)} + H_1 \right] \right\}$$

$$F_M(\sigma) = \frac{8}{1+8\gamma\alpha_M} \frac{1}{\sigma t_{1A}} \left\{ 1-F_s(\sigma)+(\alpha_L-1)\ \gamma\frac{F_s(\sigma)}{Z(\sigma)} \right\}$$

$$F_{1AL}(\sigma) = F_L(\sigma) \frac{1+\alpha_L\varepsilon}{1+\alpha_L\varepsilon G_L(\sigma)}$$

$$G_{1AL}(\sigma) = G_L(\sigma) \frac{1+\alpha_L\varepsilon}{1+\alpha_L\varepsilon G_L(\sigma)}$$

$$F_{1AS}(\sigma) = F_s(\sigma) \frac{1+\varepsilon\left[\bar{\alpha}_L - \frac{G_s(\sigma)F_{1AL}(\sigma)}{F_s(\sigma)} \frac{1+6\gamma\alpha_L}{6\gamma}\right]}{1 - \frac{\varepsilon}{6\gamma}}$$

$$G_{1AS}(\sigma) = G_s(\sigma) \frac{1+\alpha_L\varepsilon}{1+\alpha_L\varepsilon G_L(\sigma)}$$

$$G_{1AM}(\sigma) = F_s(\sigma) \frac{1+\varepsilon\alpha_L}{1+\alpha_L\varepsilon G_L(\sigma)} = F_s(\sigma) \frac{G_{1AS}(\sigma)}{G_s(\sigma)}$$

$$F_{1AM}(\sigma) = F_M(\sigma) \frac{1-\frac{4}{3} \frac{\alpha_M\varepsilon}{1+\alpha_L\varepsilon} \left(\frac{1+6\gamma\alpha_L}{1+8\gamma\alpha_M}\right) \frac{F_s(\sigma)F_{1AL}(\sigma)}{F_M(\sigma)}}{1-\frac{4}{3}\left(\frac{1+6\gamma\alpha_L}{1+8\gamma\alpha_M}\right) \frac{\alpha_M\varepsilon}{1+\alpha_L\varepsilon}}$$

$$G_{1B}(\sigma) = \left\{ 1+\sigma t_{1B}+A\sigma t_{1A}\gamma F_s(\sigma)(1+\eta)\left[1-\frac{\alpha_L\varepsilon}{1+\alpha_L\varepsilon}\ G_{1AL}(\sigma)\right] \right\}^{-1}$$

$$F_{1B}(\sigma) = G_{1B}(\sigma)\left[\bar{K}_{1ASP}F_{1AS}(\sigma)+(1-K_{1ASP})F_{1AL}(\sigma)\right]$$

$$\overline{G_{1AM}(\sigma)} = G_{1B}(\sigma)G_{1AM}(\sigma)$$

$$\overline{F_{1AM}(\sigma)} = \frac{1}{\overline{K_{1AMP}}(T_{1AMO}-\theta_{1O})} \left[\bar{K}_{1AMT}(T_{1BO}-\theta_{1O}) G_{1AM}(\sigma) F_{1B}(\sigma) \right.$$

$$\left. + K_{1AMP}(T_{1AMO}-T_{1BO}) F_{1AM}(\sigma) \right]$$

$$y_{1B}(\sigma) = \sigma t_{1ax} \frac{m_{1A}(1-G_{1B}(\sigma))}{A\gamma\sigma t_{1A}}$$

$$= \sigma t_{1ax} \left\{ \frac{m_{1A}}{A\gamma} \frac{t_{1B}}{t_{1A}} G_{1B}(\sigma) + m_{1A}(1+\eta) F_s(\sigma) G_{1B}(\sigma) \left[1 - \frac{\alpha_L \varepsilon}{1+\alpha_L \varepsilon} G_{1AL}(\sigma) \right] \right.$$

$$y_2(\sigma) = \sigma t_{2ax} + y_{2A}(\sigma) = \sigma t_{2ax} \; (1+m_{2A}F_{2A}(\sigma))$$

$$y_3(\sigma) = \sigma t_{3ax} + y_{3A}(\sigma) = \sigma t_{3ax} \; (1+m_{3A}F_{3A}(\sigma))$$

$$y_4(\sigma) = \sigma t_{4ax} + y_{4A}(\sigma) = \sigma t_{4ax} \; (1+m_{4A}F_{4A}(\sigma)+m_{4B}F_{4B}(\sigma))$$

$$F_1(\sigma) = \frac{\alpha_{1A}}{\alpha_1} F_{1B}(\sigma) + \frac{\alpha_{1C}}{\alpha_1} F_{1C}(\sigma) + \frac{\alpha_{1D}}{\alpha_1} F_{1D}(\sigma)$$

$$F_2(\sigma) = F_{2A}(\sigma)$$

$$F_3(\sigma) = F_{3A}(\sigma)$$

$$F_4(\sigma) = \frac{\alpha_{4A}}{\alpha_4} F_{4A}(\sigma) + \frac{\alpha_{4B}}{\alpha_4} F_{4B}(\sigma)$$

For the transfer functions relating the temperatures of the structure materials to the coolant temperatures and to the power ($\mathcal{G}(\sigma)$ and $\mathcal{F}(\sigma)$ respectively), the lumped model is applied. In this case they assume the following simple form /2/:

$$F_{1C}(\sigma) = G_{1C}(\sigma) = \frac{1}{1+\sigma\tau_{1C}}$$

$$F_{1D}(\sigma) = G_{1D}(\sigma) = \frac{1}{1+\sigma\tau_{1D}}$$

$$F_{2A}(\sigma) = G_{2A}(\sigma) = \frac{1}{1+\sigma\tau_{2A}}$$

$$F_{3A}(\sigma) = G_{3A}(\sigma) = \frac{1}{1+\sigma\tau_{3A}}$$

$$F_{4A}(\sigma) = G_{4A}(\sigma) = \frac{1}{1+\sigma\tau_{4A}}$$

$$F_{4B}(\sigma) = G_{4B}(\sigma) = \frac{1}{1+\sigma\tau_{4B}}$$

$$F_{9A}(\sigma) = \frac{1}{1+\sigma\tau_{9A}}$$

$$G_{17}(\sigma) = \frac{1}{1+\sigma\tau_{17}}$$

$$G_{87}(\sigma) = \frac{1}{1+\sigma\tau_{87}}$$

$$G_{5A}(\sigma) = \frac{1}{1+\sigma\tau_{5A}}$$

The transfer functions

- $W(\sigma)$ between coolant temperatures of different axial regions
- $U(\sigma)$ between coolant temperatures and the flow
- $V(\sigma)$ between coolant temperatures and the power

have been derived in /2/. According to the notations of this paper they are given by

$$W_{13}(\sigma) = e^{-y_1(\sigma)} \qquad U_{13}(\sigma) = \frac{1-e^{-y_1(\sigma)}}{y_1(\sigma)}$$

$$W_{21}(\sigma) = e^{-y_2(\sigma)} \qquad U_{21}(\sigma) = \frac{1-e^{-y_2(\sigma)}}{y_2(\sigma)}$$

$$W_{36}(\sigma) = e^{-y_3(\sigma)} \qquad U_{36}(\sigma) = \frac{1-e^{-y_3(\sigma)}}{y_3(\sigma)}$$

$$W_{46}(\sigma) = e^{-y_4(\sigma)} \qquad U_{46}(\sigma) = \frac{1-e^{-y_4(\sigma)}}{y_4(\sigma)}$$

$$V_{13}(\sigma) = U_{13}(\sigma)F_1(\sigma) \qquad W_1(\sigma) = U_{13}(\sigma)$$

$$V_{21}(\sigma) = U_{21}(\sigma)F_2(\sigma) \qquad W_2(\sigma) = U_{21}(\sigma)$$

$$V_{31}(\sigma) = U_{36}(\sigma)F_3(\sigma) \qquad W_3(\sigma) = U_{36}(\sigma)$$

$$V_{46}(\sigma) = U_{46}(\sigma)F_4(\sigma) \qquad W_4(\sigma) = U_{46}(\sigma)$$

$$W_5(\sigma) = \frac{e^{-\sigma\tau_{85}}}{1+\sigma\tau_{85}}$$

$$U_1(\sigma) = 2\,[1-U_{13}(\sigma)]\,\frac{1}{y_1(\sigma)} \qquad V_1(\sigma) = U_1(\sigma)F_1(\sigma)$$

$$U_2(\sigma) = 2\,[1-U_{21}(\sigma)]\,\frac{1}{y_2(\sigma)} \qquad V_2(\sigma) = U_2(\sigma)F_2(\sigma)$$

$$U_3(\sigma) = 2\left[1 - U_{36}(\sigma)\right]\frac{1}{Y_3(\sigma)} \qquad V_3(\sigma) = U_3(\sigma)F_3(\sigma)$$

$$U_4(\sigma) = 2\left[1 - U_{46}(\sigma)\right]\frac{1}{Y_4(\sigma)} \qquad V_4(\sigma) = U_4(\sigma)F_4(\sigma)$$

<u>Reactivity-Coolant Flow Functions</u>

$$M_1 = -\Big\{(\theta_{10}-\theta_{210})U_1(\sigma)\overline{D_1(\sigma)} + (\theta_{210}-\theta_{80})U_{21}(\sigma)W_1(\sigma)D_1(\sigma) \qquad \left(\frac{¢}{\Delta\mu/\mu}\right)$$

$$+ D1_{BOF}(\sigma)(\theta_{210}-\theta_{80})U_{21}(\sigma) + D1_{BOG}(\sigma)\left[\bar{\theta}_{130}-\theta_{210})U_{13}(\sigma) + \right.$$

$$\left. +(W_{13}(\sigma)-1)(\theta_{210}-\theta_{80})U_{21}(\sigma)\right]\Big\}$$

$$M_2 = - D_2(\sigma)(\theta_{20}-\theta_{80})U_2(\sigma) \qquad \left(\frac{¢}{\Delta\mu/\mu}\right)$$

$$M_3 = - D_3(\sigma)\Big\{(\theta_{30}-\theta_{130})U_3(\sigma) + \left[(\theta_{130}-\theta_{210})U_{13}(\sigma) + \right.$$

$$\left. + (\theta_{210}-\theta_{80})\, U_{21}(\sigma)W_{13}(\sigma)\right]W_3(\sigma)\Big\} \qquad \left(\frac{¢}{\Delta\mu/\mu}\right)$$

$$M_4 = - D_4(\sigma)\,(\theta_{40}-\theta_{80})U_4(\sigma) \qquad "$$

$$M_7 = - D_{17}(\sigma)\Big\{(\theta_{10}-\theta_{210})U_1(\sigma) + (\theta_{210}-\theta_{80})U_{21}(\sigma)W_1(\sigma)\Big\} \qquad "$$

$$M(\sigma) = M_1(\sigma)+M_2(\sigma)+M_3(\sigma)+M_4(\sigma)+M_7(\sigma) \qquad "$$

Reactivity-Inlet Temperature Functions

$$R_1(\sigma) = W_5(\sigma)W_{21}(\sigma)W_1(\sigma)D_1(\sigma)+D1_{BOG}(\sigma)W_5(\sigma)W_{21}(\sigma)$$

$$+ D1_{BOF} [\bar{W}_{13}(\sigma)-1]W_5(\sigma)W_{21}(\sigma) \qquad (\frac{¢}{^oK})$$

$$R_2(\sigma) = W_5(\sigma)W_2(\sigma)D_2(\sigma) \qquad \text{"}$$

$$R_3(\sigma) = W_5(\sigma)W_{21}(\sigma)W_{13}(\sigma)W_3(\sigma)D_3(\sigma) \qquad \text{"}$$

$$R_4(\sigma) = W_5(\sigma)W_4(\sigma)D_4(\sigma) \qquad \text{"}$$

$$R_5(\sigma) = W_5(\sigma)D_5(\sigma) \qquad \text{"}$$

$$R_7(\sigma) = D_{87}(\sigma)+D_{17}(\sigma)W_5(\sigma)W_{21}(\sigma)W_1(\sigma) \qquad \text{"}$$

$$R_8(\sigma) = C_{8E}$$

$$R(\sigma) = R_1(\sigma)+R_2(\sigma)+R_3(\sigma)+R_4(\sigma)+R_5(\sigma)+R_7(\sigma)+R_8(\sigma) \qquad \text{"}$$

Closed Loop Transfer Functions

$$G_O(\sigma) = \frac{K(\sigma)}{1+K(\sigma)Q(\sigma)} \qquad (\frac{\Delta P/P}{¢})$$

$$G_P(\sigma) = \frac{K(\sigma)}{1+K(\sigma)[Q(\sigma)+S(\sigma)]} \qquad \text{"}$$

$$G_\mu(\sigma) = G_P(\sigma)M(\sigma) \qquad (\frac{\Delta P/P}{\Delta\mu/\mu})$$

$$G_\theta(\sigma) = G_P(\sigma)R(\sigma) \qquad (\frac{\Delta P/P}{\Delta\theta_8})$$

4) Description of the Program with Input and Output lists

The program "HETRA" has been written in order to calculate all transfer functions listed in Appendix 3.

HETRA has been included in the INR Program library NUSYS and can be called by the following control cards:

```
// EXEC FHG, LIB = NUSYS, NAME = HETRA
```

One run with 50 frequences takes about 30 sec calculation time with the IBM 370/165 (the peripheric time is negligible) and uses 300 k bytes in the storage.

Main Program and Subroutines

Main: reads and prints the input data
calculates all functions which are used for the dynamic problem
regulates the output for the functions required.

CACO: Calculates from the input data the constant parameters which are used for both the steady state calculations and the transfer functions (see Appendix 2).

SCCA: performs the steady state calculations and prints the corresponding results in form of tables

ZSIG: Calculates the Bessel Functions appearing in eq.III-32 by using the routines GEBCB of the KFZ library.
For arguments with absolute values bigger than 100, the Function $Z(\sigma)$ is approximated by the asymptotic expansion /1/

$$Z(\sigma) = \frac{\sqrt{1+0.25\sigma t_{1A}}}{\sigma t_{1A}}$$

POCO: Calculates with double precision the exponent of a complex number and transforms the result to single precision.

WUV: Calculates with double precision the functions $W(\sigma)$, $U(\sigma)$ and $V(\sigma)$ and transforms the results to single precision.

STRF: Calculates the Struve Functions $H_o(\sigma)$ and $H_1(\sigma)$ appearing in eqs. III-41, 47 and 48
For arguments with absolute values smaller than 13 the power series expansion is used:

$$H_o(\sigma) = \frac{2}{\pi}\left\{\frac{\sigma}{1^2} - \frac{\sigma^3}{1^2\,3^2} + \frac{\sigma^5}{1^2\,3^2\,5^2} - \cdots\cdots\right\}$$

$$H_1(\sigma) = \frac{2}{\pi}\left\{\frac{\sigma^2}{1^2\,3} - \frac{\sigma^4}{1^2\,3^2\,5} + \frac{\sigma^6}{1^2\,3^2\,5^2\,7} - \cdots\cdots\right\}$$

For bigger arguments the following approximation is applied:

$$\frac{H_o(\sqrt{-\sigma t_{1A}})}{2\sqrt{-\sigma t_{1A}}\,Z(\sigma)} + H_1(\sqrt{-\sigma t_{1A}}) = \frac{H_1(\sqrt{-\sigma t_{1A}})J_o(\sqrt{-\sigma t_{1A}}) - H_o(\sqrt{-\sigma t_{1A}})J_1(\sqrt{-\sigma t_{1A}})}{J_o(\sqrt{-\sigma t_{1A}})}$$

$$= \frac{2}{\pi}\left\{1 + \frac{1}{(\sqrt{-\sigma t_{1A}})^2}\left[1 + \frac{1}{2Z(\sigma)}\right]\right\} + \frac{0.7979}{\sqrt{\sqrt{-\sigma t_{1A}}}}\;\frac{\frac{3}{64(\sqrt{-\sigma t_{1A}})^2} - 1}{\sin(\sqrt{-\sigma t_{1A}}+\frac{\pi}{4}) + \frac{1}{8\sqrt{-\sigma t_{1A}}}\sin(\sqrt{-\sigma t_{1A}}-\frac{\pi}{4})}$$

BILD: For printing the reactor configuration. Always one out of 3 pictures can be chosen by an input card: These are schematic configurations of KNK, SNR and SEFOR. In case any other name appears on this input card, always the configuration of the SNR will be printed.

SCRIVI: To print the tables of complex functions in dependence of the frequency ω in the following form:
real part, imaginary part, modulus and phase.
If requested, the plot program will be called for plotting modulus and phase of the corresponding function.
The following functions are always printed as a standard output: $K(\sigma)$, $Z(\sigma)$, $G_s(\sigma)$, $G_L(\sigma)$, $Q(\sigma)$, $S(\sigma)$, $M(\sigma)$, $R(\sigma)$, $G_o(\sigma)$, $G_p(\sigma)$, $G_\mu(\sigma)$.

Input Preparation

Card	format	variable	significance/remarks	units
1.1	20 A4	REAKT TITLE	name of reactor (SNR, KNK, SEFOR	-
2.1	Nuclear data			
	G10.4	L	prompt neutron lifetime	sec
	I5	NI	number of isotopes (max.6)	-
2.2			Fuel composition	
	A8	NISOT	name of isotope	-
			Parameters of isotopes	
2.3	8G10.4	BETA (I)	percentage of delayed neutrons in group I	–
		LAMBDA (I)	decay constant of delayed neutrons in group I	sec^{-1}
		I=1,6	(max. 6 groups) for each isotope repeat cards 2.2 and 2.3	
3.1		Program control		
	I5	NPAR	0 no steady state calculations	-
			>0 " " " with NPAR-groups of parameters (see card 16)	-
4.1		Core geometry		
		L1	Core length	cm
	6G10.4	N1	number of fuel pins	-
		S1	coolant cross section associated to a fuel pin	cm^2
		DEL1	coolant flow percentage in core: δ_1	-
		R1BI	inner fuel cladding radius	cm
		R1BE	outer " " "	cm

Card	format	variable	significance/remarks	units
4.2			Core FUEL	
	6G10.4	M1A	total mass of fuel	g
		CH1	coefficient for specific heat capacity χ_1	$\frac{Wattsec}{^oK\ g}$
		CH2	coefficient for specific heat capacity χ_2	$\frac{Wattsec}{^oK^2\ g}$
		CH3	coefficient for specific heat capacity χ_3	$\frac{Wattsec\ ^oK^3}{g}$
		TA	coefficient for thermal conductivity λ	^oK
		C	coefficient for thermal conductivity λ	$\frac{cm}{Watt\ ^oK}$
4.3	7G10.4	A0	coefficients to calculate the heat transfer coefficient between fuel and cladding (A0, A1, A2, A3, B1)	$\frac{Watt}{cm^2\ ^oK}$
		A1		$\frac{cm}{^oK}$
		A2		$\frac{cm^4}{Watt\ ^oK}$
		A3		$\frac{cm^7}{Watt^2\ ^oK}$
		B1		$\frac{Watt}{cm^2\ ^oK^2}$
		ALFA1A	percentage of power produced in the fuel	-
		CIAMT	if 0, than KIAMP, KIAMT, KIAST, KIASP is calculated if 1, than KIAMP, KIAMT, KIAST, KIASP is equal 1	-
4.4			CORE CLADDING	
	3G10.4	RO1B	mass density ϱ_{1B}	g/cm^3
		CHI1B	specific heat capacity χ_{1B}	$\frac{Wattsec}{^oK\ g}$
		LAM1B	thermal conductivity λ_{1B}	$\frac{Watt}{cm\ ^oK}$

Card	format	variable	significance/remarks	units
4.5	material No.1 of core structure			
	5G10.4	M1C	total mass M_{1C}	g
		CHI1C	specific heat capacity χ_{1C}	$\frac{\text{Watt sec}}{^{o}K\ g}$
		TAU1C	time constant for heat transfer	sec
		ALF1C	percentage of power released α_{1C}	-
		T1COM	maximum difference between average core structure temperature and coolant temperature $(T_{1CO} - \theta_{1O})_{max}$	^{o}K
4.6	material No.2 of core structure			
	5G10.4	M1D	total mass M_{1D}	g
		CHI1D	specific heat capacity χ_{1D}	$\frac{\text{Watt sec}}{^{o}K\ g}$
		TAU1D	time constant for heat transfer τ_{1D}	sec
		ALF1D	percentage of power released α_{1D}	-
		T1DOM	maximum difference between average core structure temperature and coolant temperature $(T_{1DO} - \theta_{1O})_{max}$	^{o}K
5.1	time constants for bowing coefficients			
	2G10.4	TAU1F	time constant related to coolant inlet temperature τ_{1F}	sec
		TAU1G	time constant related to coolant temperature rise τ_{1G}	sec
6.	Coolant			
	6G10.4	ROE	mass density ρ_{1E}	g/cm^3
		CHE	specific heat capacity χ_{1E}	$\frac{\text{Watt sec}}{^{o}K\ g}$
		LAME	thermal conductivity λ_{1E}	$\frac{\text{Watt}}{cm\ ^{o}K}$

Card	format	variable	significance/remarks	units
		NU1	coefficients for Nusselt number	-
		NU2		-
		NU3		-
7.			reactivity coefficients	
	7G10.4	C1A	for fuel C_{1A}	¢/°K
		C1B	for cladding C_{1B}	¢/°K
		C1E	for coolant C_{1E}	¢/°K
		C1C	for structure material No.1 C_{1C}	¢/°K
		C1D	" " " " 2 C_{1D}	¢/°K
		C1F	bowing coefficient for coolant inlet temperature C_{1F}	¢/°K
		C1G	bowing coefficient for coolant temperature rise C_{1G}	¢/°K
8.			reactivity correction coefficients	
	5G10.4	B1A	for fuel	-
		B1B	for cladding	-
		B1C	for structure material No.1	-
		B1D	" " " No.2	-
		B1E	for coolant	-
9.1			lower axial blanket	
	8G10.4	L2	length L_2	cm
		M2A	mass M_{2A}	g
		CH2A	specific heat capacity χ_{2A}	$\frac{\text{Watt sec}}{\text{g } ^{\circ}\text{K}}$
		TAU2A	time constant for heat transfer τ_{2A}	sec
		C2A	blanket reactivity coefficient C_{2A}	¢/°K
		C2E	coolant reactivity coefficient C_{2E}	¢/°K
		ALF2A	percentage of power α_{2A}	-
		T2AM	maximum difference between average blanket temperature and coolant temperature $(T_{2AO} - \theta_{20})_{max}$	°K

Card	format	variable	significance/remarks	units
9.2			upper axial blanket	
	8G10.4	L3	length L_3	cm
		M3A	mass M_{3A}	g
		CH3A	specific heat capacity χ_{3A}	$\frac{\text{Watt sec}}{\text{g }^{o}\text{K}}$
		TAU3A	time constant for heat transfer τ_{3A}	sec
		C3A	blanket reactivity coefficient C_{3A}	¢/°K
		C3E	coolant reactivity coefficient C_{3E}	¢/°K
		ALF3A	percentage of power α_{3A}	-
		T3AM	maximum difference between average blanket temperature and coolant temperature $(T_{3AO} - \theta_{3O})_{max}$	°K
10.1			Radial blanket: Geometry	
	3G10.4	L4	length L_4	cm
		N4	number of pins N_4	-
		S4	coolant cross section associated to one pin S_4	cm^2
10.2			radial blanket: Material parameter	
	6G10.4	M4A	mass M_{4A}	g
		CH4A	specific heat capacity χ_{4A}	$\frac{\text{Watt sec}}{^{o}\text{K g}}$
		TAU4A	time constant for heat transfer τ_{4A}	sec
		C4A	reactivity coefficient C_{4A}	¢/°K
		ALF4A	percentage of power released α_{4A}	-
		T4AM	maximum difference between average blanket temperature and coolant temperature $(T_{4AO} - \theta_{4O})_{max}$	°K

Card	format	variable	significance/remarks	units
10.3			radial blanket: structure material and coolant	
	7G10.4	M4B	mass M_{4B}	g
		CH4B	specific heat capacity χ_{4B}	$\frac{\text{Watt sec}}{^oK\ g}$
		TAU4B	time constant for heat transfer τ_{4B}	sec
		C4B	reactivity coefficient C_{4B}	¢/^{o}K
		ALF4B	percentage of power released α_{4B}	-
		T4BM	maximum difference between average structure material temperature and coolant temperature $(T_{4BO} - \theta_{4O})_{max}$	^{o}K
		C4E	coolant reactivity coefficient	¢/^{o}K
11.			Lower and lateral plenums	
	7G10.4	T85M	maximum time delay between lower and lateral plenum t_{85}	sec
		TAU85	heat transfer time constant for the materials in the lateral and lower plenums τ_{85}	sec
		TAU5A	time constant for the heat transfer from the grid plate τ_{5A}	sec
		C8E	coolant reactivity coefficient in the lateral plenum	¢/^{o}K
		C5E	coolant reactivity coefficient in the lower plenum	¢/^{o}K
		C5A	grid plate reactivity coefficient	¢/^{o}K
		TET8O	coolant temperature in the lateral plenum θ_{8O}	^{o}K
12.			static sodium between core and shroud	
	4G10.4	C7E	sodium reactivity coefficient C_{7E}	¢/^{o}K
		ALF17	Difference between average core coolant and static sodium temperature devided by difference between average core coolant and lateral plenum temperature = α_{17}	-

Card	format	variable	significance/remarks	units
		TAU17	heat transfer time constant for the material between core and static sodium = τ_{17}	sec
		TAU18	heat transfer time constant for the material between lateral plenum and static sodium = τ_{18}	sec
13.			Reflector	
	5G10.4	T9AM	maximum temperature difference between reflector and coolant $(T_{9AO} - \theta_{90})_{max}$	^oK
		TAU9A	time constant for the heat transfer τ_{9A}	sec
		C9A	reactivity coefficient C_{9A}	¢/^oK
		ALF9A	percentage of power released α_{9A}	-
		TET90	average coolant temperature θ_{90}	^oK
14.			Reactor Parameter	
	2G10.4	PMAX	maximum total power P_{max}	Watt
		NUMAX	maximum coolant flow μ_{max}	cm^3/sec
15.			Program control	
	2I5	N	=0 if no dynamic calculations are required	-
			>0 number of frequency values for dynamic calculations (maximum of 80 frequencies, see card 18)	-
		JAPLOT	0 no plot required	-
			1 plot required	-
16.	Parameters for steady state calculations. This card is to repeat NPAR-times			
	4G10.4	TET80	coolant temperature of the lateral plenum (inlet coolant temperature) θ_{80}	^oK
		TET90	average coolant temperature θ_{90}	^oK
		NU	total coolant flow μ	$\frac{cm^3}{sec}$
		PO	total reactor power P_o	Watt

Card	format	variable	significance/remarks	units
17.	Reactor parameters, only if no steady state calculation is required			
	2G10.4	PO	total reactor power P_o	Watt
		TET60	coolant temperature of upper plenum θ_{60}	^oK
18.	Frequencies for transfer functions			
	8G10.4	OMEGA(I) I=1,N	values for radiant frequencies ω	sec^{-1}
20	END of INPUT			
	empty card, if standard output is requested. In case more transfer functions are requested in the output the following cards must be used and card 20 follows at the end.			-

Card	format	NAME*	functions listed in the output
19.1	4A8	BASIC---	F_s; F_M; F_L; G_{1AL}; F_{1AL}; G_{1AS}; F_{1AS}; G_{1B}; F_{1B}; G_{1AM}; F_{1AM}; $\overline{G}_{1AM}$; $\overline{F}_{1AM}$; Y_{1B}; Y_1; F_1;
		-G1C----	G_{1C}; G_{1D}
		-Y1C----	Y_{1C}; Y_{1D}
		-W1B----	W_{13}; U_{13}; V_{13}; U_1; V_1
19.2	2A8	-G2A----	G_{2A}; Y_2; W_{21}; U_{21}; Y_{21}; U_2; V_2
		-G3A----	G_{3A}; Y_3; W_{36}; U_{36}; V_{31}; U_3; V_3
19.3	A4	-G4A	G_{4A}; G_{4B}; F_4; Y_{4A}; Y_{4B}; Y_4; W_{46}; U_{46}; V_{46}; U_4; V_4;
19.4	3A4	$-G_{17}$	G_{17}; G_{87};
		--W5	W_5; G_{5A};
		-F9A	F9A
19.5	A4	---Q	Q_1; Q_2; Q_3; Q_4; Q_9;
19.6	A4	---D	D_1; $\overline{D}_1$; D_2; D_3; D_4; D_5; D_{17}; D_{87} $D1_{BOF}$; $D1_{BOG}$
19.7	A4	---S	S_1; S_2; S_3; S_4; S_7;
19.8	A4	---M	M_1; M_2; M_3; M_4; M_7;
19.9	A4	---R	R_1; R_2; R_3; R_4; R_5; R_7
19.10	A4	KQ+S	$K(\sigma)\cdot Q(\sigma)$ $K(\sigma)\cdot S(\sigma)$ $K(\sigma)\cdot[\bar{Q}(\sigma)+S(\sigma)]$

* the sign '-' means blanc

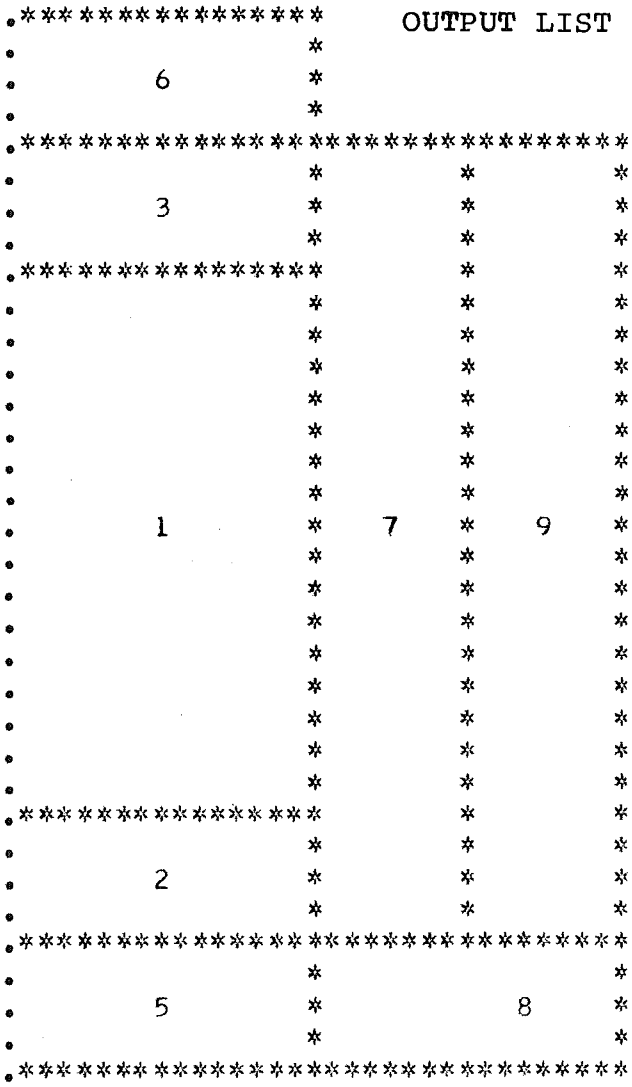
INPUT LIST

```
KNK
 2.540E-05     1
  U235
 0.253E-03 .01242      1.477E-3 .0305      1.342E-03 .1113      2.939E-03 .301
 1.019E-031.136        .234E-033.01
   14
  105.      2904.0     0.72       0.925      0.435      0.475
 1.900E 06   0.29       3.16E-05 -9.12E 02 5.450E 03 6.750E-06
  50.        0.         0.         0.         0.         0.978      1.
  7.84       0.52       0.197
  1.27E 06   0.69       13.5       0.011      15.
  0.         0.         0.         0.         0.
  0.         0.
 0.838      1.29       0.727      2.3        0.322      0.5
  -.118      .0062      0.0826     0.69       0.         0.         0.
   0.         1.         1.         1.         1.
   0.         0.         0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.         0.         0.
105.         2904.      0.76
    1.3E06   0.69       13.5       0.69       0.011      15.
   0.        0.         0.         0.         0.         0.         0.0826
   0.5       1.         40.        0.         0.         0.          620.
   0.        0.         0.         0.
   10.       10.        0.         0.         620.
   5.80E07   2.80E05
   12
620.        620.        1.89E05    0.5E06
620.        620.        1.89E05    1.0E06
620.        620.        1.89E05    5.0E06
620.        620.        1.89E05   10.0E06
620.        620.        1.89E05   15.0E06
620.        620.        1.89E05   20.0E06
620.        620.        1.89E05   25.0E06
620.        620.        1.89E05   35.0E06
620.        620.        1.89E05   40.0E06
620.        620.        1.89E05   45.0E06
620.        620.        1.89E05   50.0E06
620.        620.        1.89E05   55.0E06
620.        620.        1.89E05   60.0E06
620.        620.        1.89E05   90.0E06
 0.01        0.392     0.785     1.13        1.57       2.45        3.73        5.00
 6.16       7.41      9.22       17.68
```

CONTROL CARDS

```
//........ JOB ..........................   CLASS=A,TIME=1,REGION=300K
//  EXEC FHG,LIB=NUSYS,NAME=HETRA
//G.FT07F001 DD SYSOUT=P  *FOR PLOT ONLY*
//GO.SYSIN DD *
```

OUTPUT LIST



1 - CORE
2 - LOWER AXIAL BLANKET
3 - UPPER AXIAL BLANKET
4 - NONE
5 - LOWER PLENUM
6 - UPPER PLENUM
7 - STATIC SODIUM BETWEEN VESSEL AND SHROUD
8 - LATERAL PLENUM
9 - RADIAL REFLEKTOR

****

INPUT DATA

****

1. NUCLEAR DATA

ISOTCP U235

GROUP	BETA	LAMEDA(1/SEC)	AI= BETAI/BETA
1	2.5300006E-04	1.2419999E-02	3.4829341E-02
2	1.4770001E-03	3.0499998E-02	2.0333171E-01
3	1.3420000E-03	1.1129999E-01	1.8474686E-01
4	2.9390000E-03	3.0100000E-01	4.0459841E-01
5	1.0190001E-03	1.1359997E+00	1.4028096E-01
6	2.3400001E-04	3.0100002E+00	3.2213692E-02

PROMPT NEUTRON LIFETIME L(SEC)= 2.540000E-05

BETA= 7.263992E-03

2. ZONE 1: CORE

A. GEOMETRY

LENGTH (CM)	L1= 105.00000
NUMBER OF FUEL PINS	N1= 2904
COOLANT CROSS SECTION ASSOCIATED TO A FUEL PIN (CM**2)	S1= 0.72000
COOLANT FLOW PERCENTAGE IN CORE	DELTA1= 0.92500
INNER FUEL CLADDING RADIUS (CM)	R1BI= 0.43500
OUTER FUEL CLADDING RADIUS (CM)	R1BE= 0.47500

INPUT ERROR NR. 3

B. FUEL

TOTAL MASS OF FUEL (GR) MA= 1.900000E+06

SPECIFIC HEAT CAPACITY COEFFICIENTS:

CHI1 (WATT SEC / K G) = 2.900000E-01
CHI2 (WATT SEC / K**2 G) = 3.159999E-05
CHI3 (WATT SEC K**3 / G) = -9.120000E+02

THERMAL CONDUCTIVITY(WATT/CM K):
TA(K) = 5.450000E+03
C(CM/WATT K) = 6.750000E-06

FUEL/CLADDING HEAT TRANSFER COEFFICIENT:
A0(WATT/CM**2 K) = 5.000000E+01
A1(CM/K) = 0.0
A2(CM**4/WATT K)= 0.0
A3(CM**7/WATT**2 K)= 0.0
B1(WATT/CM K) = 0.0
PERCENTAGE OF POWER ALFA1A = 9.780000E-01

C. CLADDING

DENSITY (GR/CM**3)	RO1B= 7.84000
SPECIFIC HEAT CAPACITY (WATT SEC/K GR)	CHI1B= 0.52000

THERMAL CONDUCTIVITY (WATT/CM K)	LAMBDA1B= 0.19700

D. CORE STRUCTURE 1ST MATERIAL

TOTAL MASS (GR)	M1C= 1.270000E+06
SPECIFIC HEAT CAPACITY (WATT SEC/K GR)	CHI1B= 0.69000
TIME CONSTANT (SEC)	TAU1C= 13.50000
PERCENTAGE OF POWER	ALFA1C= 0.01100
(T1CO - TETA10)MAX=	15.00000

E. CORE STRUCTURE 2ND MATERIAL

TOTAL MASS (GR)	M1D= 0.0
SPECIFIC HEAT CAPACITY (WATT SEC/K GR)	CHI1D= 0.0
TIME CONSTANT (SEC)	TAU1D= 0.0
PERCENTAGE OF POWER	ALFA1D= 0.0
(T1DO - TETA10)MAX=	0.0

TIME CONSTANTS FOR BOWING EFFECTS:

CORE COOLANT INLET TEMPERATURE (SEC)	TAUF= 0.0
CORE COOLANT TEMPERATURE RISE (SEC)	TAU1G= 0.0

F. COOLANT

DENSITY (GR/CM**3)	ROE= 0.83800
SPECIFIC HEAT CAPACITY (WATT SEC/K GR)	CHIE= 1.29000
THERMAL CONDUCTIVITY (WATT/CM K)	LAMBDAE= 0.72700
NUSSELT NUMBER COEFFICIENTS:	NU1= 2.30000
	NU2= 0.32200
	NU3= 0.50000

G. REACTIVITY COEFFICIENTS:

FUEL (C/K)	C1A= -1.180000E-01
CLADDING (C/K)	C1B= 6.200001E-03
COOLANT (C/K)	C1E= 8.2599998E-02
STRUCTURE FIRST MATERIAL (C/K)	C1C= 6.900000E-01
STRUCTURE SECOND MATERIAL (C/K)	C1D= 0.0
BOWING COEFFICIENT/CM COOLANT INLET TEMPERATURE (C/K)	C1F= 0.0
BOWING COEFFICIENT/CM CORE COOLANT TEMPERATURE RISE(C/K)	C1G= 0.0

H. REACTIVITY CORRECTION COEFFICIENTS:

FUEL (C/K)	B1A= 0.0
CLADDING (C/K)	B1B= 1.000000E+00
COOLANT (C/K)	B1E= 1.000000E+00
STRUCTURE FIRST MATERIAL (C/K)	B1C= 1.000000E+00
STRUCTURE SECOND MATERIAL (C/K)	B1D= 1.000000E+00

3. ZONE 2: LOWER AXIAL BLANKET

LENGTH (CM)	L2= 0.0
MASS (G)	M2A= 0.0
SPECIFIC HEAT CAPACITY (WATT SEC/G K)	CHI2A= 0.0
TIME CONSTANT (SEC)	TAU2A= 0.0
BLANKET REACTIVITY COEFFICIENT (C/K)	C2A= 0.0
COOLANT REACTIVITY COEFFICIENT (C/K)	C2E= 0.0
PERCENTAGE OF POWER	ALFA2A= 0.0
MAXIMAL DIFFERENCE BETWEEN BLANKET AND COOLANT AVERAGE TEMPERATURE (K)	0.0

4. ZONE 3: UPPER AXIAL BLANKET

LENGTH (CM)	L3= 0.0
MASS (G)	M3A= 0.0

SPECIFIC HEAT CAPACITY (WATT SEC/G K) CHI3A= 0.0
TIME CONSTANT (SEC) TAU3A= 0.0
BLANKET REACTIVITY COEFFICIENT (C/K) C3A= 0.0
COOLANT REACTIVITY COEFFICIENT (C/K) C3E= 0.0
PERCENTAGE OF POWER ALFA3A= 0.0
MAXIMAL DIFFERENCE BETWEEN BLANKET AND COOLANT AVERAGE TEMPERATURE (K) 0.0

5. ZONE 4: RADIAL BLANKET

A. GEOMETRY

LENGTH (CM) L4= 105.0000
NUMBER OF PINS N4= 2904.
COOLANT CROSS SECTION ASSOCIATED TO ONE PIN(CM**2) S4= 0.7600

B. BLANKET

MASS (G) M4A= 1.300000E+06
SPECIFIC HEAT CAPACITY (WATT SEC/G K) CHI4A= 0.69000
TIME CONSTANT (SEC) TAU4A= 13.50000
BLANKET REACTIVITY COEFFICIENT (C/K) C4A= 0.69000
PERCENTAGE OF POWER ALFA4A= 0.01100
MAXIMAL DIFFERENCE BETWEEN BLANKET AND COOLANT AVERAGE TEMPERATURE (K)=15.00000

C. STRUCTURE MATERIAL

MASS (G) M4B= 0.0
SPECIFIC HEAT CAPACITY (WATT SEC/G K) CHI4B= 0.0
TIME CONSTANT (SEC) TAU4B= 0.0
BLANKET REACTIVITY COEFFICIENT (C/K) C4B= 0.0
PERCENTAGE OF POWER ALFA4B= 0.0
MAXIMAL DIFFERENCE BETWEEN AVERAGE CORE STRUCTURE AND COOLANT TEMPERATURE (K)= 0.0

D. COOLANT

REACTIVITY COEFFICIENT (C/K) C4E= 0.08260

6. ZONE 5 AND 8: LOWER AND LATERAL PLENUMS

MAXIMAL TIME DELAY (SEC) T85= 0.50000
TIME CONSTANT FOR THE MATERIALS (SEC) TAU85= 1.0000
GRID PLATE TIME CONSTANT (SEC) TAU5A= 40.00000
COOLANT REACTIVITY COEFFICIENT IN THE LATERAL PLENUM (C/K) C8E= 0.0
COOLANT REACTIVITY COEFFICIENT IN LOWER PLENUM (C/K) C5E= 0.0
GRID PLATE REACTIVITY COEFFICIENT (C/K) C5A= 0.0
COOLANT TEMPERATURE IN THE LATERAL PLENUM (K) TETA80= 620.00

7. ZONE 7: STATIC SODIUM BETWEEN CORE AND SHROUD

SODIUM REACTIVITY COEFFICIENT(C/K) C7E= 0.0
DIFF STATIC NA AND LAT PLENUM TEMP/DIFF AV COOL CORE AND LAT PLENUM TEMP ALFA17= 0.0
TIME CONSTANT FOR MATERIAL BETWEEN CORE AND STATIC NA TAU17= 0.0
TIME CONSTANT FOR MATERIAL BETW LATERAL PLENUM AND STATIC NA TAU87= 0.0

8. ZONE 9: RADIAL REFLECTOR

AVERAGE COOLANT TEMPERATURE (K) TETA90= 620.000
MAXIMAL TEMP DIFFERENCE BETWEEN REFLECTOR AND COOLANT = 10.000
REFLECTOR TIME CONSTANT (SEC) TAU9A= 10.00000
REACTIVITY COEFFICIENT (C/K) C9A= 0.0
PERCENTAGE OF POWER ALFA9A= 0.0

MAXIMAL TOTAL POWER (WATT) PMAX= 5.800000E+07

MAXIMUM COOLANT FLOW (CM**3/SEC) NUMAX= 2.800000E+05

****

STEADY STATE CALCULATIONS

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INPUT: COOLANT TEMPERATURES(K) FLOW(CM**3/SEC) POWER(WATT)

N	TETA 80	TETA90	NU	PO
1	620.0000	620.0000	1.890000E+05	5.000000E+05
2	620.0000	620.0000	1.890000E+05	1.000000E+06
3	620.0000	620.0000	1.890000E+05	5.000000E+06
4	620.0000	620.0000	1.890000E+05	1.000000E+07
5	620.0000	620.0000	1.890000E+05	1.500000E+07
6	620.0000	620.0000	1.890000E+05	2.000000E+07
7	620.0000	620.0000	1.890000E+05	2.500000E+07
8	620.0000	620.0000	1.890000E+05	3.500000E+07
9	620.0000	620.0000	1.890000E+05	4.000000E+07
10	620.0000	620.0000	1.890000E+05	4.500000E+07
11	620.0000	620.0000	1.890000E+05	5.000000E+07
12	620.0000	620.0000	1.890000E+05	5.500000E+07
13	620.0000	620.0000	1.890000E+05	6.000000E+07
14	620.0000	620.0000	1.890000E+05	9.000000E+07

OUTPUT: COOLANT TEMPERATURES FUEL TEMPERATURES CORE STRUCTURE MATERIAL TEMPERATURES POWER DENSITY

N	TETA 130	TETA 10	T1ASO	T1AMO	T1ACO	T1BO	T1CO	T1DO	PD10
1	622.6160	621.3079	621.5544	622.0188	624.1440	621.4858	621.4370	621.3079	2.6977
2	625.2327	622.6162	623.1094	625.1702	628.3101	622.9722	622.8748	622.6162	5.3954
3	646.1650	633.0825	635.5493	648.8210	662.3855	634.8625	634.3755	633.0825	26.9771
4	672.3306	646.1653	651.0991	678.6499	706.8831	649.7256	648.7515	646.1653	53.9541
5	698.4961	659.2480	666.6492	709.3049	753.5352	664.5886	663.1272	659.2480	80.9312
6	724.6614	672.3306	682.1987	740.9045	802.3794	679.4514	677.5029	672.3306	107.9081
7	750.8269	685.4133	697.7485	773.4082	853.4480	694.3145	691.8787	685.4133	134.8852
8	803.1580	711.5789	728.8481	841.1694	962.3477	724.0403	720.6304	711.5789	188.8393
9	829.3235	724.6616	744.3979	876.4468	1020.2026	738.9033	735.0063	724.6616	215.8164
10	855.4890	737.7444	759.9480	912.6511	1080.3301	753.7664	749.3821	737.7444	242.7934
11	881.6545	750.8271	775.4978	949.7632	1142.7180	768.6294	763.7581	750.8271	269.7703
12	907.8201	763.9099	791.0476	987.8064	1207.3459	783.4924	778.1340	763.9099	296.7476
13	933.9854	776.9927	806.5977	1026.7563	1274.1807	798.3555	792.5098	776.9927	323.7246
14	1090.9783	855.4890	899.8965	1278.7136	1718.2520	887.5332	878.7646	855.4890	485.5869

POWER REACTIVITIES WITH CONSTANT COOLANT TEMPERATURES (CENT)

N	ROQ1A	ROQ1C	ROQ1D	ROQ2	ROQ3	ROQ4A	ROQ4B	ROQ4	ROQ9	ROQ
2	-2.1637E-01	8.9282E-02	0.0	0.0	0.0	8.9282E-02	0.0	8.9282E-02	0.0	-3.7808E-02
3	-1.7633E+00	8.0303E-01	0.0	0.0	0.0	8.0303E-01	0.0	8.0303E-01	0.0	-1.5725E-01
4	-3.7283E+00	1.6954E+00	0.0	0.0	0.0	1.6954E+00	0.0	1.6954E+00	0.0	-3.3762E-01
5	-5.7908E+00	2.5875E+00	0.0	0.0	0.0	2.5875E+00	0.0	2.5875E+00	0.0	-6.1581E-01
6	-7.9648E+00	3.4798E+00	0.0	0.0	0.0	3.4798E+00	0.0	3.4798E+00	0.0	-1.0052E+00
7	-1.0245E+01	4.3720E+00	0.0	0.0	0.0	4.3720E+00	0.0	4.3720E+00	0.0	-1.5015E+00
8	-1.5132E+01	6.1564E+00	0.0	0.0	0.0	6.1564E+00	0.0	6.1564E+00	0.0	-2.8188E+00
9	-1.7740E+01	7.0487E+00	0.0	0.0	0.0	7.0487E+00	0.0	7.0487E+00	0.0	-3.6420E+00
10	-2.0457E+01	7.9409E+00	0.0	0.0	0.0	7.9409E+00	0.0	7.9409E+00	0.0	-4.5750E+00
11	-2.3281E+01	8.8332E+00	0.0	0.0	0.0	8.8332E+00	0.0	8.8332E+00	0.0	-5.6148E+00
12	-2.6216E+01	9.7255E+00	0.0	0.0	0.0	9.7255E+00	0.0	9.7255E+00	0.0	-6.7645E+00
13	-2.9257E+01	1.0618E+01	0.0	0.0	0.0	1.0618E+01	0.0	1.0618E+01	0.0	-8.0215E+00
14	-4.9659E+01	1.5971E+01	0.0	0.0	0.0	1.5971E+01	0.0	1.5971E+01	0.0	-1.7717E+01

REACTIVITY POWER FEEDBACKS THROUGH THE COOLANT TEMPERATURE(CENT)

N	ROS1	ROS2	ROS3	ROS4	ROS7	ROS
2	8.645566E-01	0.0	0.0	1.386380E-01	0.0	1.003194E+00
3	7.780693E+00	0.0	0.0	1.247741E+00	0.0	9.028434E+00
4	1.642577E+01	0.0	0.0	2.634309E+00	0.0	1.906007E+01
5	2.507086E+01	0.0	0.0	4.020877E+00	0.0	2.909174E+01
6	3.371579E+01	0.0	0.0	5.407444E+00	0.0	3.912323E+01
7	4.236087E+01	0.0	0.0	6.794012E+00	0.0	4.915488E+01
8	5.965106E+01	0.0	0.0	9.566959E+00	0.0	6.921802E+01
9	6.829614E+01	0.0	0.0	1.095353E+01	0.0	7.924966E+01
10	7.694124E+01	0.0	0.0	1.234010E+01	0.0	8.928133E+01
11	8.558633E+01	0.0	0.0	1.372666E+01	0.0	9.931299E+01
12	9.423141E+01	0.0	0.0	1.511323E+01	0.0	1.093446E+02
13	1.028765E+02	0.0	0.0	1.649960E+01	0.0	1.193761E+02
14	1.547469E+02	0.0	0.0	2.481882E+01	0.0	1.795657E+02

COOLANT FLOW REACTIVITIES (CENT)

N	ROM1	ROM2	ROM3	ROM4	ROM7	ROM
2	-8.645566E-01	0.0	0.0	-1.386380E-01	0.0	-1.003194E+00
3	-7.780693E+00	0.0	0.0	-1.247741E+00	0.0	-9.028434E+00
4	-1.642577E+01	0.0	0.0	-2.634309E+00	0.0	-1.906007E+01
5	-2.507086E+01	0.0	0.0	-4.020877E+00	0.0	-2.909174E+01
6	-3.371579E+01	0.0	0.0	-5.407444E+00	0.0	-3.912323E+01
7	-4.236087E+01	0.0	0.0	-6.794012E+00	0.0	-4.915488E+01
8	-5.965106E+01	0.0	0.0	-9.566959E+00	0.0	-6.921802E+01
9	-6.829614E+01	0.0	0.0	-1.095353E+01	0.0	-7.924966E+01
10	-7.694124E+01	0.0	0.0	-1.234010E+01	0.0	-8.928133E+01
11	-8.558633E+01	0.0	0.0	-1.372666E+01	0.0	-9.931299E+01
12	-9.423141E+01	0.0	0.0	-1.511323E+01	0.0	-1.093446E+02
13	-1.028765E+02	0.0	0.0	-1.649960E+01	0.0	-1.193761E+02
14	-1.547469E+02	0.0	0.0	-2.481882E+01	0.0	-1.795657E+02

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CALCULATED CONSTANTS

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9. ZONE 6: UPPER PLENUM

COOLANT TEMPERATURE (K)	TETA60= 1060.501

REACTOR TOTAL POWER (WATT)	PO= 9.000000E+07

1. TOTAL PERCENTAGE OF POWER, OUTLET TEMPERATURE AND COOLANT FLOW

CORE	ALFA1= 0.98900
LOWER REFLECTOR	ALFA2= 0.0
UPPER REFLECTOR	ALFA3= 0.0
RADIAL BLANKET	ALFA4= 0.01100
RADIAL REFLECTOR	ALFA9= 0.0
TOTAL PERCENTAGE	ALFA= 1.00000
COOLANT FLOW (CM**3/SEC)	NUO= 1.890000E+05

2. CORE

TOTAL FUEL VOLUME (CM**3)	VOL= 1.812651E+05

A. TEMPERATURES AND HEAT TRANSFER NUMBERS

OUTLET COOLANT TEMPERATURE	TET130= 1090.978
AVERAGE COOLANT TEMPERATURE	TETA10= 855.489
PECLET NUMPER	PE= 118.11288
NUSSELT NUMBER	NU= 5.79949
AVERAGE CLADDING TEMPERATURE	T1BO= 887.53320
FUEL POWER DENSITY (WATT/CM**3)	PD10= 485.5869
FUEL GAP COEFFICIENT (WATT/CM**2 K)	50.00000
FUEL TO CLADDING HEATTRANSFER COEFFICIENT (WATT/CM**2 K)	H1AB= 8.54261
FUEL SURFACE TEMPERATURE	T1ASO= 899.89648
	PHI1A= 0.001740
AVERAGE FUEL TEMPERATURE	T1AMO= 1278.71362
AVERAGE FIRST STRUCTURE MATERIAL TEMPERATURE	T1CO= 878.76465
AVERAGE SECOND STRUCTURE MATERIAL TEMPERATURE	T1DC= 855.48901
CENTRAL FUEL TEMPERATURE	T1ACO= 1718.252

B. THERMAL CONSTANTS

FUEL SPECIFIC THERMAL CAPACITY (WATT SEC/G K)	CHI1A= 0.3297881

FUEL NON LINEAR GLOBAL COEFFICIENTS

SURFACE TEMPERATURE	K1AST= 1.000000E+00	K1ASP= 1.000000E+00
AVERAGE TEMPERATURE	K1AMT= 1.000000E+00	K1AMP= 1.000000E+00
	K1AMTS= 1.000000E+00	K1AMPS= 1.000000E+00

NON LINEAR CORRECTION COEFFICIENTS FOR CLADDING TEMPERATURE CHANGE

AVERAGE TEMPERATURE	ALFAM= 1.0000
LINEAR AVERAGE TEMPERATURE	ALFAL= 1.0000

GAP COEFFICIENTS:

	EPSILON= 0.0
	ETA= 0.0

GAMMA= 0.004080
A= 2.591884

C. TIME CONSTANTS AND DELAYS

FUEL RADIAL TIME SCALE (SEC)	T1A= 21.573807
CLADDING TIME CONSTANT (SEC)	T1B= 0.006601
AXIAL TIME DELAY (SEC)	T1AX= 1.255783

D. MATERIAL THERMAL CAPACITIES TO COOLANT THERMAL CAPACITY RATIO

FUEL	M1A= 2.321665
FIRST STRUCTURE MATERIAL	M1C= 3.692332
SECOND STRUCTURE MATERIAL	M1D= 0.0

E. REACTIVITY CORRECTION COEFFICIENTS

B1A= 1.00000

3. LOWER AXIAL BLANKET

A. TEMPERATURES

OUTLET COOLANT TEMPERATURE	TETA210= 620.000
AVERAGE COOLANT TEMPERATURE	TETA20= 620.000
AVERAGE BLANKET TEMPERATURE	T2A0= 620.000

B. TIME CONSTANTS AND DELAYS

AXIAL TIME DELAY — T2AX= 0.0

C. MATERIALS THERMAL CAPACITIES TO COOLANT THERMAL CAPACITY RATIO

BLANKET TO COOLANT — M2A= 0.0

4. UPPER AXIAL BLANKET

A. TEMPERATURES

OUTLET COOLANT TEMPERATURE	TETA360=1090.979
AVERAGE COOLANT TEMPERATURE	TETA30= 1090.978
AVERAGE BLANKET TEMPERATURE	T3A0= 1090.978

B. TIME CONSTANTS AND DELAYS

AXIAL TIME DELAY — T3AX= 0.0

C. MATERIALS THERMAL CAPACITIES TO COOLANT THERMAL CAPACITY RATIO

BLANKET — M3A= 0.0

5. RADIAL BLANKET

A. TEMPERATURES

OUTLET COOLANT TEMPERATURE	TETA460= 684.607
AVERAGE COOLANT TEMPERATURE	TETA40= 652.303
AVERAGE BLANKET TEMPERATURE	T4A0= 675.579
AVERAGE STRUCTURE MATERIAL TEMPERATURE	T4B0= 652.303

B. TIME CONSTANTS AND DELAYS

AXIAL TIME DELAY — T4AX= 16.348

C. MATERIAL THERMAL CAPACITIES TO COOLANT THERMAL CAPACITY RATIO

BLANKET	M4A=	3.580629
STRUCTURE MATERIAL	M4B=	0.0

6. LOWER AND LATERAL PLENUM

TIME DELAY	T85=	0.33750

7. STATIC SODIUM BETWEEN CORE AND SHROUD

	ALFA87=	1.000000

8. RADIAL REFLECTOR

A. TEMPERATURES

AVERAGE REFLECTOR TEMPERATURE	T9A0=	635.5171

1. KINETIC TRANSFER FUNCTION

OMEGA	K RE	K IM	K MOD	K PHASE
1.000000E-02	2.716958E-02	-8.332497E-02	8.764261E-02	-7.194046E+01
3.920000E-01	1.220662E-02	-5.574480E-03	1.341925E-02	-2.454507E+01
7.850000E-01	1.120181E-02	-3.358724E-03	1.169451E-02	-1.669069E+01
1.130000E+00	1.083793E-02	-2.598708E-03	1.114513E-02	-1.348376E+01
1.570000E+00	1.057460E-02	-2.058877E-03	1.077317E-02	-1.101766E+01
2.450000E+00	1.031556E-02	-1.498646E-03	1.042385E-02	-8.266106E+00
3.730000E+00	1.015747E-02	-1.123827E-03	1.021945E-02	-6.313549E+00
5.000000E+00	1.008526E-02	-9.411434E-04	1.012908E-02	-5.331324E+00
6.160000E+00	1.004836E-02	-8.481096E-04	1.008409E-02	-4.824487E+00
7.410000E+00	1.002327E-02	-7.908624E-04	1.005442E-02	-4.511438E+00
9.220000E+00	1.000017E-02	-7.534048E-04	1.002850E-02	-4.308475E+00
1.767999E+01	9.944785E-03	-8.422092E-04	9.980384E-03	-4.840738E+00

2. THERMODYNAMIC BASIC FUNCTIONS

CORE

OMEGA	Z RE	Z IM	Z MOD	Z PHASE
1.000000E-02	1.249855E-01	-4.636378E+00	4.638062E+00	-8.845575E+01
3.920000E-01	1.073663E-01	-1.524128E-01	1.864328E-01	-5.483743E+01
7.850000E-01	8.363760E-02	-1.016123E-01	1.316066E-01	-5.054198E+01
1.130000E+00	7.035488E-02	-8.287919E-02	1.087142E-01	-4.967255E+01
1.570000E+00	5.990732E-02	-6.881225E-02	9.123600E-02	-4.895743E+01
2.450000E+00	4.820577E-02	-5.369274E-02	7.215750E-02	-4.808223E+01
3.730000E+00	3.919769E-02	-4.269908E-02	5.796266E-02	-4.744807E+01
5.000000E+00	3.390554E-02	-3.647555E-02	4.980012E-02	-4.709125E+01
6.160000E+00	3.057114E-02	-3.263582E-02	4.471791E-02	-4.687090E+01
7.410000E+00	2.788950E-02	-2.959173E-02	4.066319E-02	-4.669621E+01
9.220000E+00	2.501610E-02	-2.637215E-02	3.634962E-02	-4.651157E+01
1.767999E+01	1.808388E-02	-1.877619E-02	2.606860E-02	-4.607599E+01

OMEGA	GS RE	GS IM	GS MOD	GS PHASE	GL RE	GL IM	GL MOD	GL PHASE
1.000000E-02	9.999752E-01	-8.792139E-04	9.999756E-01	-5.037647E-02	9.985881E-01	-3.678270E-02	9.992653E-01	-2.109519E+00
3.920000E-01	9.872472E-01	-1.744107E-02	9.874012E-01	-1.012102E+00	3.284641E-01	-4.363586E-01	5.461661E-01	-5.302977E+01
7.850000E-01	9.801407E-01	-2.300471E-02	9.804106E-01	-1.344532E+00	1.385178E-01	-2.675794E-01	3.013069E-01	-6.263069E+01
1.130000E+00	9.755304E-01	-2.724598E-02	9.759108E-01	-1.599820E+00	1.040823E-01	-1.892723E-01	2.160026E-01	-6.119324E+01
1.570000E+00	9.704359E-01	-3.179373E-02	9.709566E-01	-1.876471E+00	9.259641E-02	-1.404256E-01	1.682066E-01	-5.659918E+01
2.450000E+00	9.620231E-01	-3.899877E-02	9.628132E-01	-2.321401E+00	8.352774E-02	-1.035075E-01	1.330063E-01	-5.109738E+01
3.730000E+00	9.522331E-01	-4.712868E-02	9.533986E-01	-2.833416E+00	7.036740E-02	-8.410984E-02	1.096632E-01	-5.008368E+01
5.000000E+00	9.441240E-01	-5.365548E-02	9.456474E-01	-3.252675E+00	5.999807E-02	-7.258350E-02	9.417075E-02	-5.042258E+01
6.160000E+00	9.376106E-01	-5.876156E-02	9.394501E-01	-3.586122E+00	5.332992E-02	-6.434804E-02	8.357477E-02	-5.034894E+01
7.410000E+00	9.312747E-01	-6.361490E-02	9.334448E-01	-3.907772E+00	4.647949E-02	-5.807227E-02	7.438231E-02	-5.132712E+01
9.220000E+00	9.230260E-01	-6.976891E-02	9.256590E-01	-4.322604E+00	4.264186E-02	-5.208503E-02	6.731403E-02	-5.069289E+01
1.767999E+01	8.928408E-01	-9.078228E-02	8.974442E-01	-5.805766E+00	2.896030E-02	-3.677581E-02	4.680981E-02	-5.178015E+01

4. RADIAL BLANKET

OMEGA	Q RE	Q IM	Q MOD	Q PHASE
1.000000E-02	-1.812180E+01	-2.358905E+00	1.827467E+01	-1.725835E+02
3.920000E-01	-1.480093E+01	1.635793E+01	2.206012E+01	1.321393E+02
7.850000E-01	-5.785635E+00	1.171456E+01	1.306539E+01	1.162841E+02

1.130000E+00	-3.440557E+00	8.984719E+00	9.620946E+00	1.109536E+02
1.570000E+00	-2.144236E+00	6.919024E+00	7.243661E+00	1.072185E+02
2.450000E+00	-1.115860E+00	4.754242E+00	4.883436E+00	1.032087E+02
3.730000E+00	-5.923874E-01	3.277731E+00	3.330832E+00	1.002446E+02
5.000000E+00	-3.773488E-01	2.509936E+00	2.538143E+00	9.855000E+01
6.160000E+00	-2.722964E-01	2.069112E+00	2.086952E+00	9.749712E+01
7.410000E+00	-2.031848E-01	1.740576E+00	1.752395E+00	9.665831E+01
9.220000E+00	-1.429997E-01	1.415773E+00	1.422976E+00	9.576765E+01
1.767999E+01	-4.854058E-02	7.570887E-01	7.586432E-01	9.366855E+01

REACTIVITY POWER FEEDBACKS THROUGH THE COOLANT TEMPERATURES

OMEGA	S RE	S IM	S MOD	S PHASE
1.000000E-02	1.713800E+02	-4.103394E+01	1.762239E+02	-1.346499E+01
3.920000E-01	-4.378776E+00	-9.839954E+00	1.077025E+01	-1.139891E+02
7.850000E-01	-7.823556E-01	-4.355941E+00	4.425640E+00	-1.001822E+02
1.130000E+00	-3.521948E-01	-3.234344E+00	3.253464E+00	-9.621461E+01
1.570000E+00	-3.506147E-01	-2.478439E+00	2.503117E+00	-9.805200E+01
2.450000E+00	-4.708310E-01	-1.558406E+00	1.627977E+00	-1.068108E+02
3.730000E+00	-4.184262E-01	-8.597825E-01	9.561937E-01	-1.159506E+02
5.000000E+00	-3.197710E-01	-5.595396E-01	6.444672E-01	-1.197476E+02
6.160000E+00	-2.677176E-01	-4.156593E-01	4.944142E-01	-1.227848E+02
7.410000E+00	-2.300390E-01	-3.099548E-01	3.859921E-01	-1.265817E+02
9.220000E+00	-1.822214E-01	-2.130617E-01	2.803567E-01	-1.305388E+02
1.767999E+01	-8.327585E-02	-6.505674E-02	1.056752E-01	-1.420023E+02

REACTIVITY COOLANT FLOW FUNCTIONS

OMEGA	M RE	M IM	M MOD	M PHASE
1.000000E-02	-1.738817E+02	3.352805E+01	1.770846E+02	1.690861E+02
3.920000E-01	-4.652365E+00	1.828368E+01	1.886629E+01	1.042763E+02
7.850000E-01	-5.989579E+00	9.261057E+00	1.102915E+01	1.228927E+02
1.130000E+00	-6.094783E+00	7.563745E+00	9.713734E+00	1.288615E+02
1.570000E+00	-5.562414E+00	6.867417E+00	8.837525E+00	1.290065E+02
2.450000E+00	-3.976521E+00	6.117990E+00	7.296746E+00	1.230227E+02
3.730000E+00	-2.424300E+00	4.856554E+00	5.428014E+00	1.165275E+02
5.000000E+00	-1.809649E+00	3.941453E+00	4.337035E+00	1.146614E+02
6.160000E+00	-1.477831E+00	3.464755E+00	3.766764E+00	1.130999E+02
7.410000E+00	-1.162864E+00	3.078405E+00	3.290719E+00	1.106940E+02
9.220000E+00	-8.679831E-01	2.598028E+00	2.739187E+00	1.084742E+02
1.767999E+01	-3.568563E-01	1.544548E+00	1.585237E+00	1.030095E+02

REACTIVITY INLET TEMPERATURE FUNCTIONS

OMEGA	R RE	R IM	R MOD	R PHASE
1.000000E-02	1.272811E+00	-4.681537E-01	1.356176E+00	-2.019406E+01
3.920000E-01	-3.668328E-02	-6.892115E-02	7.807547E-02	-1.180242E+02
7.850000E-01	-2.130070E-02	-2.661473E-02	3.408905E-02	-1.286715E+02

1.130000E+00	-1.831796E-02	-1.417936E-02	2.316467E-02	-1.422576E+02
1.570000E+00	-1.469467E-02	-4.761774E-03	1.544693E-02	-1.620452E+02
2.450000E+00	-6.881461E-03	2.071394E-03	7.186458E-03	1.632476E+02
3.730000E+00	-2.183531E-03	1.951294E-03	2.928371E-03	1.382147E+02
5.000000E+00	-9.157758E-04	1.839580E-03	2.054921E-03	1.164650E+02
6.160000E+00	1.291368E-04	1.524315E-03	1.529775E-03	8.515753E+01
7.410000E+00	5.771518E-04	8.276694E-04	1.009029E-03	5.511107E+01
9.220000E+00	6.114221E-04	2.707830E-04	6.687006E-04	2.388730E+01
1.767999E+01	-1.721321E-04	-1.031188E-04	2.006563E-04	-1.490755E+02

CLOSED LOOPS TRANSFER FUNCTIONS

OMEGA	GO RE	GO IM	GO MOD	GO PHASE	GP RE	GP IM	GP MOD	GP PHASE
1.000000E-02	3.365656E-02	-2.052246E-02	3.941998E-02	-3.137320E+01	-5.904187E-03	-2.138962E-03	6.279696E-03	-1.600856E+02
3.920000E-01	1.174162E-02	-2.075485E-03	1.192364E-02	-1.002423E+01	1.065725E-02	-2.994801E-03	1.107004E-02	-1.569593E+01
7.850000E-01	1.116390E-02	-1.635174E-03	1.128301E-02	-8.332850E+00	1.089095E-02	-2.117287E-03	1.109485E-02	-1.100152E+01
1.130000E+00	1.083851E-02	-1.426510E-03	1.093198E-02	-7.497884E+00	1.068688E-02	-1.780762E-03	1.083423E-02	-9.460313E+00
1.570000E+00	1.058066E-02	-1.227676E-03	1.065164E-02	-6.618443E+00	1.047159E-02	-1.487726E-03	1.057674E-02	-8.086045E+00
2.450000E+00	1.031955E-02	-9.710328E-04	1.036514E-02	-5.375495E+00	1.023676E-02	-1.123819E-03	1.029826E-02	-6.264994E+00
3.730000E+00	1.016015E-02	-7.769843E-04	1.018982E-02	-4.373103E+00	1.010323E-02	-8.577364E-04	1.013958E-02	-4.852613E+00
5.000000E+00	1.008820E-02	-6.812122E-04	1.011117E-02	-3.863066E+00	1.004797E-02	-7.330969E-04	1.007468E-02	-4.172886E+00
6.160000E+00	1.005188E-02	-6.361743E-04	1.007199E-02	-3.621362E+00	1.001955E-02	-6.743376E-04	1.004222E-02	-3.850321E+00
7.410000E+00	1.002746E-02	-6.139041E-04	1.004624E-02	-3.503404E+00	1.000060E-02	-6.419716E-04	1.002118E-02	-3.672964E+00
9.220000E+00	1.000524E-02	-6.104510E-04	1.002384E-02	-3.491467E+00	9.984463E-03	-6.293955E-04	1.000428E-02	-3.607005E+00
1.767999E+01	9.952128E-03	-7.669905E-04	9.981640E-03	-4.406957E+00	9.942945E-03	-7.721148E-04	9.972878E-03	-4.440363E+00

OMEGA	GMU RE	GMU IM	GMU MOD	GMU PHASE	GTET RE	GTET IM	GTET MOD	GTET PHASE
1.000000E-02	1.098344E+00	1.739703E-01	1.112036E+00	9.000494E+00	-8.516274E-03	4.157308E-05	8.516375E-03	1.797203E+02
3.920000E-01	5.174570E-03	2.087865E-01	2.088506E-01	8.858022E+01	-5.973477E-04	-6.246504E-04	8.642988E-04	-1.337201E+02
7.850000E-01	-4.562385E-02	1.135433E-01	1.223667E-01	1.118913E+02	-2.883356E-04	-2.447597E-04	3.782124E-04	-1.396730E+02
1.130000E+00	-5.166494E-02	9.168619E-02	1.052408E-01	1.194012E+02	-2.210119E-04	-1.189132E-04	2.509714E-04	-1.517179E+02
1.570000E+00	-4.803047E-02	8.018804E-02	9.347212E-02	1.209205E+02	-1.609607E-04	-2.800168E-05	1.633782E-04	-1.701313E+02
2.450000E+00	-3.383118E-02	6.709719E-02	7.514369E-02	1.167578E+02	-6.811596E-05	2.893787E-05	7.400800E-05	1.569826E+02
3.730000E+00	-2.032763E-02	5.114631E-02	5.503777E-02	1.116749E+02	-2.038701E-05	2.158726E-05	2.969241E-05	1.333621E+02
5.000000E+00	-1.529383E-02	4.093026E-02	4.369424E-02	1.104885E+02	-7.853098E-06	1.915538E-05	2.070265E-05	1.122921E+02
6.160000E+00	-1.247079E-02	3.571185E-02	3.782666E-02	1.092495E+02	2.321795E-06	1.518587E-05	1.536233E-05	8.130722E+01
7.410000E+00	-9.653080E-03	3.153241E-02	3.297688E-02	1.070211E+02	6.303202E-06	7.906673E-06	1.011167E-05	5.143811E+01
9.220000E+00	-7.031154E-03	2.648622E-02	2.740359E-02	1.048672E+02	6.275151E-06	2.318796E-06	6.689866E-06	2.028029E+01
1.767999E+01	-2.355634E-03	1.563289E-02	1.580936E-02	9.856918E+01	-1.791119E-06	-8.923986E-07	2.001120E-06	-1.535159E+02

PROGRAM LIST

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MAIN
 REAL*4 BETA(6,5),AI(6,5),DRUCK(20),REACT(20)
 REAL*8 SEP/'--------'/
 REAL*8 NISOT(6)
 REAL*4    LAMBDA(6,5),N1,L,L1,M1A, LAM1B,M1C,M1D,LAME,NU1,NU2,NU3,
1L2,M2A,L3,M3A,L4,N4,M4A,NUMAX,NUO,NU,M4B,K1AST,K1ASP,K1AMP,K1AMT,
2K1AMPS,MP1A,MP1C,MP1D,MP3A,MP4A,MP4B,MP2A,K1ALT,K1AMTS
 COMPLEX COM,K(50),SIGMA,AR, ZSIGMA(50),GS(50),FS(50),H(2)
 REAL*4 OM(50),FELD(100,86),FNAM(86),BFELD(100,13),BNAM(14)
 COMPLEX FM(50),GL(50),FL(50),G1AL(50),F1AL(50),G1AS(50),F1AS(50),
1G1B(50),F1B(50),G1AM(50),F1AM(50),GPAM(50),FPAM(50),G1C(50),
2G1D(50),Y1B(50),Y1C(50),Y1D(50),Y1(50),F1(50),
3W13(50),U13(50),V13(50),U1(50),V1(50),G2A(50),Y2(50),W21(50),
4U21(50),V21(50),U2(50),V2(50),G3A(50),Y3(50),W36(50),U36(50),
5V31(50),U3(50),V3(50)
6,Q(50),S(50),M(50),R(50),G0(50),GP(50),GMU(50),GTET(50)
7 ,QK(50),SK(50),QSK(50)
 EQUIVALENCE (BFELD(1,1),GS(1)),(BFELD(1,2),GL(1)),(BFELD(1,3),Q(1)
1),(BFELD(1,4),S(1)),(BFELD(1,5),M(1)),(BFELD(1,6),R(1)),
2(BFELD(1,7),G0(1)),(BFELD(1,8),GP(1)),(BFELD(1,9),GMU(1)),
3(BFELD(1,10),GTET(1)),(BFELD(1,11),QK(1)),(BFELD(1,12),SK(1)),
4(BFELD(1,13),QSK(1))
 COMPLEX G4A(50),G4B(50),F4(50),Y4A(50),Y4B(50),Y4(50),W46(50),
1U46(50),V46(50),U4(50),V4(50),G17(50),G87(50),W5(50),G5A(50),
2F9A(50),Q1(50),Q2(50),Q3(50),Q4(50),Q9(50),D1(50),D2(50),D3(50),
3D4(50),D5(50),D17(50),D87(50),D1P(50),D1BOF(50),D1BOG(50),
4ES1(50),ES2(50),ES3(50),ES4(50),ES7(50),EM1(50),EM2(50),EM3(50),
5EM4(50),EM7(50),R1(50),R2(50),R3(50),R4(50),R5(50),R7(50)
 EQUIVALENCE (FELD(1,1),FS(1)),(FELD(1,2),FM(1)),(FELD(1,3),FL(1)),
1(FELD(1,4),G1AL(1)),(FELD(1,5),F1AL(1)),(FELD(1,6),G1AS(1)),
2(FELD(1,7),F1AS(1)),(FELD(1,8),G1B(1)),(FELD(1,9),F1B(1)),
3(FELD(1,10),G1AM(1)),(FELD(1,11),F1AM(1)),(FELD(1,12),GPAM(1)),
4(FELD(1,13),FPAM(1)),(FELD(1,14),Y1B(1)),(FELD(1,15),Y1(1)),
5(FELD(1,16),F1(1)),(FELD(1,17),G1C(1)),(FELD(1,18),G1D(1)),
6(FELD(1,19),Y1C(1)),(FELD(1,20),Y1D(1)),(FELD(1,21),W13(1)),
7(FELD(1,22),U13(1)),(FELD(1,23),V13(1)),(FELD(1,24),U1(1)),
8(FELD(1,25),V1(1)),(FELD(1,26),G2A(1)),(FELD(1,27),Y2(1)),
9(FELD(1,28),W21(1)),(FELD(1,29),U21(1)),(FELD(1,30),V21(1)),
1(FELD(1,31),U2(1)),(FELD(1,32),V2(1)),(FELD(1,33),G3A(1)),
2(FELD(1,34),Y3(1)),(FELD(1,35),W36(1)),(FELD(1,36),U36(1)),
3(FELD(1,37),V31(1)),(FELD(1,38),U3(1)),(FELD(1,39),V3(1))
 EQUIVALENCE (FELD(1,40),G4A(1)),(FELD(1,41),G4B(1)),
1(FELD(1,42),F4(1)),(FELD(1,43),Y4A(1)),(FELD(1,44),Y4B(1))
2,(FELD(1,45),Y4(1)),(FELD(1,46),W46(1)),(FELD(1,47),U46(1))
3,(FELD(1,48),V46(1)),(FELD(1,49),U4(1)),(FELD(1,50),V4(1))
4,(FELD(1,51),G17(1)),(FELD(1,52),G87(1)),(FELD(1,53),W5(1))
5,(FELD(1,54),G5A(1)),(FELD(1,55),F9A(1)),(FELD(1,56),Q1(1))
6,(FELD(1,57),Q2(1)),(FELD(1,58),Q3(1)),(FELD(1,59),Q4(1))
7,(FELD(1,60),Q9(1)),(FELD(1,61),D1(1)),(FELD(1,62),D1P(1))
8,(FELD(1,63),D2(1)),(FELD(1,64),D3(1)),(FELD(1,65),D4(1))
9,(FELD(1,66),D5 (1)),(FELD(1,67),D17(1)),(FELD(1,68),D87(1))
1,(FELD(1,69),D1BOF(1)),(FELD(1,70),D1BOG(1))
1,(FELD(1,71),ES1(1)),(FELD(1,72),ES2(1)),(FELD(1,73),ES3(1))
2,(FELD(1,74),ES4(1)),(FELD(1,75),ES7(1)),(FELD(1,76),EM1(1))
3,(FELD(1,77),EM2(1)),(FELD(1,78),EM3(1)),(FELD(1,79),EM4(1))
4,(FELD(1,80),EM7(1)),(FELD(1,81),R1(1)),(FELD(1,82),R2(1))
5,(FELD(1,83),R3(1)),(FELD(1,84),R4(1)),(FELD(1,85),R5(1))
6,(FELD(1,86),R7(1))
 COMPLEX Q1A,Q1C,Q1D,Q4A,Q4B
 COMMON FELD
 COMMON /INKO/IN,NOU,L1,N1,S1,DEL1,R1BI,R1BE,M1A,CH1,
1CH2,CH3,TA,C,A0,A1,A2,A3,B1,ALF1A,RO1B,CH1B,LAM1B,M1C,CH1C,
2TAU1C,ALF1C,T1COM,M1D,CH1D,TAU1D,ALF1D,T1DOM,ROE,CHE,LAME,
3NU1,NU2,NU3,C1A,C1B,C1E,C1C,C1D,B1A,B1B,B1C,B1D,B1E,C1F,C1G,
4L2,M2A,CH2A,TAU2A,C2A,C2E,ALF2A,T2AM,L3,M3A,CH3A,TAU3A,C3A,C3E,
5ALF3A,T3AM,L4,N4,S4,M4A,CH4A,TAU4A,C4A,ALF4A,T4AM,M4B,CH4B,
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6TAU4B,C4B,ALF4B,T4BM,C4E,T85M,TAU85,TAU5A,C8E,C5E,C5A,C7E,
7ALF17,TAU17,TAU87,T9AM,TAU9A,C9A,ALF9A,PMAX,TET60,P0,NUMAX
8,TET80,TET90,NPAR,CKIAMT
 COMMON /BERCO/  ALF1,ALFA,ALF4,TET360,NUO,VOL,MP2A,
1TET210,TET20,T2A0,T2AX,TET130,TET10,PE,NU,T1B0,PD1C,PD2,H1A,
2H1AB,T1ASO,PHI1A,T1AMO,T1CO,T1DO,T1ACC,CH1A,K1AST,K1ASP,K1AMP,
3K1AMT,K1AMPS,K1AMTS,A,ALFAM,ALFAL,GAMMA,GA6,EPS,ETA,ALFE,
4T1A,T1B,T1AX,MP1A,MP1C,MP1D,B1ACOR,TET30,T3A0,T3AX,MP3A,TET460,
5TET40,T4A0,T4B0,T4AX,MP4A,MP4B,T85,ALF87,T9A0
 DATA BNAM/'  GS','  GL','   Q','   S','   M','   R','  G0',
1'  GP',' GMU','GTET','  QK','  SK','KQ+S','    '/,BB/'   D'/
 DATA FNAM/'  FS','  FM','  FL','G1AL','F1AL','G1AS','F1AS',' G1B',
1' F1B','G1AM','F1AM','GPAM','FPAM',' Y1B','  Y1','  F1',' G1C',
2' G1D',' Y1C',' Y1D',' W13',' U13',' V13','  U1','  V1',' G2A',
3'  Y2',' W21',' U21',' V21','  U2','  V2',' G3A','  Y3',' W36',
4' U36',' V31','  U3','  V3',' G4A',' G4B','  F4',' Y4A',' Y4B',
5'  Y4',' W46',' U46',' V46','  U4','  V4',' G17',' G87','  W5',
6' G5A',' F9A','  Q1','  Q2','  Q3','  Q4','  Q9','  D1',' D1P',
7'  D2','  D3','  D4','  D5',' D17',' D87','D1BF','D1BG',
8'  S1','  S2','  S3','  S4','  S7','  M1','  M2','  M3','  M4',
9'  M7','  R1','  R2','  R3','  R4','  R5','  R7'/
 DATA BASIC/'BASI'/,FKNA/'   K'/,ZNA/'   Z'/
 IN=5
 NOU=6
 NG=6
 BLANK=BNAM(14)
 NFEHL=0
100 FORMAT(8G10.4)
 READ(IN,312) REACT
312 FORMAT(20A4)
 CALL BILD(REACT)
 WRITE(NOU,313) SEP,SEP
 READ(IN,104) L,NI
104 FORMAT(G10.4,I5)
313 FORMAT('1',131('*')//50X,'INPUT DATA'/'0',131('*')///'0 1. NUCLEAR
  1 DATA'/' ',2A8)
 BET=0.
 DO 2 ISOT=1,NI
 READ(IN,102) NISOT(ISOT),(BETA(J,ISOT),LAMBDA(J,ISOT),J=1,NG)
102 FORMAT (A8/(8G10.4))
 DO 3 J=1,NG
  3 BET=BET+BETA(J,ISOT)
  2 CONTINUE
 DO 5 ISOT=1,NI
 DO 4 J=1,NG
  4 AI(J,ISOT)=BETA(J,ISOT)/BET
 WRITE(NOU,214)NISOT(ISOT),(J,BETA(J,ISOT),LAMBDA(J,ISOT),
  1 AI(J,ISOT),J=1,NG)
  5 CONTINUE
214 FORMAT('0ISOTOP  ',A8/'0GROUP      BETA        LAMBDA(1/SEC)      AI=
  1BETAI/BETA'//(I6,1P3E15.7))
 WRITE(NOU,314) L ,BET
314 FORMAT('0PROMPT NEUTRON LIFETIME L(SEC)=',1PE15.6/'0 BETA=',E15.6)
C   READ NPAR: NUMBER OF INPUT POWER VALUES FOR STEADY STATE
 READ(IN,101) NPAR
 DO 602 I=1,86
 DO 602 J=1,100
602 FELD(J,I)=0.
C   READ AND PRINT INPUT CONSTANTS
 READ(IN,100) L1,NI,S1,DEL1,R1BI,R1BE
 IF(L1.GT.400.) NFEHL=1
 IF(NFEHL.EQ.1) WRITE(NOU,400) NFEHL
400 FORMAT('0INPUT ERROR NR.',I5)
 N=IFIX(N1)
 WRITE(NOU,315) SEP,SEP,L1,N,S1
315 FORMAT('0 2. ZONE 1: CORE'/' ',2A8/'0 A. GEOMETRY'/'0LENGTH (CM) '
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 1,43X,'L1=',F10.5/' NUMBER OF FUEL PINS',36X,'N1=    ',I6/' COOLANT
 2CROSS SECTION ASSOCIATED TO A FUEL PIN (CM**2) S1=',F10.5)
  WRITE(NOU,316) DEL1,R1BI,R1BE
316 FORMAT(' COOLANT FLOW PERCENTAGE IN CORE',24X,'DELTA1=',F10.5/' IN
 1NER FUEL CLADDING RADIUS (CM)',24X,'R1BI=',F10.5/' OUTER FUEL CLAD
 2DING RADIUS (CM)',24X,'R1BE=',F10.5)
  READ(IN,100)M1A,CH1,CH2,CH3,TA,C
  IF(M1A.GT.1.E 07) NFEHL=2
  IF(NFEHL.EQ.2) WRITE(NOU,400) NFEHL
  READ(IN,100) A0,A1,A2,A3,B1,ALF1A,CKIAMT
  IF(A0.GT.1.) NFEHL=3
  IF(NFEHL.EQ.3) WRITE(NOU,400) NFEHL
  WRITE(NOU,318)M1A,CH1,CH2,CH3
318 FORMAT('0 B. FUEL'/'OTOTAL MASS OF FUEL (GR)',32X,'MA=',1PE15.6/'0
 1SPECIFIC HEAT CAPACITY COEFFICIENTS:'/'0CHI1 (WATT SEC / K G)    ='
 2,E17.6/' CHI2 (WATT SEC / K**2 G) =',E16.6/' CHI3 (WATT SEC K**3 /
 3 G) =',E16.6)
333 FORMAT('1',131('*')//45X,'CALCULATED CONSTANTS'/'0',131('*'))
  WRITE(NOU,319) TA,C,A0,A1,A2,A3,B1,ALF1A
319 FORMAT('0 THERMAL CONDUCTIVITY(WATT/CM K):'/' TA(K) =',1PE22.6/' C
 1(CM/WATT K) =',E15.6/'0FUEL/CLADDING HEAT TRANSFER COEFFICIENT:'/'
 2 A0(WATT/CM**2 K) =',E26.6/' A1(CM/K) =',E34.6/' A2(CM**4/WATT K)=
 3',E27.6/' A3(CM**7/WATT**2 K)=',E24.6/' B1(WATT/CM K) =',E29.6/'
 4 PERCENTAGE OF POWER ALFA1A =',E14.6)
  READ(IN,100) RO1B,CH1B,LAM1B
  IF(RO1B.GT.20.) NFEHL=4
  IF(NFEHL.EQ.4) WRITE(NOU,400) NFEHL
  WRITE(NOU,320) RO1B,CH1B,LAM1B
320 FORMAT('0 C. CLADDING'/'ODENSITY (GR/CM**3)',37X,'RO1B=',F10.5/' S
 2PECIFIC HEAT CAPACITY (WATT SEC/K GR)',17X,'CHI1B=',F10.5/' THERMA
 2L CONDUCTIVITY (WATT/CM K)',23X,'LAMBDA1B=',F10.5)
  READ(IN,100) M1C,CH1C,TAU1C,ALF1C,T1COM
  IF(M1C.GT.1.E 07) NFEHL=5
  IF(NFEHL.EQ.5) WRITE(NOU,400) NFEHL
  WRITE(NOU,321) M1C,CH1C,TAU1C,ALF1C,T1COM
321 FORMAT('0 D. CORE STRUCTURE 1ST MATERIAL'/'OTOTAL MASS (GR)',40X,'
 1M1C=',1PE14.6/' SPECIFIC HEAT CAPACITY (WATT SEC/K GR)',17X,'CHI1B
 2=',0P1F10.5/' TIME CONSTANT (SEC)',36X,'TAU1C=',F10.5/' PERCENTAGE
 3 OF POWER',36X,'ALFA1C=',F10.5/' (T1CO - TETA10)MAX=',35X,F10.5)
 32 READ(IN,100) M1D,CH1D,TAU1D,ALF1D,T1DOM
  READ(IN,100) TAU1F,TAU1G
  IF(M1D.GT.1.E 07) NFEHL=6
  IF(NFEHL.EQ.6) WRITE(NOU,400) NFEHL
  WRITE(NOU,322) M1D,CH1D,TAU1D,ALF1D,T1DOM,TAU1F,TAU1G
322 FORMAT('0 E. CORE STRUCTURE 2ND MATERIAL'/'OTOTAL MASS (GR)',40X,'
 2M1D=',1PE14.6/' SPECIFIC HEAT CAPACITY (WATT SEC/K GR)',17X,'CHI1D
 2=',0P1F10.5/' TIME CONSTANT (SEC)',36X,'TAU1D=',F10.5/' PERCENTAGE
 3 OF POWER',35X,'ALFA1D=',F10.5/' (T1DO - TETA10)MAX=',35X,F10.5/'0
 4 TIME CONSTANTS FOR BOWING EFFECTS:'/' CORE COOLANT INLET TEMPERAT
 5URE (SEC)',19X,'TAUF=',F10.5/' CORE COOLANT TEMPERATURE RISE (SEC)
 6',20X,'TAU1G=',F10.5)
 31 READ(IN,100) ROE,CHE,LAME,NU1,NU2,NU3
  IF(ROE.GT.5.) NFEHL=7
  IF(NFEHL.EQ.7) WRITE(NOU,400) NFEHL
  WRITE(NOU,323) ROE,CHE,LAME,NU1,NU2,NU3
323 FORMAT('0 F. COOLANT '/'ODENSITY (GR/CM**3)',37X,'ROE= ',F10.5/' S
 2PECIFIC HEAT CAPACITY (WATT SEC/K GR)',17X,'CHIE= ',F10.5/' THERMA
 2L CONDUCTIVITY (WATT/CM K)',23X,'LAMBDAE=',F10.5/' NUSSELT NUMBER
 3COEFFICIENTS:',27X,'NU1=',F10.5/' ',55X,'NU2=',F10.5/' ',55X,'NU3=
 4',F10.5)
  READ(IN,100) C1A,C1B,C1E,C1C,C1D,C1F,C1G
  IF(C1A.GT.5.) NFEHL=8
  IF(NFEHL.EQ.8) WRITE(NOU,400) NFEHL
  WRITE(NOU,324) C1A,C1B,C1E,C1C,C1D,C1F,C1G
324 FORMAT('0 G. REACTIVITY COEFFICIENTS:              '/'OFUEL (C/K)',45
 1X,'C1A=',1PE14.6/' CLADDING (C/K)',41X,'C1B=',E14.6/' COOLANT (C/K
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 2)',42X,'C1E=',E14.7/' STRUCTURE FIRST MATERIAL (C/K)',25X,'C1C=',E
 314.6/' STRUCTURE SECOND MATERIAL (C/K)',24X,'C1D=',E14.6/' BOWING
 4COEFFICIENT/CM COOLANT INLET TEMPERATURE (C/K)  C1F=',E14.6/' BOWI
 5NG COEFFICIENT/CM CORE COOLANT TEMPERATURE RISE(C/K) C1G=',E14.6)
  READ(IN,100) B1A,B1B,B1C,B1D,B1E
  IF(B1A.GT.1.) NFEHL=9
  IF(NFEHL.EQ.9) WRITE(NOU,400) NFEHL
  WRITE(NOU,325) B1A,B1B,B1E,B1C,B1D
325 FORMAT('0 H. REACTIVITY CORRECTION COEFFICIENTS:'/'OFUEL (C/K)',45
 1X,'B1A=',1PE14.6/' CLADDING (C/K)',41X,'B1B=',E14.6/' COOLANT (C/K
 2)',42X,'B1E=',E14.6/' STRUCTURE FIRST MATERIAL (C/K)',25X,'B1C=',E
 314.6/' STRUCTURE SECOND MATERIAL (C/K)',24X,'B1D=',E14.6)
  READ(IN,100) L2,M2A,CH2A,TAU2A,C2A,C2E,ALF2A,T2AM
  IF(L2.GT.100.) NFEHL=10
  IF(NFEHL.EQ.10)WRITE(NOU,400) NFEHL
  WRITE(NOU,326) SEP,SEP,SEP,SEP,L2,M2A,CH2A,TAU2A,C2A
326 FORMAT('0 3. ZONE 2: LOWER AXIAL BLANKET'/' ',4A8/'OLENGTH (CM)',4
 14X,'L2=',F10.5/' MASS (G)',47X,'M2A=',1PE14.6/' SPECIFIC HEAT CAPA
 2CITY (WATT SEC/G K)',18X,'CHI2A=',E14.6/' TIME CONSTANT (SEC)',36X
 3,'TAU2A=',E14.6/' BLANKET REACTIVITY COEFFICIENT (C/K)',19X,'C2A='
 4,E14.6)
  WRITE(NOU,327) C2E,ALF2A,T2AM
327 FORMAT(' COOLANT REACTIVITY COEFFICIENT (C/K)',19X,'C2E=',1PE14.6/
 1' PERCENTAGE OF POWER',36X,'ALFA2A=',E14.6/' MAXIMAL DIFFERENCE BE
 2TWEEN BLANKET AND COOLANT AVERAGE TEMPERATURE (K)',0PF10.5)
  READ(IN,100) L3,M3A,CH3A,TAU3A,C3A,C3E,ALF3A,T3AM
  WRITE(NOU,328) SEP,SEP,SEP,SEP,L3,M3A,CH3A,TAU3A,C3A
328 FORMAT('0 4. ZONE 3: UPPER AXIAL BLANKET'/' ',4A8/'OLENGTH (CM)',4
 14X,'L3=',F10.5/' MASS (G)',47X,'M3A=',1PE14.6/' SPECIFIC HEAT CAPA
 2CITY (WATT SEC/G K)',18X,'CHI3A=',E14.6/' TIME CONSTANT (SEC)',36X
 4,'TAU3A=',E14.6/' BLANKET REACTIVITY COEFFICIENT (C/K)',19X,'C3A='
 4,E14.6)
  WRITE(NOU,329) C3E,ALF3A,T3AM
329 FORMAT(' COOLANT REACTIVITY COEFFICIENT (C/K)',19X,'C3E=',1PE14.6/
 1' PERCENTAGE OF POWER',36X,'ALFA3A=',E14.6/' MAXIMAL DIFFERENCE BE
 2TWEEN BLANKET AND COOLANT AVERAGE TEMPERATURE (K)',0PF10.5)
  READ(IN,100) L4,N4,S4
  WRITE(NOU,330) SEP,SEP,SEP,L4,N4,S4
  IF(L4.LE.0) GO TO 33
  IF(L4.GT.400.) NFEHL=11
  IF(NFEHL.EQ.11)WRITE(NOU,400) NFEHL
  READ(IN,100) M4A,CH4A,TAU4A,C4A,ALF4A,T4AM
  WRITE(NOU,331) M4A,CH4A,TAU4A,C4A,ALF4A,T4AM
330 FORMAT('0 5. ZONE 4: RADIAL BLANKET'/' ',3A8/'0 A. GEOMETRY'/'OLEN
 1GTH (CM)',44X,'L4=',F10.4/' NUMBER OF PINS',41X,'N4=',F8.0/' COOLA
 2NT CROSS SECTION ASSOCIATED TO ONE PIN(CM**2)       S4=',F10.4)
331 FORMAT('0 B. BLANKET'/'OMASS (G)',47X,'M4A=',1PE14.6/' SPECIFIC HE
 1AT CAPACITY (WATT SEC/G K)',18X,'CHI4A=',0P1F10.5/' TIME CONSTANT
 2(SEC)',36X,'TAU4A=',F10.5/' BLANKET REACTIVITY COEFFICIENT (C/K)',
 319X,'C4A=',F12.5/' PERCENTAGE OF POWER',36X,'ALFA4A=',F9.5/' MAXIM
 4AL DIFFERENCE BETWEEN BLANKET AND COOLANT AVERAGE TEMPERATURE (K)=
 5',F8.5)
  READ(IN,100) M4B,CH4B,TAU4B,C4B,ALF4B,T4BM,C4E
  WRITE(NOU,3331) M4B,CH4B,TAU4B,C4B,ALF4B,T4BM,C4E
3331 FORMAT('0 C. STRUCTURE MATERIAL'/'OMASS (G)',47X,'M4B=',1PE14.6/'
 1SPECIFIC HEAT CAPACITY (WATT SEC/G K)',18X,'CHI4B=',0P1F10.5/' TIM
 2E CONSTANT (SEC)',36X,'TAU4B=',F10.5/' BLANKET REACTIVITY COEFFICI
 3ENT (C/K)',19X,'C4B=',F12.5/' PERCENTAGE OF POWER',36X,'ALFA4B=',F
 49.5/' MAXIMAL DIFFERENCE BETWEEN AVERAGE CORE STRUCTURE AND COOLAN
 5T TEMPERATURE (K)=',F8.5/'0 D. COOLANT'/'OREACTIVITY COEFFICIENT (
 6C/K)',33X,'C4E=',F12.5)
 33 READ(IN,100)T85M,TAU85,TAU5A,C8E,C5E,C5A,TET80
  IF(T85M.GT.20.) NFEHL=12
  IF(NFEHL.EQ.12)WRITE(NOU,400) NFEHL
  WRITE(NOU,303) SEP,SEP,SEP,SEP,SEP,T85M,TAU85,TAU5A,C8E
303 FORMAT('0 6. ZONE 5 AND 8: LOWER AND LATERAL PLENUMS'/' ',5A8/'OMA
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     1XIMAL TIME DELAY (SEC)',31X,'T85=',F10.5/' TIME CONSTANT FOR THE M
     2ATERIALS (SEC)',18X,'TAU85=',F9.4/' GRID PLATE TIME CONSTANT (SEC)
     3',25X,'TAU5A=',F10.5/' COOLANT REACTIVITY COEFFICIENT IN THE LATER
     4AL PLENUM (C/K) C8E=',F10.5)
      WRITE(NOU,334) C5E,C5A,TET80
  334 FORMAT(' COOLANT REACTIVITY COEFFICIENT IN LOWER PLENUM (C/K)   C5
     1E=',F10.5/' GRID PLATE REACTIVITY COEFFICIENT (C/K)',16X,'C5A=',F1
     20.5/' COOLANT TEMPERATURE IN THE LATERAL PLENUM (K)',10X,'TETA80='
     3,F8.2/'0 7. ZONE 7: STATIC SODIUM BETWEEN CORE AND SHROUD')
      READ(IN,100) C7E,ALF17,TAU17,TAU87
      IF(C7E.GT.0.1) NFEHL=13
      IF(NFEHL.EQ.13)WRITE(NOU,400) NFEHL
      WRITE(NOU,335) SEP,SEP,SEP,SEP,SEP,SEP,C7E,ALF17,TAU17,TAU87
  335 FORMAT(' ',6A8/'OSODIUM REACTIVITY COEFFICIENT(C/K)',21X,'C7E=',F9
     1.5/' DIFF STATIC NA AND LAT PLENUM TEMP/DIFF AV COOL CORE AND LAT
     2PLENUM TEMP ALFA17=',F10.5/' TIME CONSTANT FOR MATERIAL BETWEEN CO
     3RE AND STATIC NA  TAU17=',F10.5/' TIME CONSTANT FOR MATERIAL BETW
     4LATERAL PLENUM AND STATIC NA TAU87=',F9.4)
      READ(IN,100) T9AM,TAU9A,C9A,ALF9A,TET90
      READ(IN,100) PMAX,NUMAX
      READ(IN,101) N,JAPLOT
C   READ N: NUMBER OF INPUT FREQUENCE VALUES FOR DINAMICAL CALCULATIONS
  101 FORMAT(16I5)
      IF(N.GT.50 ) WRITE(NOU,207) N
  207 FORMAT('1FEHLER IN DER    EINGABE      N=',I10,' GROESSER ALS 50')
      WRITE(NOU,336) SEP,SEP,SEP,TET90,T9AM,TAU9A,C9A,ALF9A
  336 FORMAT('0 8. ZONE 9: RADIAL REFLECTOR'/'  ',3A8/'OAVERAGE COOLANT
     1TEMPERATURE (K)',24X,'TETA90=',F10.3/' MAXIMAL TEMP DIFFERENCE BET
     2WEEN REFLECTOR AND COOLANT  =',F16.3/' REFLECTOR TIME CONSTANT (SE
     3C)',26X,'TAU9A=',F10.5/' REACTIVITY COEFFICIENT (C/K)',27X,'C9A=',
     4F12.5/' PERCENTAGE OF POWER',36X,'ALFA9A=',F9.5)
  337 FORMAT('0 9. ZONE 6: UPPER PLENUM'/' ',3A8/'OCOOLANT TEMPERATURE (
     1K)',32X,'TETA60=',F10.3///'0 REACTOR TOTAL POWER (WATT)',28X,'PO='
     2,1PE16.6)
      ALF1=ALF1A+ALF1C+ALF1D
      ALF4=0.
      IF(L4.NE.0.) ALF4=ALF4A+ALF4B
      ALFA=ALF1+ALF2A+ALF3A+ALF4+ALF9A
      WRITE(NOU,338) PMAX,NUMAX
  338 FORMAT(//'0 MAXIMAL TOTAL POWER (WATT)',28X,'PMAX=',1PE14.6/'0 MAX
     1IMUM COOLANT FLOW (CM**3/SEC)',22X,'NUMAX=',E15.6)
      IF(NPAR.EQ.0) GO TO 601
C   CALL SSCA: SUBROUTINE FOR STEADY SYATE CALCULATIONS
      CALL SSCA
      WRITE(NOU,333)
      WRITE(NOU,337) SEP,SEP,SEP,TET60,PO
      GO TO 600
  601 CONTINUE
      IF((N.NE.0).OR.((N.EQ.0).AND.(NPAR.EQ.0))) READ(IN,100) PO,TET60
      WRITE(NOU,337) SEP,SEP,SEP,TET60,PO
      CALL CACO
       WRITE(NOU,333)
  600 CONTINUE
      IF(TET60.GT.1300.) NFEHL=14
      IF(NFEHL.EQ.14)WRITE(NOU,400) NFEHL
C   PRINT CALCULATED CONSTANTS
      WRITE(NOU,350) ALF1,ALF2A,ALF3A,ALF4,ALF9A,ALFA,NUO
  350 FORMAT('0 1. TOTAL PERCENTAGE OF POWER, OUTLET TEMPERATURE AND COO
     1LANT FLOW'/'OCORE',51X,'ALFA1=',F10.5/' LOWER REFLECTOR',40X,'ALFA
     22=',F10.5/' UPPER REFLECTOR',40X,'ALFA3=',F10.5/' RADIAL BLANKET',
     341X,'ALFA4=',F10.5/' RADIAL REFLECTOR',39X,'ALFA9=',F10.5/' TOTAL
     4PERCENTAGE',39X,'ALFA=',F11.5/' COOLANT FLOW (CM**3/SEC)',31X,'NUO
     55=',1PE15.6)
      WRITE(NOU,353) SEP,VOL,TET130,TET10,PE,NU,T1B0
  353 FORMAT('0 2. CORE'/' ',A8/'OTOTAL FUEL VOLUME (CM**3)',30X,'VOL=',
     11PE14.6/'0 A. TEMPERATURES AND HEAT TRANSFER NUMBERS'/'OOUTLET COO
     2LANT TEMPERATURE',29X,'TET130=',0P1F10.3/' AVERAGE COOLANT TEMPERA
     3TURE',28X,'TETA10=',F10.3/' PECLET NUMPER',42X,'PE=',F14.5/' NUSSE
     4LT NUMBER',41X,'NU=',F14.5/' AVERAGE CLADDING TEMPERATURE',27X,'T1
     5B0=',F12.5)
      WRITE(NOU,355) PD1C,H1A,H1AB
  355 FORMAT(' FUEL POWER DENSITY (WATT/CM**3)',24X,'PD10=',F10.4/' FUEL
     1 GAP COEFFICIENT (WATT/CM**2 K)',20X,F16.5/' FUEL TO CLADDING HEAT
     2TRANSFER COEFFICIENT (WATT/CM**2 K) H1AB=',F10.5)
      WRITE(NOU,356) T1ASO,PHI1A,T1AMO,T1CO,T1DO,T1ACO
  356 FORMAT(' FUEL SURFACE TEMPERATURE',31X,'T1ASO=',F12.5/' ',55X,'PHI
     11A=',F12.6/' AVERAGE FUEL TEMPERATURE',31X,'T1AMO=',F12.5/' AVERAG
     2E FIRST STRUCTURE MATERIAL TEMPERATURE',11X,'T1CO=',F12.5/' AVERAG
     3E SECOND STRUCTURE MATERIAL TEMPERATURE',10X,'T1DO=',F12.5/' CENTR
     4AL FUEL TEMPERATURE',31X,'T1ACO=',F10.3)
      WRITE(NOU,357) CH1A
  357 FORMAT(/'0 B. THERMAL CONSTANTS'/'OFUEL SPECIFIC THERMAL CAPACITY
     1(WATT SEC/G K)',10X,'CHI1A=',F12.7)
      WRITE(NOU,358) K1AST,K1ASP,K1AMT,K1AMP,K1AMTS,K1AMPS
  358 FORMAT('OFUEL NON LINEAR GLOBAL COEFFICIENTS'/'OSURFACE TEMPERATUR
     1E         K1AST=',1PE14.6,10X,'K1ASP=',E14.6/' AVERAGE TEMPERATURE'
     1,8X,'K1AMT=',E14.6,10X,'K1AMP=',E14.6/' ',26X,'K1AMTS=',E14.6,10X,
     2'K1AMPS=',E14.6)
      WRITE(NOU,395) ALFAM,ALFAL,EPS,ETA,GAMMA,A
  395 FORMAT('ONON LINEAR CORRECTION COEFFICIENTS FOR CLADDING TEMPERATU
     1RE CHANGE'/'OAVERAGE TEMPERATURE',36X,'ALFAM=',F10.4/' LINEAR AVER
     2AGE TEMPERATURE',29X,'ALFAL=',F10.4/'OGAP COEFFICIENTS:'/' ',55X,'
     3EPSILON=',F12.6/' ',55X,'ETA=',F12.6/' ',55X,'GAMMA=',F12.6/' ',55
     4X,'A=',F12.6)
      WRITE(NOU,359) T1A,T1B,T1AX
  359 FORMAT('0 C. TIME CONSTANTS AND DELAYS'/'OFUEL RADIAL TIME SCALE
     1(SEC)',26X,'T1A=',F12.6/' CLADDING TIME CONSTANT (SEC)',27X,'T1B='
     2,F12.6,/' AXIAL TIME DELAY (SEC)',33X,'T1AX=',F11.6)
      WRITE(NOU,360) MP1A,MP1C,MP1D,B1ACOR
  360 FORMAT('0 D. MATERIAL THERMAL CAPACITIES TO COOLANT THERMAL CAPACI
     1TY RATIO'/'OFUEL',51X,'M1A=',F12.6/' FIRST STRUCTURE MATERIAL',31X
     2,'M1C=',F12.6/' SECOND STRUCTURE MATERIAL',30X,'M1D=',F12.6/'0 E.
     3REACTIVITY CORRECTION COEFFICIENTS'/'0',55X,'B1A=',F10.5)
      WRITE(NOU,352) SEP,SEP,SEP,TET210,TET20,T2A0,T2AX,MP2A
  352 FORMAT('0 3. LOWER AXIAL BLANKET'/' ',3A8/'0 A. TEMPERATURES'/'OOU
     1TLET COOLANT TEMPERATURE',29X,'TETA210=',F8.3/' AVERAGE COOLANT TE
     2MPERATURE',28X,'TETA20=',F9.3/' AVERAGE BLANKET TEMPERATURE',28X,'
     3T2A0=',F11.3/'0 B. TIME CONSTANTS AND DELAYS'/'OAXIAL TIME DELAY',
     439X,'T2AX=',F11.6/'0 C. MATERIALS THERMAL CAPACITIES TO COOLANT TH
     5ERMAL CAPACITY RATIO '/'OBLANKET TO COOLANT',37X,'M2A=',F12.6)
      WRITE(NOU,361) SEP,SEP,SEP,TET360,TET30,T3A0,T3AX,MP3A
  361 FORMAT('0 4. UPPER AXIAL BLANKET'/' ',3A8/'0 A. TEMPERATURES'/'0 O
     1UTLET COOLANT TEMPERATURE',28X,'TETA360=',F8.3/' AVERAGE COOLANT T
     2EMPERATURE',28X,'TETA30=',F9.3/' AVERAGE BLANKET TEMPERATURE',28X,
     3'T3A0=',F11.3/'0 B. TIME CONSTANTS AND DELAYS'/'OAXIAL TIME DELAY'
     4,39X,'T3AX=',F11.6/'0 C. MATERIALS THERMAL CAPACITIES TO COOLANT T
     5HERMAL CAPACITY RATIO'/'OBLANKET',48X,'M3A=',F12.6)
      IF(L4.LE.0) GO TO 366
      WRITE(NOU,362) SEP,SEP,TET460,TET40,T4A0,T4B0,T4AX,MP4A,MP4B
  362 FORMAT('0 5. RADIAL BLANKET'/'  ',2A8/' A. TEMPERATURES'/'OOUTLET
     1COOLANT TEMPERATURE',29X,'TETA460=',F8.3/' AVERAGE  COOLANT TEMPER
     2ATURE',27X,'TETA40=',F9.3/' AVERAGE BLANKET TEMPERATURE',28X,'T4A0
     3=',F11.3/' AVERAGE STRUCTURE MATERIAL TEMPERATURE',17X,'T4B0=',F11
     4.3/'0 B. TIME CONSTANTS AND DELAYS'/'OAXIAL TIME DELAY',39X,'T4AX=
     5',F11.3/'0 C. MATERIAL THERMAL CAPACITIES TO COOLANT THERMAL CAPAC
     6ITY RATIO'/'OBLANKET',48X,'M4A=',F12.6/' STRUCTURE MATERIAL',37X,'
     7M4B=',F12.6)
  366 WRITE(NOU,363) SEP,SEP,SEP,SEP,T85
  363 FORMAT('0 6. LOWER AND LATERAL PLENUM'/' ',4A8/'OTIME DELAY',45X,'
     1T85=',F12.5)
      WRITE(NOU,364) SEP,SEP,SEP,SEP,SEP,ALF87,SEP,SEP,T9A0
  364 FORMAT('0 7. STATIC SODIUM BETWEEN CORE AND SHROUD'/' ',5A8/' ',55
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     1X,'ALFA87=',F12.6/'0 8. RADIAL REFLECTOR'/'  ',2A8/'0 A. TEMPERATU
     2RES'/'0AVERAGE REFLECTOR TEMPERATURE',26X,'T9A0=',F12.4)
      IF(N.EQ.0) GO TO 200
      READ(IN,100) (OM(I),I=1,N)
      PIHALB=1.570796
      EE=EPS*ALFAL/(1.+EPS*ALFAL)
      EA=1.333333*ALFAM*EPS*(1.+GA6*ALFAL)/(ALFE*(1.+8.*GAMMA*ALFAM))
C   CALCULATION OF THE REACTIVITY POWER TRANSFER FUNCTION K(SIGMA)
      DO 30 I=1,N
      OM2=OM(I)*OM(I)
      SUM=0.
      SUM1=0.
      DO 6 ISOT=1,NI
      DO 6 J=1,NG
      FAC=LAMBDA(J,ISOT)*LAMBDA(J,ISOT)+OM2
      SUM=SUM+(AI(J,ISOT)*LAMBDA(J,ISOT))/FAC
    6 SUM1=SUM1+AI(J,ISOT)/FAC
      K(I)=0.01/CMPLX(OM2*SUM1,OM(I)*(L/BET+SUM))
      ARG=SQRT(T1A*OM(I))*0.7071067
      SIGMA   =CMPLX(0.,OM(I))
C   CALCULATE Z(SIGMA)
      XN=OM(I)*T1A
      IF(XN.LE.700.) GO TO 10
      COM=CSQRT(CMPLX(1.,0.25*XN ))
      RE=-REAL(COM)
      XIM=AIMAG(COM)
      ZSIGMA(I)=1./XN*CMPLX(XIM,RE)
      GO TO 11
   10 CALL ZSIG(ARG,ZSIGMA(I))
   11 GS(I)=ZSIGMA(I)/(ZSIGMA(I)+GAMMA)
      FS(I)=GS(I)/(T1A*SIGMA    *ZSIGMA(I))
      AR=CMPLX(ARG,-ARG)
      CALL STRF(AR,H,KEN)
      IF(KEN.EQ.1) GO TO 401
C    CALCULATE THE TRANSFER FUNCTIONS
      COM=PIHALB*((0.5*H(1))/(CMPLX(ARG,-ARG)*ZSIGMA(I))+H(2))
      GO TO 402
  401 COM=PIHALB*((1.+H(1)+H(1)/(2.*ZSIGMA(I)))*0.6366 + H(2))
  402 CONTINUE
      GL(I)=GS(I)*(1.-COM)
      FL(I)=(6.*ALFAL)/((1.+GA6*ALFAL)*T1A*SIGMA)*
     1 (1.-GL(I)-(ALFAL-1.)/ALFAL*COM)
      FM(I)=8./((1.+8.*GAMMA*ALFAM)*T1A*SIGMA)*
     1 (1.-FS(I)+(ALFAL-1.)*GAMMA*FS(I)/ZSIGMA(I))
      COM=1.+EPS*ALFAL*GL(I)
      G1AL(I)=ALFE*GL(I)/COM
      F1AL(I)=ALFE*FL(I)/COM
      G1AS(I)=ALFE*GS(I)/COM
      COM=A*GAMMA*T1A*(1.+ETA)*SIGMA*FS(I)
      G1B(I)=1./(1.+T1B*SIGMA    +COM-EE*COM*G1AL(I))
      F1AS(I)=(FS(I)+EPS*ALFAL*FS(I) -EPS*(1.+GA6*ALFAL)/GA6
     1 *GS(I)*F1AL(I))/(1.-EPS/GA6)
      F1B(I)=G1B(I)*(K1ASP*(F1AS(I)-F1AL(I))+F1AL(I))
      G1AM(I)=FS(I)*ALFE/(1.+ALFAL*EPS*GL(I))
      COM=MP1A*(1.+ETA)*G1B(I)*FS(I)
      Y1B(I)=T1AX*SIGMA*((MP1A*T1B)/(A*GAMMA*T1A)*G1B(I)+COM-
     1 ALFAL*EPS/ALFE*COM*G1AL(I))
      F1AM(I)=(FM(I)-EA*FS(I)*F1AL(I))/(1.-EA)
      GPAM(I)=G1B(I)*G1AM(I)
      FPAM(I)=(1./(K1AMPS*(T1AMO-TET10)))*(K1AMT*(T1BO-TET10)*G1AM(I)*
     1 F1B(I)+K1AMP*(T1AMO-T1BO)*F1AM(I))
      G1C(I)=1./(1.+SIGMA*TAU1C)
      G1D(I)=1./(1.+SIGMA*TAU1D)
      Y1C(I)=T1AX*MP1C*SIGMA*G1C(I)
      Y1D(I)=T1AX*MP1D*SIGMA*G1D(I)
      Y1(I)=Y1B(I)+Y1C(I)+Y1D(I)+T1AX*SIGMA
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      F1(I)=(ALF1A*F1B(I)+ALF1C*G1C(I)+ALF1D*G1D(I))/ALF1
      CALL WUV(Y1(I),F1(I),W13(I),U13(I),V13(I),U1(I),V1(I))
      G2A(I)=1./(1.+TAU2A*SIGMA)
      Y2(I)=T2AX*SIGMA+T2AX*MP2A*SIGMA*G2A(I)
      CALL WUV(Y2(I),G2A(I),W21(I),U21(I),V21(I),U2(I),V2(I))
      G3A(I)=1./(1.+TAU3A*SIGMA)
      Y3(I)=T3AX*SIGMA+T3AX*MP3A*SIGMA*G3A(I)
      CALL WUV(Y3(I),G3A(I),W36(I),U36(I),V31(I),U3(I),V3(I))
   39 IF(L4.LE.0)GO TO 15
      G4A(I)=1./(1.+TAU4A*SIGMA)
      G4B(I)=1./(1.+TAU4B*SIGMA)
      F4(I)=ALF4A/ALF4*G4A(I)+ALF4B/ALF4*G4B(I)
      Y4A(I)=MP4A*T4AX*SIGMA*G4A(I)
      Y4B(I)=MP4B*T4AX*SIGMA*G4B(I)
      Y4(I)=T4AX*SIGMA+Y4A(I)+Y4B(I)
      Q4A=C4A*(T4A0-TET40)*G4A(I)
      Q4B=C4B*(T4B0-TET40)*G4B(I)
      Q4(I)=Q4A+Q4B
      D4(I)=C4E+C4A*G4A(I)+C4B*G4B(I)
      CALL WUV(Y4(I),F4(I),W46(I),U46(I),V46(I),U4(I),V4(I))
      ES4(I)=(TET40-TET80)*V4(I)*D4(I)
      EM4(I)=(TET80-TET40)*U4(I)*D4(I)
   15 G17(I)=1./(1.+TAU17*SIGMA)
      G87(I)=1./(1.+TAU87*SIGMA)
      W5(I)=CEXP(-T85*SIGMA)/(1.+TAU85*SIGMA)
      G5A(I)=1./(1.+TAU5A*SIGMA)
      F9A(I)=1./(1.+TAU9A*SIGMA)
      Q1A= C1B*(T1BO-TET10)*F1B(I)+C1A*K1AMPS*(T1AMO-TET10)*FPAM(I)
      Q1C=C1C*(T1CO-TET10)*G1C(I)
      Q1D=C1D*(T1DO-TET10)*G1D(I)
      Q1(I)=Q1A+Q1C+Q1D
      Q2(I)=C2A*(T2A0-TET20)*G2A(I)
      Q3(I)=C3A*(T3A0-TET30)*G3A(I)
      Q9(I)=C9A*(T9A0-TET90)*F9A(I)
      Q(I)=Q1(I)+Q2(I)+Q3(I)+Q4(I)+Q9(I)
      D1(I)=C1E+C1B*G1B(I)+C1A*K1AMTS*GPAM(I)+C1C*G1C(I)+C1D*G1D(I)
      D1P(I)=B1E*C1E+B1B*C1B*G1B(I)+B1ACOR*C1A*K1AMTS*GPAM(I)+
     1B1C*C1C*G1C(I)+B1D*C1D*G1D(I)
      D2(I)=C2E+C2A*G2A(I)
      D3(I)=C3E+C3A*G3A(I)
      D5(I)=C5A*G5A(I)
      D17(I)=C7E*ALF17*G17(I)
      D87(I)=C7E*ALF87*G87(I)
      D1BOF(I)=C1F/(1.+TAU1F*SIGMA)
      D1BOG(I)=C1G/(1.+TAU1G*SIGMA)
      ES1(I)=(TET10-TET210)*D1P(I)*V1(I)+
     1(TET210-TET80)*V21(I)*U13(I)*D1(I)
     2+D1BOF(I)*(TET210-TET80)*V21(I)+D1BOG(I)*((TET130-TET210)*V13(I)
     3 +(TET210-TET80)*V21(I)*(W13(I)-1.))
      ES2(I)=(TET20-TET80)*D2(I)*V2(I)
      ES3(I)=D3(I)*((TET30-TET130)*V3(I)+(TET130-TET210)*V13(I)*U36(I)
     1 +(TET210-TET80)*V21(I)*W13(I)*U36(I))
      ES7(I)=D17(I)*((TET10-TET210)*V1(I)+(TET210-TET80)*V21(I)*U13(I))
      S(I)=ES1(I)+ES2(I)+ES3(I)+ES4(I)+ES7(I)
      EM1(I)=(TET210-TET10)*U1(I)*D1P(I)+(TET80-TET210)*
     1U21(I)*U13(I)*D1(I)+D1BOF(I)*(TET210-TET80)*U21(I)+
     2 D1BOG(I)*((TET130-TET210)*U13(I)+(TET210-TET80)*U21(I)*
     3 (W13(I)-1.))
      EM2(I)=(TET80-TET20)*U2(I)*D2(I)
      EM3(I)=-D3(I)*((TET30-TET130)*U3(I)+(TET130-TET210)*U13(I)*U36(I)
     1+(TET210-TET80)*U21(I)*W13(I)*U36(I))
      EM7(I)=D17(I)*((TET210-TET10)*U1(I)+(TET80-TET210)*U21(I)*U13(I))
      M(I)=EM1(I)+EM2(I)+EM3(I)+EM4(I)+EM7(I)
      R1(I)=W5(I)*W21(I)*U13(I)*D1(I)
      R2(I)=W5(I)*U21(I)*D2(I)
      R3(I)=W5(I)*W21(I)*W13(I)*U36(I)*D3(I)
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      R4(I)=W5(I)*U46(I)*D4(I)
      R5(I)=W5(I)*D5(I)
      R7(I)=D87(I)+D17(I)*W5(I)*W21(I)*U13(I)
      R(I)=C8E+R1(I)+R2(I)+R3(I)+R4(I)+R5(I)+R7(I)
      QK(I)=K(I)*Q(I)
      SK(I)=K(I)*S(I)
      GO(I)=K(I)/(1.-QK(I))
      QSK(I)=QK(I)+SK(I)
      GP(I)=K(I)/(1.-QSK(I))
      GMU(I)=GP(I)*M(I)
      GTET(I)=GP(I)*R(I)
   30 CONTINUE
      WRITE(NOU,119)
  119 FORMAT('1',50X,'FUNCTIONS'///'0   1.  KINETIC TRANSFER FUNCTION')
  110 FORMAT('0  2.  THERMODYNAMIC BASIC FUNCTIONS'///'0    CORE')
      CALL SCRIVI(N,OM,FKNA,K,BLANK,K)
      WRITE(NOU,110)
      CALL SCRIVI(N,OM,ZNA,ZSIGMA,BLANK,K)
      NN=1
      CALL SCRIVI(N,OM,BNAM(NN),BFELD(1,NN),BNAM(NN+1),BFELD(1,NN+1))
      NDRU=100
      READ(IN,103) (DRUCK(I),I=1,20)
  103 FORMAT(20A4)
      JAQ=0
      JAS=0
      JAR=0
      JAM=0
      KARTE=0
      IF(DRUCK(1).EQ.BASIC) GO TO 91
      JI=1
      GO TO 14
   91 NDRU=16
      DO 901 NDR=1,NDRU,2
      CALL SCRIVI(N,OM,FNAM(NDR),FELD(1,NDR),FNAM(NDR+1),FELD(1,NDR+1))
  901 CONTINUE
      JI=3
   14 DRU=DRUCK(JI)
      KARTE=10
      IF(DRU.EQ.BLANK) GO TO 12
      IF(DRU.EQ.FNAM(17)) GO TO 17
      IF(DRU.EQ.FNAM(19)) GO TO 19
      IF(DRU.EQ.FNAM(21)) GO TO 21
      GO TO 12
   19 CALL SCRIVI(N,OM,FNAM(19),FELD(1,19),FNAM(20),FELD(1,20))
      JI=JI+2
      GO TO 14
   17 CALL SCRIVI(N,OM,FNAM(17),FELD(1,17),FNAM(18),FELD(1,18))
      JI=JI+2
      GO TO 14
   21 NDR1=21
      NDR2=26
      DO 16 JJ=NDR1,NDR2,2
      FNA=FNAM(JJ+1)
      IF(JJ.EQ.25) FNA=BLANK
   16 CALL SCRIVI(N,OM,FNAM(JJ),FELD(1,JJ),FNA,FELD(1,JJ+1))
   12 IF((JI.EQ.1).AND.(DRU.EQ.BLANK)) GO TO 90
      IF(KARTE.EQ.0) GO TO 13
   18 READ(IN,103) (DRUCK(I),I=1,20)
      JI=1
   22 DRU=DRUCK(JI)
      IF(DRUCK(1).EQ.BLANK) GO TO 90
      IF(DRU.EQ.BLANK) GO TO 18
   13 IF((DRU.EQ.FNAM(26)).OR.(DRU.EQ.FNAM(33)))KARTE=1
      IF((DRU.EQ.FNAM(40)).OR.(DRU.EQ.FNAM(51)))KARTE=2
      IF((DRU.EQ.FNAM(52)).OR.(DRU.EQ.FNAM(55)))KARTE=2
      IF(DRU.EQ.BNAM(3)) KARTE=3
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      IF(DRU.EQ.BB) KARTE=4
      IF(DRU.EQ.BNAM(4)) KARTE=5
      IF(DRU.EQ.BNAM(5)) KARTE=6
      IF(DRU.EQ.BNAM(6)) KARTE=7
      IF(DRU.EQ.BNAM(13)) KARTE=8
      GO TO (520,530,540,550,560,570,580,590),KARTE
  520 IF(DRU.EQ.FNAM(26)) GO TO 26
   34 WRITE(NOU,233)
  233 FORMAT(///'0   3.  UPPER AXIAL BLANKET'///)
      I1=33
      I2=39
      GO TO 500
   26 WRITE(NOU,226)
  226 FORMAT(///'0   2.   LOWER AXIAL BLANKET'///)
      I1=26
      I2=32
      GO TO 500
  530 IF(DRU.EQ.FNAM(40)) GO TO 40
      IF(DRU.EQ.FNAM(51)) GO TO 51
      IF(DRU.EQ.FNAM(53)) GO TO 53
      I2=55
      WRITE(NOU,255)
  255 FORMAT(///'0   9.  RADIAL REFLECTOR'///)
      GO TO 502
   40 I1=40
      I2=50
      WRITE(NOU,240)
  240 FORMAT(///'0   4.  RADIAL BLANKET'///)
      GO TO 500
   51 I1=51
      I2=52
      WRITE(NOU,251)
  251 FORMAT(///'0   7.  STATIC SODIUM BETWEEN CORE AND SHROUD'///)
      GO TO 500
   53 I1=53
      I2=54
      WRITE(NOU,253)
  253 FORMAT(///'0   5.  LOWER PLENUM AND GRID PLATE'///)
      GO TO 500
  540 I1=56
      I2=60
      JAQ=1
      WRITE(NOU,290)
  290 FORMAT(///'0   POWER FEEDBACKS WITH CONSTANT COOLANT TEMPERATURES'
     1///)
      CALL SCRIVI(N,OM,BNAM(3),Q,BLANK,Q)
      GO TO 500
  550 I1=61
      I2=70
      WRITE(NOU,250)
  250 FORMAT(///'0   COOLANT TEMPERATURES REACTIVITY FEEDBACK FUNCTIONS'
     1///)
      GO TO 500
  560 I1=71
      I2=75
      JAS=1
      WRITE(NOU,260)
  260 FORMAT(///'0   REACTIVITY POWER FEEDBACKS THROUGH THE COOLANT TEMP
     1ERATURES'///)
      CALL SCRIVI(N,OM,BNAM(4),S,BLANK,S)
      GO TO 500
  570 I1=76
      I2=80
      JAM=1
      WRITE(NOU,270)
  270 FORMAT(///'0   REACTIVITY COOLANT FLOW FUNCTIONS'///)
```

```
      CALL SCRIVI(N,OM,BNAM(5),M,BLANK,M)
      GO TO 500
  580 I1=81
      I2=86
      JAR=1
      WRITE(NOU,280)
  280 FORMAT(///'0   REACTIVITY INLET TEMPERATURE FUNCTIONS'///)
      CALL SCRIVI(N,OM,BNAM(6),R,BLANK,R)
  500 II=I2-1
      DO 501 I=I1,II,2
      CALL SCRIVI(N,OM,FNAM(I),FELD(1,I),FNAM(I+1),FELD(1,I+1))
  501 CONTINUE
      IF((I2-I).EQ.1) GO TO 20
  502 CALL SCRIVI(N,OM,FNAM(I2),FELD(1,I2),BLANK,K)
   20 JI=JI+1
      GO TO 22
  590 I1=11
      I2=14
      DO 591 I=I1,I2,2
  591 CALL SCRIVI(N,OM,BNAM(I),BFELD(1,I),BNAM(I+1),BFELD(1,I+1))
      GO TO 18
   90 IF(JAQ.EQ.1) GO TO 96
      WRITE(NOU,240)
      CALL SCRIVI(N,OM,BNAM(3),Q,BLANK,Q)
   96 IF(JAS.EQ.1) GO TO 92
      WRITE(NOU,260)
      CALL SCRIVI(N,OM,BNAM(4),S,BLANK,S)
   92 IF(JAM.EQ.1) GO TO 93
      WRITE(NOU,270)
      CALL SCRIVI(N,OM,BNAM(5),M,BLANK,M)
   93 IF(JAR.EQ.1) GO TO 95
      WRITE(NOU,280)
      CALL SCRIVI(N,OM,BNAM(6),R,BLANK,R)
   95 I1=7
      I2=10
      WRITE(NOU,230)
  230 FORMAT('1   CLOSED LOOPS TRANSFER FUNCTIONS'///)
      DO 94 I=I1,I2,2
      IF(JAPLOT.NE.0) N=-N
      CALL SCRIVI(N,OM,BNAM(I),BFELD(1,I),BNAM(I+1),BFELD(1,I+1))
   94 CONTINUE
  200 STOP
      END
=============================================================================

    SUBROUTINE  FOR STEADY STATE CALCULATIONS

=============================================================================
      SUBROUTINE SSCA
      REAL NUI,NUMAX,NUO,K1AMPS,L1,N1,M1A,LAM1B,M1C,M1D,LAME,NU1,NU2,NU3
     1,L3,M2A,M3A,L4,M4A,N4,M4B,MP2A,NU,K1AST,K1ASP,K1AMP,K1AMT,K1AMPS,
     2K1AMTS,MP1A,MP1C,MP1D,MP3A,MP4A,MP4B
      COMMON TE80I(50),TE90I(50),NUI(50),POI(50),TE130I(50),TE10I(50),
     1T1ASOI(50),T1AMOI(50),T1ACOI(50),T1BOI(50),T1DOI(50),T1COI(50),
     2ROQ1A(50),ROQ1C(50),ROQ1D(50),ROQ2(50),ROQ3(50),ROQ4A(50),
     3ROQ4B(50),ROQ4(50),ROQ9(50),ROQ(50),
     4ROS1(50),ROS2(50),ROS3(50),ROS4(50),ROS7(50),ROS(50),
     5ROM1(50),ROM2(50),ROM3(50),ROM4(50),ROM7(50),ROM(50),
     6ROR1(50),ROR2(50),ROR3(50),ROR4(50),ROR5(50),ROR7(50),ROR8(50),
     7ROR(50),PD10I(50)
      COMMON /INKO/IN,NOU,L1,N1,S1,DEL1,R1BI,R1BE,M1A,CH1,
     1CH2,CH3,TA,C,A0,A1,A2,A3,B1,ALF1A,RO1B,CH1B,LAM1B,M1C,CH1C,
     2TAU1C,ALF1C,T1COM,M1D,CH1D,TAU1D,ALF1D,T1DOM,ROE,CHE,LAME,
     3NU1,NU2,NU3,C1A,C1B,C1E,C1C,C1D,B1A,B1B,B1C,B1D,B1E,C1F,C1G,
     4L2,M2A,CH2A,TAU2A,C2A,C2E,ALF2A,T2AM,L3,M3A,CH3A,TAU3A,C3A,C3E,
     5ALF3A,T3AM,L4,N4,S4,M4A,CH4A,TAU4A,C4A,ALF4A,T4AM,M4B,CH4B,
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     6TAU4B,C4B,ALF4B,T4BM,C4E,T85M,TAU85,TAU5A,C8E,C5E,C5A,C7E,
     7ALF17,TAU17,TAU87,T9AM,TAU9A,C9A,ALF9A,PMAX,TET60,PO,NUMAX
     8,TET80,TET90,NPAR,CKIAMT
      COMMON /BERCO/  ALF1,ALFA,ALF4,TET360,NUO,VOL,MP2A,
     1TET210,TET20,T2A0,T2AX,TET130,TET10,PE,NU,T1B0,PD1C,PD2,H1A,
     2H1AB,T1ASO,PHI1A,T1AMO,T1CO,T1DO,T1ACO,CH1A,K1AST,K1ASP,K1AMP,
     3K1AMT,K1AMPS,K1AMTS,A,ALFAM,ALFAL,GAMMA,GA6,EPS,ETA,ALFE,
     4T1A,T1B,T1AX,MP1A,MP1C,MP1D,B1ACOR,TET30,T3A0,T3AX,MP3A,TET460,
     5TET40,T4A0,T4B0,T4AX,MP4A,MP4B,T85,ALF87,T9A0
      M=NPAR
      I=0
    1 I=I+1
      READ(IN,100) TET80,TET90,NUO,PO
      TE80I(I)=TET80
      TE90I(I)=TET90
      NUI(I)=NUO
      POI(I)=PO
      TET60=TET80+PO*(ALF1+ALF2A+ALF3A+ALF4)/(NUO*CHE*ROE)
      CALL CACO
      TE130I(I)=TET130
      TE10I(I)=TET10
      T1ASOI(I)=T1ASO
      T1AMOI(I)=T1AMO
      T1ACOI(I)=T1ACO
      T1BOI(I)=T1BO
      T1COI(I)=T1CO
      T1DOI(I)=T1DO
      PD10I(I)=PD1C
      D1=C1E+C1B+C1A*K1AMTS+C1C+C1D
      D2=C2E+C2A
      D3=C3E+C3A
      IF(L4.NE.0) GO TO 2
      D4=0.
      GO TO 3
    2 CONTINUE
      D4=C4E+C4A+C4B
    3 D5=C5A
      D17=C7E*ALF17
      D87=C7E*ALF87
      D1S=B1E*C1E+B1B*C1B+B1ACOR*C1A*K1AMTS+B1C*C1C+B1D*C1D
      S=D1*(TET210-TET80)+C1F*(TET210-TET80)+      C1G*(TET130-TET210)
      XM1=-D1S*(TET10-TET210)+S
      XM2=-D2*(TET20-TET80)
      XM3=-D3*(TET30-TET80)
      IF(L4.EQ.0) TET40=0.
      XM4=-D4*(TET40-TET80)
      XM7=-D17*(TET10-TET80)
      XM=XM1+XM2+XM3+XM4+XM7
      SS=D1S*(TET10-TET210)+S
      ROQ1A(I)=C1B*(T1B0-TET10)+C1A*K1AMPS*(T1AMO-TET10)- ROQ1A(1)
      ROQ1C(I)=C1C*(T1CO-TET10) - ROQ1C(1)
      ROQ1D(I)=C1D*(T1DO-TET10) - ROQ1D(1)
      ROQ2(I)=C2A*(T2A0-TET20) - ROQ2(1)
      ROQ3(I)=C3A*(T3A0-TET30) - ROQ3(1)
      IF(L4.NE.0) GO TO 4
      ROQ4(I)=0.
      GO TO 5
    4 ROQ4A(I)=C4A*(T4A0-TET40) - ROQ4A(1)
      ROQ4B(I)=C4B*(T4B0-TET40) - ROQ4B(1)
      ROQ4(I)= ROQ4A(I)+ROQ4B(I)
    5 ROQ9(I)= C9A*(T9A0-TET90) - ROQ9(1)
      ROQ(I)=ROQ1A(I)+ROQ1C(I)+ROQ1D(I)+ROQ2(I)+ROQ3(I)+ROQ4(I)+ROQ9(I)
      ROS1(I)=SS-ROS1(1)
      ROS2(I)= -XM2 - ROS2(1)
      ROS3(I)= -XM3 - ROS3(1)
      ROS4(I)= -XM4 - ROS4(1)
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      ROS7(I)= -XM7 - ROS7(1)
      ROS(I)=ROS1(I)+ROS2(I)+ROS3(I)+ROS4(I)+ROS7(I)
      ROM1(I)= XM1 - ROM1(1)
      ROM2(I)= XM2 - ROM2(1)
      ROM3(I)= XM3 - ROM3(1)
      ROM4(I)= XM4 - ROM4(1)
      ROM7(I)= XM7 - ROM7(1)
      ROM(I)=ROM1(I)+ROM2(I)+ROM3(I)+ROM4(I)+ROM7(I)
      ROR1(I)=D1*TET80 - ROR1(1)
      ROR2(I)=D2*TET80 - ROR2(1)
      ROR3(I)=D3*TET80 - ROR3(1)
      ROR4(I)=D4*TET80 - ROR4(1)
      ROR5(I)=D5*TET80 - ROR5(1)
      ROR7(I)=(D87 + D17)*TET80 -ROR7(1)
      ROR8(I)=C8E*TET80 - ROR8(1)
      ROR(I)= ROR1(I)+ROR2(I)+ROR3(I)+ROR4(I)+ROR5(I)+ROR7(I)+ROR8(I)
      IF(I.LT.M) GO TO 1
      WRITE(NOU,11)
   11 FORMAT('1',131('*')//50X,'STEADY STATE CALCULATIONS'/'0',131('*'))
      WRITE(NOU,12) (I,TE80I(I),TE90I(I),NUI(I),POI(I),I=1,M)
   12 FORMAT(//'0 INPUT:  COOLANT TEMPERATURES(K)  FLOW(CM**3/SEC)  POWE
     1R(WATT)'/'0       N',7X,'TETA 80',8X,'TETA90',8X,'NU',12X,'PO'//(I8
     2,0P2F15.4,1P2E15.6))
  100 FORMAT(8G10.4)
      WRITE(NOU,13)
   13 FORMAT(///'0 OUTPUT:  COOLANT TEMPERATURES',15X,'FUEL TEMPERATURES
     1',12X,'CORE STRUCTURE MATERIAL TEMPERATURES   POWER DENSITY'/'0
     2  N  TETA 130',9X,'TETA 10',9X,'T1ASO',9X,'T1AMO',9X,'T1ACO',9X,'T
     31BO',9X,'T1CO',9X,'T1DO',9X,'PD1O')
      WRITE(NOU,10) (I,TE130I(I),TE10I(I),T1ASOI(I),T1AMOI(I),T1ACOI(I),
     1T1BOI(I),T1COI(I),T1DOI(I),PD1OI(I),I=1,M)
   10 FORMAT(I7,F12.4,8F14.4)
   20 FORMAT(I7,1P10E12.4)
   30 FORMAT(I7,1P6E14.6)
      WRITE(NOU,14)
   14 FORMAT('1',50X,'REACTIVITIES'///'0  POWER REACTIVITIES WITH CONSTA
     1NT COOLANT TEMPERATURES (CENT)'/'0      N    ROQ1A',7X,'ROQ1C',7X,'R
     2OQ1D',7X,'ROQ2',8X,'ROQ3',8X,'ROQ4A',7X,'ROQ4B',7X,'ROQ4',8X,'ROQ9
     3',8X,'ROQ'/)
      WRITE(NOU,20) (I,ROQ1A(I),ROQ1C(I),ROQ1D(I),ROQ2(I),ROQ3(I),ROQ4A(
     1I),ROQ4B(I),ROQ4(I),ROQ9(I),ROQ(I),I=2,M)
      WRITE(NOU,15)
   15 FORMAT(///'0  REACTIVITY POWER FEEDBACKS THROUGH THE COOLANT TEMPE
     1RATURE(CENT)'/'0       N        ROS1',10X,'ROS2',10X,'ROS3',10X,'ROS4'
     2,10X,'ROS7',10X,'ROS'/)
      WRITE(NOU,30) (I,ROS1(I),ROS2(I),ROS3(I),ROS4(I),ROS7(I),ROS(I),
     1 I=2,M)
      WRITE(NOU,16)
   16 FORMAT(///'0  COOLANT FLOW REACTIVITIES (CENT)'/'0      N       ROM1'
     1,10X,'ROM2',10X,'ROM3',10X,'ROM4',10X,'ROM7',10X,'ROM'/)
      WRITE(NOU,30) (I,ROM1(I),ROM2(I),ROM3(I),ROM4(I),ROM7(I),ROM(I),
     1 I=2,M)
   40 FORMAT(I7,8F14.7)
      WRITE(NOU,18)
   18 FORMAT(///'0  INLET TEMPERATURE REACTIVITIES (CENT)'/'0      N
     1ROR1',10X,'ROR2',10X,'ROR3',10X,'ROR4',10X,'ROR5',10X,'ROR7',10X,'
     2ROR8',10X,'ROR'/)
      WRITE(NOU,40) (I,ROR1(I),ROR2(I),ROR3(I),ROR4(I),ROR5(I),ROR7(I),
     1ROR8(I),ROR(I),I=2,M)
      RETURN
      END
```

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   SUBROUTINE TO PRINT THE REACTOR CONFIGURATION

==========================================================================
      SUBROUTINE BILD(REAKT)
      REAL*4 SEFOR/'SEFO'/,KNK/'KNK '/,SNR/'SNR '/
      REAL*8 ST2/'   *    '/,ST4/'****    '/
      REAL*4 REAKT(20)
      REAL*8 BLANK/'        '/,NONE/' NONE   '/,FMT(31)/
     1'(9H01 - ','CORE/24H',' 2 - LOW','ER AXIAL',' BLANKET',
     2'/24H 3 -',' UPPER A','XIAL BLA','NKET/24H',' 4 -    ',
     3'RADIAL B','LANKET  ','/20H 5 -',' LOWER P','LENUM   ',
     4'/17H 6 -',' UPPER P','LENUM/47','H 7 -    ','STATIC S',
     5'ODIUM BE','TWEEN VE','SSEL AND',' SHROUD ','/19H 8 -',
     6' LATERAL',' PLENUM/','21H 9 - ','RADIAL R','EFLEKTOR',
     7')       '/
      REAL*8 ST/'********'/,ST1/'       *'/,ONE/'       1'/,
     1TWO/'       2'/,THREE/'       3'/,FOUR/'4  *    '/,
     2FIVE/'       5'/,SIX/'       6'/,SEVEN/'   7   *'/,
     3EIGHT/'  8    *'/,NINE/'   9   *'/,FMBL(7),FMB(7)/
     1'(9X,41H.','        ','        ','        ','        ',
     2'       ',')       '/
      NOU=6
   50 FORMAT('1',40X,20A4////)
      IF(REAKT(1).EQ.SEFOR) L=1
      IF(REAKT(1).EQ.KNK) L=2
      IF(REAKT(1).EQ.SNR) L=3
      GO TO (1,1,3),L
    3  FMT(29)=NONE
       FMT(30)=BLANK
       DO 20 I=21,24
   20 FMT(I)=BLANK
       FMT(20)=NONE
       GO TO 10
    1 FMT(11)=NONE
      FMT(12)=BLANK
   10 WRITE(NOU,50) (REAKT(I),I=1,20)
      DO 5 I=1,7
    5 FMBL(I)=FMB(I)
      FMB(2)=ST
      FMB(3)=ST
      IF(L.EQ.2) GO TO 11
      FMB(4)=ST
      FMB(5)=ST
      IF(L.EQ.3) FMB(5)=ST4
   11 WRITE(NOU,FMB)
            GO TO (21,22,23) ,L
   21 FMBL(5)=ST1
      GO TO 24
   22 FMBL(3)=ST1
      GO TO 24
   23 FMBL(5)=ST2
   24 WRITE(NOU,FMBL)
      FMBL(2)=SIX
      WRITE(NOU,FMBL)
      FMBL(2)=BLANK
      WRITE(NOU,FMBL)
      IF(L.EQ.1) FMB(6)=ST
      IF(L.NE.2) GO TO 6
      FMB(4)=ST
      FMB(5)=ST
    6 WRITE(NOU,FMB)
      DO 13 J=3,6
   13 FMBL(J)=ST1
      DO 14 K=1,3
```

```
      FMBL(2)=BLANK
      IF(K.EQ.2) FMBL(2)=THREE
         IF(L.EQ.1) GO TO 14
      FMBL(6)=BLANK
      IF(L.EQ.2) GO TO 14
      FMBL(5)=ST2
      FMBL(4)=BLANK
   14 WRITE(NOU,FMBL)
      DO 15 J=3,6
   15 FMB(J)=ST1
      GO TO(41,42,43),L
   43 FMB(4)=BLANK
      FMB(5)=ST2
   42 FMB(6)=BLANK
   41 FMB(3)=ST
      WRITE(NOU,FMB)
      FMB(2)=BLANK
      FMB(3)=ST1
      DO 16 K=1,15
      IF(K.NE.8) GO TO 16
      FMBL(2)=ONE
      FMBL(3)=ST1
      GO TO (31,32,33),L
   31 FMBL(4)=SEVEN
      FMBL(5)=EIGHT
      FMBL(6)=NINE
      GO TO 35
   32 FMBL(4)=SEVEN
      FMBL(5)=NINE
      GO TO 34
   33 FMBL(4)=BLANK
      FMBL(5)=FOUR
   34 FMBL(6)=BLANK
   35 WRITE(NOU,FMBL)
   16 WRITE(NOU,FMB)
      FMB(2)=ST
      FMB(3)=ST
      WRITE(NOU,FMB)
      FMBL(2)=BLANK
      DO 19 K=3,6
      FMBL(K)=ST1
   19 CONTINUE
      GO TO (36,37,38),L
   38 FMBL(4)=BLANK
      FMBL(5)=ST2
   37 FMBL(6)=BLANK
   36 WRITE(NOU,FMBL)
      FMBL(2)=TWO
      WRITE(NOU,FMBL)
      FMBL(2)=BLANK
      WRITE(NOU,FMBL)
      FMB(4)=ST
      GO TO (45,46,47),L
   46 FMB(5)=ST
      FMB(6)=BLANK
      GO TO 45
   47 FMB(6)=ST
      FMB(5)=ST
   45 WRITE(NOU,FMB)
      FMBL(3)=ST1
      GO TO (26,27,28),L
   26 FMBL(3)=BLANK
      GO TO 29
   28 FMBL(3)=BLANK
      FMBL(5)=ST2
      FMBL(6)=ST1
   27 FMBL(4)=BLANK
   29 WRITE(NOU,FMBL)
      FMBL(2)=FIVE
      GO TO (51,52,53),L
   52 FMBL(5)=EIGHT
      FMBL(3)=ST1
      GO TO 51
   53 FMBL(6)=EIGHT
   51 WRITE(NOU,FMBL)
       FMBL(2)=BLANK
      GO TO (55,56,57),L
   56 FMBL(5)=ST1
      GO TO 55
   57 FMBL(6)=ST1
   55 WRITE(NOU,FMBL)
      FMB(5)=ST
      FMB(6)=ST
      IF(L.EQ.2) FMB(6)=BLANK
      WRITE(NOU,FMB)
      WRITE(NOU,FMT)
      RETURN
      END
=========================================================================

   SUBROUTINE FOR CONSTANTS CALCLLATION

=========================================================================
      SUBROUTINE CACO
      REAL*4 N1,               L1,M1A, LAM1B,M1C,M1D,LAME,NU1,NU2,NU3,
     1L2,M2A,L3,M3A,L4,N4,M4A,NUMAX,NUO,NU,M4B,K1AST,K1ASP,K1AMP,K1AMT,
     2K1AMPS,MP1A,MP1C,MP1D,MP3A,MP4A,MP4B,MP2A,K1ALT,K1AMTS
      COMMON /INKO/IN,NOU,L1,N1,S1,DEL1,R1BI,R1BE,M1A,CH1,
     1CH2,CH3,TA,C,A0,A1,A2,A3,B1,ALF1A,RO1B,CH1B,LAM1B,M1C,CH1C,
     2TAU1C,ALF1C,T1COM,M1D,CH1D,TAU1D,ALF1D,T1DOM,ROE,CHE,LAME,
     3NU1,NU2,NU3,C1A,C1B,C1E,C1C,C1D,B1A,B1B,B1C,B1D,B1E,C1F,C1G,
     4L2,M2A,CH2A,TAU2A,C2A,C2E,ALF2A,T2AM,L3,M3A,CH3A,TAU3A,C3A,C3E,
     5ALF3A,T3AM,L4,N4,S4,M4A,CH4A,TAU4A,C4A,ALF4A,T4AM,M4B,CH4B,
     6TAU4B,C4B,ALF4B,T4BM,C4E,T85M,TAU85,TAU5A,C8E,C5E,C5A,C7E,
     7ALF17,TAU17,TAU87,T9AM,TAU9A,C9A,ALF9A,PMAX,TET60,PO,NUMAX
     8,TET80,TET90,NPAR,CK1AMT
      COMMON /BERCO/  ALF1,ALFA,ALF4,TET36C,NUC,VOL,MP2A,
     1TET210,TET20,T2A0,T2AX,TET130,TET10,PE,NU,T1B0,PD10,PD2,H1A,
     2H1AB,T1AS0,PHI1A,T1AM0,T1C0,T1D0,T1ACC,CH1A,K1AST,K1ASP,K1AMP,
     3K1AMT,K1AMPS,K1AMTS,A,ALFAM,ALFAL,GAMMA,GA6,EPS,ETA,ALFE,
     4T1A,T1B,T1AX,MP1A,MP1C,MP1D,B1ACOR,TET3C,T3A0,T3AX,MP3A,TET460,
     5TET40,T4A0,T4B0,T4AX,MP4A,MP4B,T85,ALF87,T9A0
      PGREC=3.141593
      AA=ALF1+ALF2A+ALF3A
      TET360 =TET80+(TET60-TET80)*AA/DEL1
      IF(NPAR.NE.0) GO TO 1
      NUO=(PO*(ALF1+ALF2A+ALF3A+ALF4))/(CHE*ROE*(TET60-TET80))
    1 CONTINUE
      TET210=TET80+ALF2A*(TET36C-TET80)/AA
      TET20=0.5*(TET210+TET80)
      T2A0=TET20+T2AM*PO/PMAX
      T2AX=(L2*S1*N1)/(DEL1*NUO)
      MP2A=(CH2A*M2A)/(S1*L1*ROE*CHE*N1)
      VOL=N1*L1*PGREC*R1BI*R1BI
      TET130=TET210+(TET360-TET8C) *ALF1/AA
      TET10=0.5*(TET210+TET130)
      PE=(2.*NUO*DEL1*CHE*ROE*R1BE)/(S1*N1*LAME)
      NU=NU1+NU2*PE**NU3
      T1B0=TET10+(ALF1A*PO)/(PGREC*N1*L1)*((0.5*(R1BE-R1BI)/(LAM1B*(R1BE
     1+R1BI)))+1./(LAME*NU))
      PD10=(ALF1A*PO)/VOL
      PD2=PD10*PD10
```

```
      H1A=A0+A1*PD10+A2*PD2+A3*PD2*PD10+B1*T1BC
      H1AB=1./(1./H1A+(R1BI*(R1BE-R1BI))/(LAM1B*(R1BE+R1BI)))
      T1ASO=T1BO+(ALF1A*PO)/(N1*L1*H1AB*2.*PGREC*R1BI)
      PHI1A=0.25*R1BI*R1BI*TA*C
      ESP=EXP(PHI1A*PD10)
      T1AMO=TA/(PHI1A*PD10)*ALOG(1.+T1ASO/TA*(ESP-1.))
      T1ACO=(TA*T1ASO*ESP)/(TA-T1ASO+T1ASO*ESP)
      T1CO=TET10+(PO*T1COM)/PMAX
      T1DO=TET10+(PO*T1DOM)/PMAX
      CH1A=CH1+CH3/(TA*TA)+CH2*T1AMO+(CH3*(T1ACO-T1ASO))/
     1 (PHI1A*PD10*T1ACO*T1ASO)*(1./TA+(T1ACO+T1ASO)/(2.*T1ACO*T1ASO))
      K1AST=1.-(PD10*R1BI*B1)/(2.*H1A*H1A)
      K1ASP=1.-H1AB/(H1A*H1A)*PD10*(A1+2.*A2*PD10+3.*A3*PD2)
      XNEN=1.+(T1ASO*ESP-T1ASO)/TA
      IF(CKIAMT.EQ.0) GO TO 2
      K1AMP=1.
      K1AMT=1.
      GO TO 3
    2 CONTINUE
      K1AMP=(K1ASP*(T1ASO*ESP-T1BO*ESP-T1ASO+T1BO)/(PHI1A*PD10*(T1AMO-
     1T1BO))+T1ASO*ESP/(T1AMO-T1BO))/XNEN-T1AMO/(T1AMO-T1BO)
      K1AMT=K1AST*(ESP-1.)/(PHI1A*PD10*XNEN)
    3 K1AMTS=K1AMT
      K1AMPS=(K1AMT*(T1BO-TET10)+K1AMP*(T1AMO-T1BO))/(T1AMO-TET10)
      A =(T1BO-TET10)/(T1ASO-T1BO)
      ALFAM=K1AMT/K1AST
       ALFAL=ALFAM
      GAMMA=0.125*(T1ASO-T1BO)/(K1AMP*(T1AMO-T1BO )-K1ASP*ALFAM*
     1 (T1ASO-T1BO))
      GA6=6.*GAMMA
      EPS=((1.-K1ASP)*GA6)/(1.+GA6*ALFAL*K1ASP)
      ETA=K1AST*(1.+ALFAL*EPS)-1.
      ALFE=1.+ALFAL*EPS
      T1A=(8.*M1A*CH1A*(K1AMP*(T1AMO-T1BO)-K1ASP*(T1ASO-T1BO)))/
     1(ALF1A*PO)
      T1B=(T1BO-TET10)/(ALF1A*PO)*N1*L1*PGREC*CH1B*(R1BE*R1BE-R1BI*R1BI)
      T1AX=(L1*S1*N1)/(DEL1 *NUO)
      XNEN=N1*L1*S1*ROE*CHE
      MP1A=(M1A*CH1)/XNEN
      MP1C=(M1C*CH1C)/XNEN
      MP1D=(M1D*CH1D)/XNEN
      B1ACOR=1.+B1A/C1A
      TET30=TET130+0.5*ALF3A*(TET360-TET80)
      T3AO  =TET30+PO/PMAX*T3AM
      T3AX=(L3*S1*N1)/(DEL1*NUO)
      MP3A=(CH3A*M3A)/(S1*L1*ROE*CHE*N1)
      IF(L4.LE.0) GO TO 366
      TET460=TET80+(TET60-TET80)*ALF4/(1.-DEL1)
      TET40=TET80+0.5*(TET460-TET80)
      T4AO  =TET40+PO/PMAX*T4AM
      T4BO=TET40+PO/PMAX*T4BM
      T4AX=(L4*S4*N4)/(NUO*(1.-DEL1))
      XNEN=S4*L4*ROE*CHE*N4
      MP4A=(CH4A*M4A)/XNEN
      MP4B=(CH4B*M4B)/XNEN
  366 T85=NUO/NUMAX*T85M
      ALF87=1.-ALF17
      T9AO=TET90+PO/PMAX*T9AM
      RETURN
      END
```

===

SUBROUTINE ZUR BERECHNUNG DER FUNKTIONEN W,U,V

===

```
      SUBROUTINE WUV(Y,F,W,U1,V1,U2,V2)
      COMPLEX Y,W,U1,V1,U2,V2,F
      COMPLEX*16 WW,YY,UU1,VV1,UU2,VV2,FF
       DATA      WW,YY,UU1,VV1,UU2,VV2,FF/7*(0.,0.)/
      YY=Y
      FF=F
      WW=CDEXP(-YY)
      IF((REAL(Y).NE.0).OR. (AIMAG(Y).NE.0)) GO TO 1
      UU1=CMPLX(1.,0.)
      UU2=CMPLX(1.,0.)
      GO TO 2
    1 UU1=(1.-WW)/YY
      UU2=(2.-2.*UU1)/YY
    2 VV1=UU1*FF
      VV2=UU2*FF
      W=WW
      U1=UU1
      V1=VV1
      U2=UU2
      V2=VV2
      RETURN
      END
```

SUBROUTINE ZUR POTENZIEREN VON COMPLEXEN ZAHLEN

```
      SUBROUTINE POCO(ARG,EX,RES)
      COMPLEX ARG,RES
      REAL*8 AIM,ARE,PHI,PSI,DCO,DSI,PI
      DATA AIM,ARE,PHI,PSI,DCO,DSI/6*0./,PI/3.1415926535898/
      IF(EX.NE.0.)  GO TO 3
      RES=CMPLX(1.,0.)
      RETURN
    3 CONTINUE
      AIM=AIMAG(ARG)
      ARE=REAL(ARG)
      R=SNGL(DSQRT(ARE*ARE+AIM*AIM))
      RHO=R**EX
      IF(ARE.NE.0) GO TO 1
      PHI=0.5*PI
      GO TO 2
    1 PHI=DATAN2(AIM,ARE)
    2 PSI=PHI*EX
      DCO=DCOS(PSI)
      DSI=DSIN(PSI)
      RES=RHO*CMPLX(SNGL(DCO),SNGL(DSI))
      RETURN
      END
```

===

SUBROUTINE TO PRINT TABLES OF COMPLEX FUNCTIONS

===

```
      SUBROUTINE SCRIVI(N,OM,FNAM1,COM1,FNAM2,COM2)
      COMPLEX COM,COM1(N),COM2(N)
      REAL*4 BETRAG(50),PHASE(50),BETR(50),PH(50),FMT(34),FMT1(3),
     1 FMT2(3),OM(50),FMAT(20),TEXT(15)
     1,OMLOG(50),Y(50)
      DATA TEXT(1)/'FUNC'/,TEXT(2)/'TICN'/
      DATA FMA/'67H '/,     FMT/'(1HC','3X,','122H',
     1                   '  OM','EGA ','    ','    ',' RE ','    ','    ',
     1'    ',' IM ','    ','    ',' MOD','    ','    ','    ',' PHA',
     2'SE  ','    ',' RE ','    ','    ','    ',' IM ','    ','    ',
     3' MOD','    ','    ','    ',' PHA','SE) '/,
     4FMT1/'(1P9','E14.','6)  '/,FMT2/'(1P5','E14.','6)  '/
      NOU=6
      DO 30 I=3,15
   30 TEXT(I)=FMT(6)
      JAPLOT=0
      IF(N.LT.0) JAPLOT=1
```

```
      N=IABS(N)
       RAD=57.29578
      FMT(7)=FNAM1
      FMT(11)=FNAM1
      FMT(14)=FNAM1
      FMT(18)=FNAM1
      FMT(21)=FNAM2
      FMT(25)=FNAM2
      FMT(28)=FNAM2
      FMT(32)=FNAM2
      NFALL=0
    6 DO 5 I=1,N
      COM=COM1(I)
      IF(NFALL.NE.0) COM=COM2(I)
      RE=REAL(COM)
      AIM=AIMAG(COM)
      IF(RE.EQ.0) GO TO 1
      PHA=ATAN2(AIM,RE)*RAD
      GO TO 3
    1 PHA=SIGN(90.,AIM)
      IF(AIM.EQ.0.) PHA=0.
    3 CONTINUE
      IF(NFALL.EQ.1) GO TO 2
      BETRAG(I)=CABS(COM)
      PHASE(I)=PHA
      GO TO 5
    2 BETR(I)=CABS(COM)
      PH(I)=PHA
    5 CONTINUE
      IF(FNAM2.EQ.FMT(6)) GO TO 4
      NFALL=NFALL+1
      IF(NFALL.EQ.1) GO TO 6
      WRITE(NOU,FMT)
      WRITE(NOU,FMT1) (OM(I),COM1(I),BETRAG(I),PHASE(I),
     1 COM2(I),BETR(I),PH(I),I=1,N)
      IF(JAPLOT.EQ.0) GO TO 7
      DO 16 I=1,N
      OMLOG(I)=ALOG10(OM(I))
   16 CONTINUE
      DO 31 IDPLOT=1,4
      YMAX=0.
      YMIN=10.
      DO 18 I=1,N
      GO TO (10,11,12,13),IDPLOT
   10 Y(I)=BETRAG(I)
      TEXT(4)=FNAM1
      TEXT(5)=FMT(15)
      TEXT(6)=FMT(6)
      GO TO 15
   11 Y(I)=PHASE(I)
      TEXT(4)=FNAM1
      TEXT(5)=FMT(19)
      TEXT(6)=FMT(20)
      GO TO 15
   12 Y(I)=BETR(I)
              TEXT(4)=FNAM2
      TEXT(5)=FMT(15)
      TEXT(6)=FMT(6)
      GO TO 15
   13 Y(I)=PH(I)
      TEXT(4)=FNAM2
      TEXT(5)=FMT(19)
      TEXT(6)=FMT(20)
   15 YMAX=AMAX1(YMAX,Y(I))
      YMIN=AMIN1(YMIN,Y(I))
   18 CONTINUE
      CALL PLOTA(OMLOG,Y,N,3,9,1,2,1,1,OMLOG(N),OMLOG(1),0,YMAX,YMIN,
     1 0, TEXT, IDPLOT,-1,OM(1),1.,OM(N),4HE9.2,1,-1,1,2,0,0)
   31 CONTINUE
      GO TO 7
    4 DO 8 I=1,19
    8 FMAT(I)=FMT(I)
      FMAT(3)=FMA
      FMAT(20)=FMT(34)
      WRITE(NOU,FMAT)
      WRITE(NOU,FMT2) (OM(I),CCM1(I),BETRAG(I),PHASE(I),I=1,N)
    7 RETURN
      END
=============================================================================

      SUBROUTINE ZSIG(ARG,RES)

=============================================================================
      COMPLEX J0,J1,SIG,RES
      COMPLEX CARG,WU,SARG,SARG1
      DIMENSION A(10),B(10)
      PI=3.141593
    1 CALL GEBCB(-ARG,ARG,0.,4,A,B,KEN)
      IF(KEN.NE.0) WRITE(6,100) KEN,ARG
  100 FORMAT('  KENN=',I10,'  ARG=',1PE15.8)
      IF(KEN.NE.0) GO TO 2
      J0=CMPLX(-A(1),-B(1))
      J1=CMPLX(-A(2),-B(2))
      SIG=CMPLX(-ARG,ARG)
      RES=-J0/(2.*SIG*J1)
      GO TO 4
    2 CARG=CMPLX(ARG,-ARG)
      WU=CSQRT(2./(PI*CARG))
      SARG=CARG+PI/4.
      SARG1=CARG-PI/4.
      J0=WU*(CSIN(SARG)+0.125/CARG*CSIN(SARG1))
      J1=WU*(CSIN(SARG1)+0.375/CARG*CSIN(SARG))
      RES=-J0/(2.*CARG*J1)
    4 CONTINUE
      RETURN
      END
=============================================

   SUBROUTINE TO CALCULATE THE STRUWE FUNCTIONS

=============================================
      SUBROUTINE STRF(ARG,H,KEN)
      COMPLEX *8 ARG,H(2),WU
      REAL*8 PI,GAM,FAK,RE,AI
      COMPLEX*16 Z,ZAE,SUM,ZZ,GLIED,H0,H1
     1 ,Y0,Y1,SARG,SARG1
      DATA PI/3.14159265358S8/
      KEN=0
      ASINT=CABS(ARG)
      FAK=2.00D 00/PI
      EX=1.
      AI=DBLE(AIMAG(ARG))
      RE=DBLE(REAL(ARG))
      X=1.
      Z=DCMPLX(RE,AI)
      ZZ=Z*Z
      IF(RE.GT.9.00D 00 ) GO TO 5
      GAM=1.00D 00
      ZAE=Z
      SUM=Z
    1 EX=EX+2.
      GAM=GAM*EX**2
      ZAE=ZAE*ZZ
      X=-X
      GLIED=X*ZAE/GAM
      IF(CDABS(GLIED/SUM).LT.1.0D-6) GO TO 12
      SUM=SUM+GLIED
      GO TO 1
   12 H0=FAK*SUM
      GAM=1.00D  00
      EX=3.
      X=1.
      GAM=GAM*EX
      SUM=ZZ/GAM
      ZAE=ZZ
    2 ZAE=ZAE*ZZ
      GAM=GAM*EX*(EX+2.)
      X=-X
      GLIED=X*ZAE/GAM
      IF(CDABS(GLIED/SUM).LT.1.CD-6) GO TO 15
      EX=EX+2.
      SUM=SUM+GLIED
      GO TO 2
   15 H1=FAK*SUM
      GO TO 6
    5 KEN=1
      SARG=Z-PI/4.
      SARG1=Z+PI/4.
      WU=0.7979/CDSQRT(Z)
      Y0=CDSIN(SARG1)
      Y1=0.125/Z*CDSIN(SARG)
      H1=WU*(-1.+3./(64.*ZZ))/(Y0+Y1)
      H0=1./ZZ
    6 CONTINUE
      RE=DREAL(H0)
      AI=DIMAG(H0)
      H(1)=CMPLX(SNGL(RE),SNGL(AI))
      RE=DREAL(H1)
      AI=DIMAG(H1)
      H(2)=CMPLX(SNGL(RE),SNGL(AI))
      RETURN
      END
```

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