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Abstract

A parametric thermohydraulic study for an Advanced Pressurized Light Water Reactor (APWR) with a tight fuel rod lattice has been performed. The APWR improves the uranium utilisation. The APWR core should be placed in a modern German PWR plant. Within this study about 200 different reactors have been calculated. The tightening of the fuel rod lattice implies a decrease of the net electrical output of the plant, which is greater for the heterogeneous reactor than for the homogeneous reactor. APWR cores mean higher core pressure drops and higher water velocities in the core region. The cores tend to be shorter and the number of fuel rods to be higher than for the PWR. At the higher fuel rod pitch to diameter ratios (p/d) the DNB limitation is more stringent than the limitation on the fuel rod linear rating given by the necessity of reflooding after a reactor accident. The contrary is true for the lower p/d ratios. Subcooled boiling in the highest rated coolant channels occurs for the most of the calculated reactors.

Eine parametrische thermohydraulische Untersuchung eines Fortgeschrittenen Druckwasser-Reaktors mit einer engen Brennstabteilung

Zusammenfassung

Eine parametrische thermohydraulische Untersuchung für einen Fortgeschrittenen Druckwasser-Reaktor (FDWR) mit einer engen Brennstabteilung wurde durchgeführt. Der FDWR verbessert die Uranausnutzung. Der FDWR-Kern sollte in einem modernen deutschen DWR von 1300 MWe eingebaut werden. Im Rahmen dieser Studie wurden etwa 200 Reaktoren berechnet. Das Engermachen der Brennstabteilung bedeutet eine Abnahme der elektrischen Nettoleistung des Kraftwerks. Diese Abnahme ist größer für einen heterogenen Reaktor als für einen homogenen Reaktor. FDWR-Kerne verlangen größere Druckverluste im Kern und höhere Wassergeschwindigkeiten im Kernbereich. Die Kerne sind kürzer und die Zahl der Brennstäbe höher als beim DWR. Die Begrenzung durch die kritische Heizflächenbelastung ist bei höheren Brennstabteilungen maßgebender als die der Brennstableistung, welche durch die Notwendigkeit des Reaktorflutens nach einem Reaktorunfall bedingt wird. Das Gegenteil tritt bei niedrigeren Brennstabteilungen ein. Unterkühltes Sieden in den höchstbelasteten Kühlkanälen findet bei den meisten berechneten Reaktoren statt.

A Parametric Thermohydraulic Study of an Advanced Pressurized Light Water Reactor with a Tight Fuel Rod Lattice

by

M. Dalle Donne and W. Hame

1. Introduction

Recently the Karlsruhe Nuclear Research Center and Kraftwerk Union, in collaboration with the Technical University of Braunschweig, have started an investigation on the possibility of increasing the conversion ratio of a Pressurized Light Water Reactor in order to improve the uranium utilisation /1,2/. The fuel element is based on UO_2-PuO_2 fuel, where the plutonium vector for the fresh fuel is given by the fuel discharged from a Light Water Reactor. Two types of cores have been considered: a modular core formed by hexagonal fuel elements containing an external blanket with lower enrichment and an internal seed with higher enrichment /3/ and a homogeneous core where all the rods in the core have the same diameter /2/.

The results of preliminary parametric thermohydraulic calculations for these two types of core configurations have been published /4/. However these calculations have been performed with a very simple computer program. Since then, the computer code has been rewritten and considerably improved. In the present paper we shall give a description of how the calculations are performed, of the assumptions used in the calculations and detailed information on the results obtained.

2. Main Assumptions for the Thermohydraulic Calculations

For both alternatives mentioned in the introduction the water volume fraction in the core must be considerably smaller than in a PWR, thus the neutron spectrum becomes harder and the conversion ratio higher. As a consequence the pressure drop across the core is increased. The main boundary condition is that this high converting core should be placed in a modern PWR plant of German design, with only some changes of the main components such as the pressure vessel lid, possibly the primary circuit water pumps and some pressure vessel internals. In our calculations we assume that the primary circuit water pumps should be the same as those used in the PWR, thus, to compensate for the higher hydraulic resistance of the core, the water flow is reduced. This might imply a decrease of the reactor thermal output, which can be partly compensated by an increase of the coolant temperature rise across the core. This essentially means a decrease of the water temperature at the core inlet, because to avoid boiling the core outlet water temperature cannot be increased. A decrease of the water temperature at core inlet means of course a corresponding decrease of the temperature of the water at the outlet of the heat exchangers on the primary circuit side. As a consequence of this, the boiling temperature and pressure of the water of the secondary circuit must be decreased because we mantain the same heat exchangers as in the PWR. The turbine gets the same steam volume flow as for the PWR, but with a less dense working fluid; thus one can assume with a good approximation that the turbine power de-decreases proportionally to the steam pressure. Furthermore the thermodynamic efficiency decreases slightly due to the de-crease of the boiling temperature. Thus the smaller coolant volume fraction in the reactor core leads to a decrease of the net electrical power of the plant. The present paper investigates this functional dependence for a large modern PWR of German design.

3. Plant Operating Conditions at Lower Power

If K is the ratio of the turbine pressure for the Advanced Pressurized Light Water Reactor (APWR) case to the turbine pressure for the PWR case, one can write:

$$p_s = K\, p_{so} \qquad (1)$$

and for the reasons discussed in section 2 the reactor thermal output is reduced by the same ratio:

$$Q = K\, Q_o \qquad (2)$$

The steam saturation temperature at the turbine is given by:

$$T_s = f_s(p_s) \qquad (3)$$

where f_s is the saturation function for water.
The average enthalpy of the water at the core outlet is obtained as a function of temperature and pressure:

$$H_2 = f(T_2, p_{2,o}) \qquad (4)$$

(because we keep the pressure constant at the core outlet: $p_2 = p_{2,o}$) and the average enthalpy at core inlet is given by:

$$H_1 = H_2 - \frac{Q}{M} \quad (5)$$

where M is the total mass flow of water in the primary circuit. The core inlet pressure drop is given by:

$$p_1 = p_2 + \Delta p_c{}^{+)} \quad (6)$$

(Δp_c = core pressure drop) and the core inlet water temperature can be obtained from

$$T_1 = f(H_1, p_1) \quad (7)$$

The heat transfer characteristics of a typical PWR of 1300 MWe of KWU design may be described by the following equations /5/:

$$T_1 = T_s + \frac{T_2 - T_1}{e^y - 1} \quad (8)$$

$$y = \frac{KF(T_2 - T_1)}{Q+N} \quad (9)$$

$$KF = \frac{KF_o}{0.58+0.18K^{0.24} + 0.24\left(\frac{M_o}{M}\right)^{0.8}} \quad (10)$$

where N is the power required to pump the water in the primary circuit and KF is the average total heat transfer coefficient times the total surface of the heat exchangers, as a function of water mass flow at the primary circuit and of the steam pressure at the secondary circuit.

The water temperature at the outlet of the hot channel is given by:

+) For the calculation of p_1 we neglect the small difference between Δp_c (irreversible or friction core pressure drop) and Δp_{tot} inclusive of the reversible pressure drops as well (see eq. (52) to (55) below)

$$T_{2H} = T_1 + F_{\Delta H}\, O_P (T_2 - T_1) \qquad (11)$$

where $F_{\Delta H}$ is the hot channel factor for the water enthalpy rise in the core (it includes the radial form factor of the power distribution as well). For the present study we assume $F_{\Delta H} = 1.6$ as in a PWR /5/. O_P is an overpower factor. Calculations for nominal reactor operation are made with $O_P = 1$, however a PWR, and thus an APWR, must be able to operate with an overpower, usually of 12% ($O_P = 1.12$).

In a normal PWR one allows a small amount of vapor in the hot channels. However in the present design we will be more conservative, especially because smaller coolant channels, due to the tight fuel rod lattice, could favour flow instabilities between various channels in parallel, and we shall require that the temperature T_{2H} is equal to the saturation temperature at the core outlet pressure:

$$T_{2H} = f_s(p_2) \qquad (12)$$

The water density at reactor core inlet may be calculated from

$$\rho_{1,o} = f(p_{1,o}, T_{1,o}) \qquad (13)$$

$$\rho_1 = f(p_1, T_1) \qquad (14)$$

while the average water density in the core results from

$$\rho_{av,o} = f(p_{av,o}, \frac{T_{1,o} + T_{2,o}}{2}) \qquad (15)$$

$$\rho_{av} = f(p_{av}, \frac{T_1 + T_2}{2}) \qquad (16)$$

where

$$p_{av} = \frac{p_{1,o} + p_{2,o}}{2} \qquad (17)$$

$$p_{av} = \frac{p_1 + p_2}{2} \qquad (18)$$

In a German PWR of the 1300 MWe class there are 4 main pumps in parallel in the primary water circuit, thus the water volume flow at each pump is:

$$V = \frac{M}{4\rho_1} \tag{19}$$

where we have assumed that the water density at the pumps is equal to the water density at the core inlet (pressure and temperature are practically the same).

The total pressure head of the standard pumps for the German 1300 MWe PWR, given in a graph of reference /5/ as a function of water volume flow, has been fitted with the following analytical expression:

$$H_T = 111.678 + 22.244\,V - 4.0524V^2 \tag{20}$$

For the APWR only the hydraulic resistance of the core changes, while the rest of the primary circuit remains the same as in the PWR. Thus the pressure head available for the core is given by:

$$H_c = H_T - H_{R,o}\left(\frac{M}{M_o}\right)^2 \frac{\rho_{1,o} \times \rho_{av,o}}{\rho_1 \times \rho_{av}} \tag{21}$$

where $H_{R,o}$ is the pressure head required by the rest of the circuit.

Finally, the pressure drop available for the core is given by:

$$\Delta p_c = 9.80665\times10^{-5}\times H_c\rho_1 \tag{22}$$

The power of the four primary circuit water pumps N, which appears in equation (9), is a function of M:

$$N = N_o \frac{H_T\times M}{H_{To}\times M_o} \tag{23}$$

We have solved the system of 23 equations with 24 variables ($T_1, T_2, T_{2H}, T_s, p_1, p_s, \Delta p_c, H, H_2, Q, K, M, y, KF, \rho_{1,o}, \rho_1, \rho_{av,o}, \rho_{av}, p_{av,o}, p_{av}, V, H_T, H_c, N$). The constant values used in the equations (symbols with the subscript 'o') are those of a modern German PWR of the 1300 MWe class. These values are shown in Table I and they have been obtained either from the open literature or from Ref. /5/. The thermodynamic and physical properties used in the present calculations have been obtained from Ref. /6/.

The system of 23 equations in 24 variables has one degree of freedom and allows the establishment of a relationship between Q and Δp_c: if we reduce the total reactor thermal output we can allow a higher pressure drop for the core. Of course for each pair of values of Q and Δp_c, all the other variables (in particular T_1 and T_2) are fixed. We would like to recall here that the pressure at core outlet is fixed ($p_2 = p_{2,o}$), this of course being a condition imposed by the fact that we want to use the standard reactor pressure vessel of the 1300 MWe PWR.

For each value of Δp_c the plant net electrical power is calculated considering the variations in T_s, Q and N:

$$Q_{el,net} = \frac{T_s + 273,16 - T_o}{T_s + 273,16} (Q+N) - N_{el,o} \qquad (24)$$

where $N_{el,o}$ is the total electrical power required for internal use in the plant (inclusive of the electrical power N required by the primary pumps; in this we neglect the small variations of N relative to the considerably greater value of $N_{el,o}$), T_o is an equivalent reject heat temperature calculated in such a way that equation (24) is satisfied by the values of the variables for the reference PWR (see Table I).

4. Homogeneous Reactor: Pressure Drop Calculations

In the homogeneous reactor all the fuel rods have the same diameter. Due to the fact that the amount of moderator (water) in the core should be as low as possible in a APWR, to increase the average energy of the neutrons and thus the fuel conversion ratio, the fuel rod lattice is very tight. For minimum distances between the fuel rods of less than 1 mm the practical use of grid spacers becomes difficult because the crosspieces of the grid would be too thin and the grid too weak /7/. Furthermore, with tight lattices the solidity of the grid (ratio of the cross section area of the grid to the cross section area of the coolant channel without grid) becomes too high and the pressure drop caused by the grid is excessively high. Thus for the homogeneous reactor core we propose to use spacers formed by six integral spiral ribs per rod. This type of spacer has been suggested in the past for other types of reactors (see for instance Ref. /8/) and tubes of stainless steel with integral spiral ribs have been manufactured in the sizes suitable for nuclear fuel rods. It is not clear at this stage if these tubes may be manufactured in zircaloy.

The fuel rods in a PWR are usually arranged in a square array. For an APWR, the triangular rod array is preferred because the minimum distance between the rods is greater for a given water fraction and rod diameter. Indeed this minimum distance is given for a square array by

$$p-d = d\left[\sqrt{\frac{\pi}{4(1-\alpha)}} - 1\right] \qquad (25)$$

and for a triangular array by

$$p-d = d\left[\sqrt{\frac{\pi}{2\sqrt{3}(1-\alpha)}} - 1\right] \qquad (26)$$

where p is the pitch of rods, d the rod diameter and α is the water fraction of the unit cell in the array (square or triangular). The calculations are performed for various values of p and d. The thickness of the integral spiral ribs is related to the minimum distance between the rods:

$$b = K_o (p-d) \qquad (27)$$

Experience suggests spiral ribs with a thickness equal to $\frac{2}{3}$ of the rib height, thus $K_o = \frac{1}{3}$, however if equation (27) gives values of b less than 0.4 mm, we have taken b = 0.4 mm which is the smallest thickness of integral spiral pins, to our knowledge, so far manufactured.

The area of the unit cell is given by:

$$A_c = \frac{p\sqrt{3}}{4} \qquad (28)$$

the cell water flow area:

$$A = A_c - \frac{\pi d^2}{8} - 1.5(p-d)b \qquad (29)$$

and the hydraulic diameter of the coolant channel:

$$d_h = \frac{4A}{\frac{\pi d}{2} + 3(p-d)} \qquad (30)$$

The average rod linear power rating should be chosen on the base of considerations of the possibility of reflooding the core after a Loss of Coolant Accident (LOCA). Indeed the hydraulic resistance of a APWR core is considerably higher than that of a PWR core and the time required to flood the core after a LOCA may be higher, (an advantage for the APWR is the fact that the core, being shorter, is also lower than in the case of the PWR: cf. Ref. /1/ and /3/). To avoid an unduly high increase of the cladding temperature during the time between the LOCA and the quenching action of the flooding water, a reduction of the average fuel rod linear rating may be required. This rating for a modern German 1300 MWe PWR is q_L=2.08×10^4 W/m /2/. Preliminary LOCA and reflooding calculations performed at KWU with a computer code tested for a PWR /2/ have shown that this linear rating should be decreased with decreasing values of p/d; i.e. for p/d = 1.1 and 1.2, q_L values of 1.6 x 10^4 W/m and 1.8 x 10^4 W/m respectively have been suggested /5/. The p/d value for the 1300 MWe PWR is p/d = 1.43 (for an equivalent triangular array, i.e. for a triangular array with the same α). The calculation of q_L has been thus performed with the following equation:

$$q_L = \left[-372.27 + 744.11 \frac{p}{d} - 236.57 \left(\frac{p}{d}\right)^2\right] 10^2 \qquad (31)$$

which fits the three values given above.
The useful total cross section area of the core (that is the area occupied by the fuel rods and the relative water cooling channels) is given by:

$$A_T = K_1 \frac{\pi}{4} D_{eq}^2 \qquad (32)$$

where K_1 is a correction factor which takes account of the area occupied by the interspace between fuel elements and by the control and tie rods and their relative cooling water. A detailed design of the fuel element of a particular homogeneous core performed in collaboration with Kraftwerk Union has shown that K_1=0.92 /2/ and for the present parametric calculations we shall assume this value of K, independently of the variations of p and d. D_{eq} is the equivalent diameter of the core (=diameter of the circle which has the same cross section area as the actual core). The inner diameter of the core barrel in a pressure vessel of the 1300 MWe German PWR is 4.21 m, however D_{eq} must be considerably smaller for the following reasons:

- space between the core barrel inner surface and the outer elements is necessary for the charge and discharge operations
- the outer row should be made of shield elements to protect the core barrel walls from the neutrons coming from the APWR core, which has of course a harder spectrum than the PWR
- even with relatively small hexagonal fuel elements the maximum outer diameter of the actual core is always greater than D_{eq}.

The detailed design performed for the homogeneous reactor of Ref. /2/ shows that a core with $D_{eq} = 3.733$ m may be contained in the core barrel of the 1300 MWe PWR. We have assumed this value for the present calculations.

We can then obtain the total number of fuel rods:

$$n_T = \frac{A_T}{2A_c} \qquad (33)$$

and the core active length:

$$L_c = \frac{Q}{n_T q_L} \qquad (34)$$

The total length of the fuel rods is given by L_C plus the length of the fission gas plenum and of the end pieces. If we allow the same maximum fission gas pressure as in the PWR fuel rods, the fuel rod total length is given by:

$$L_R = L_c + \frac{51000}{33300}\,\frac{0.48}{3.90}\,L_c + 0.02 = 1.1885\,L_c + 0.02 \qquad (35)$$

where 51000 MWd/t = discharge burn-up forseen for the APWR /2/
33300 MWd/t = discharge burn-up for the PWR fuel
0.48 m = length of the plenum for the PWR rods
3.90 m = PWR core active height
0.02 m = length of the endpieces

If M is the total water mass flow in the primary circuit, the mass flow of water which actually cools the fuel rods is ("useful mass flow"):

$$M_u = M \frac{2n_T A}{2n_T A + (1-K_1) K_2 \frac{\pi}{4} D_{eq}^2} \tag{36}$$

where K_2 is fraction of the "non-useful" cross section area (interface between fuel elements, control and tie rods) occupied by flowing water. In the present calculation we assume $K_2 = 0.5$. In equation (36) the assumption is implicit that the water velocity and density are the same in the "useful" and "non-useful" cross section areas of the core. This is a good approximation because the interspace between the fuel elements in very small and the outer diameter of the tie rods and of the control rods is not very different from the fuel rod diameter.

The average water enthalpy and temperature at the outlet of the coolant channels may be then calculated:

$$H_{2u} = H_1 + \frac{Q}{M_u} \tag{37}$$

$$T_{2u} = f(H_{2u}, p_2) \tag{38}$$

and subsequently the average properties of the water in the coolant channels:

$$p_{av} = \frac{p_1 + p_2}{2} \tag{39}$$

$$T_{av} = \frac{T_1 + T_{2u}}{2} \tag{40}$$

$$\rho_{av} = \rho(p_{av}, T_{av}) \tag{41}$$

$$\eta_{av} = \eta(p_{av}, T_{av}) \tag{42}$$

$$\nu_{av} = \eta_{av}/\rho_{av} \tag{43}$$

The average water velocity is:

$$u = \frac{M_u}{2n_T A \rho_{av}} \tag{44}$$

and the Reynolds number:

$$Re = \frac{u d_h}{\nu_{av}} \tag{45}$$

The pressure drop for a cluster of rods with spiral spacers may be calculated with the correlation of Ref./9/. This correlation was obtained from experiments with spiral wires, however subsequent experiments /10,11/ have shown that it is valid for integral spiral ribs as well for $p/d \geq 1.125$. Recent experiments /12/ have shown that this correlation is valid down to $p/d \geq 1.03$, at least for spiral ribs with relatively high axial pitches ($H/d \geq 37$). These high axial pitches are relevant for the present calculations, because for the APWR it is necessary to reduce the core pressure drop as much as possible. For the present calculations we have chosen $H/d=50$.

Following Ref./9/ a new Reynolds number is defined:

$$Re' = Re\sqrt{F} \tag{46}$$

with

$$F = \left(\frac{p}{d}\right)^{0.5} + \left[7.6\ \frac{(p/d)^3}{(H/d)}\right]^{2.16} \tag{47}$$

and the friction factor for the flow of water in the cluster of rods with integral spiral ribs is:

$$\lambda = 0.1317 \; F \times C \; Re'^{-0.17} \qquad \text{for} \quad Re' \geq 1.9 \times 10^4 \tag{48}$$

$$\lambda = F \times C \left[0.1317 \; Re'^{-0.17} + \frac{60}{Re'} - 3.2 \times 10^{-3} \right]$$

$$\text{for} \quad 2 \times 10 \leq Re' < 1.9 \times 10^4 \tag{49}$$

C is a correction factor which allows the application of equations (48) and (49) down to $1 \leq p/d < 1.03$:

$$C=1 \qquad \text{for} \qquad p/d \geq 1.03 \tag{50}$$

$$C=1.6-e^{-\frac{p/d-1}{0.05873}} \qquad \text{for } 1 \leq p/d < 1.03 \tag{51}$$

Equation (51) has been obtained by interpolation between the values of equations (48) (49) down to p/d=1.03 and the experimental values available for p/d=1 (for a resumé of the data at p/d=1 see for instance Ref./13/).

The irreversible core pressure drop may thus be calculated:

$$\Delta p = \left[K_I + \frac{\lambda L_R}{d_h} \right] \frac{\rho_{av} \; u^2}{2} \; 10^{-5} \tag{52}$$

where K_I is the inlet pressure drop coefficient. It takes account of the acceleration and losses at the bundle inlet. In the present calculation we assume K_I=1.2 and neglect the pressure recovery at the core outlet. This value is suggested by experiments with rod bundles (see for instance Ref./14/).

By means of equations (27) to (52) we obtain a value of Δp for each pair of values p and d, and by putting Δp_C (pressure drop available for the core) equal to Δp+) (pressure drop caused by the required flow of water through the chosen core characterized by p and d), we obtain for each chosen geometry of the core (p,d) a certain value of Q, i.e. the amount of heat we can extract from the core, and of course the net electrical output of the plant as well (eq.(24)).

+) We consider here only the irreversible pressure drop component of the total core pressure drop, because it is only this component which goes into the calculation of the pumping power. The elevation and acceleration pressure drops are recovered in the other parts of the primary water circuit.

We may also calculate the reversible core pressure drop due to the acceleration caused by the change in temperature ($\Delta p_{acc.}$) and the core pressure drop due to the elevation difference ($\Delta p_{el.}$):

$$\Delta p_{acc} = 10^{-5} \rho_{av}^{2} u^{2} \left(\frac{1}{\rho_2} - \frac{1}{\rho_1}\right) \tag{53}$$

$$\Delta p_{el} = 9.80665 \times 10^{-5} L_R \rho_{av} \tag{54}$$

and

$$\Delta p_{tot} = \Delta p + \Delta p_{acc} + \Delta p_{el} \tag{55}$$

This value is of interest for the fuel element mechanical design.

Finally the ratio between area occupied by the water (moderator) and the fuel rods is calculated:

$$\frac{V_M}{V_F} = \frac{2n_T A + (1-K_1') K_2 \frac{\pi}{4} D_{eq}^2}{n_T \frac{\pi d^2}{4}} \tag{56}$$

This value is of interest for the neutronic calculations.

5. <u>Heterogeneous Reactor: Pressure Drop Calculations</u>

In the heterogeneous reactor the fuel elements are made up of two portions:

- The "seed" with a higher fissile enrichment (in our case plutonium) and thus a higher power density. The high power density requires the use of fuel rods of small diameter (the number of rods per unit volume increases) because the maximum fuel rod temperature and thus the rod linear rating are independent of the fuel rod diameter. Furthermore cooling requirements require larger coolant channels i.e. relatively high values of p/d ($p/d \geq 1.2$). These high values of p/d dictate the choice of the spacers, which have to be grid spacers placed in discrete positions along the length of the fuel rods.

- The "blanket" with a lower fissile enrichment and thus a lower power density. The lower power density allows the use of bigger fuel rod diameters. The cooling requirements are not so stringent as in the seed case, thus the coolant channels may be relatively smaller (lower values of p/d). This dictates the choice of the spacers, which, as in the case of the homogeneous reactor, are integral spiral ribs.

While the function of the seed is mainly that of producing power and fission neutrons, the function of the blanket is mainly that of converting fertile into fissile material and thus of increasing the overall core conversion ratio. In each fuel element the seed is placed in the center, while the blanket surrounds the seed (see for instance Ref./3/). This type of fuel element configuration is similar to that of the Shippingport Light Water Breeder Reactor (LWBR) /15/, however there is a basic difference. While in the LWBR the reactor control is obtained by the movement of the seed in axial direction, in the present design we have preferred a non-movable seed and blanket and operate the reactor control and shut-down with the usual system of movable neutron absorbing rods. The use of a LWBR type of fuel element would cause a decrease of the plant net electrical power of about 40%, if one uses only two fuel element enrichments (one for the seed and one for the blanket) plus an axial blanket with depleted uranium /16/. To obtain about the same plant power with the boundary conditions of the present study, and a movable seed, requires the use of a fuel element with 18 different enrichments in seed and blanket and the adoption of a movable seed shorter in axial direction than the blanket, so that during the total fuel element life the seed is always surrounded by the blanket /17/.
The flow of the cooling in the core is divided into two parts: one for the cooling of the seed and one for the blanket. The optimum thermohydraulic design of the fuel element requires that the water temperature rise across the seed and the blanket is the same when the flow of cooling water in the two parts of the fuel element is such that the pressure drop is the

same, without the use of any extra flow orificing device in seed and blanket.

Two other boundary conditions are required to define the geometry of the heterogeneous fuel element:

- the ratio between the seed and the blanket volume in the fuel element
- the ratio between the volumetric power density in the seed and in the blanket.

These two parameters have an effect not only on the core thermal output, but on the conversion ratio and fuel inventory as well. Improvements in conversion ratio require large blanket volumes with lower power densities in the blanket (lower fissile enrichment in the blanket), while to increase the core thermal output it is necessary to decrease the blanket volume and increase the power density in the blanket as well. It is clear that in practice a reasonable compromise between these two requirements is required. For the present calculations we shall adopt the values used in the core of the LWBR /15/ and in the design suggested by A. Radkowsky /17/, i.e. volume ratio between seed and blanket equal to 0.5, and power density ratio between seed and blanket equal to 2. This means that the thermal output of the seed and of the blanket are the same.

5.1 Pressure drop calculations in the seed

The "useful" total area of the seed (that is the area occupied by the seed rods and the relative water cooling channels) is:

$$A_{TS} = K_1 \, K_{2S} \, \frac{\pi}{4} \, D_{eq}^2 \tag{57}$$

where K_1 is the volume splitting between seed and blanket (in our case $K_1 = \frac{1}{3}$: see previous section); K_{2S} takes account of the useful area in the seed, i.e. total area minus area occupied by the interspace between seed and blanket and by the control and tie rods in the seed and relative cooling water.

The useful total area of the blanket is :

$$A_{TB} = (1-K_1)\ K_{2B}\ \frac{\pi}{4}\ D_{eq}^2 \qquad (58)$$

where K_{2B} takes account of the interspace between fuel elements and of the tie rods in the blanket (the control and shut-down rods are all in the seed). A detailed design of the fuel element of a heterogeneous reactor performed in collaboration with Kraftwerk Union has shown that $K_{2S}=K_{2B}=0.88$ /3/. D_{eq} is of course the same as in the case of the homogeneous reactor i.e. $D_{eq}=3.733$ m.

The calculations are performed by choosing as the two variable parameters the volume power density in the seed, q_{vS}, and the outer diameter of the seed fuel rod, d_S.

The area of the unit seed cell is:

$$A_{cS} = \frac{q_{LS}}{2q_{vS}} \qquad (59)$$

where q_{LS} is the average fuel rod linear rating in the seed. The seed rod pitch is thus (triangular rod array):

$$p_S = \sqrt{\frac{4}{\sqrt{3}}\ A_{cS}} \qquad (60)$$

and q_{LS} may be calculated from equation (31) as a function of p_S/d_S.
The blanket volumetric power density is:

$$q_{vB} = K_3 \ q_{vS} \tag{61}$$

where K_3 is the power splitting factor between seed and blanket (in our case $K_3 = 0.5$; see previous section)

The total number of seed rods in the case is given by:

$$n_S = \frac{A_{TS}}{2A_{cS}} \tag{62}$$

and the core active length:

$$L_c = \frac{Q}{A_{TS} \ q_{vS} + A_{TB} \ q_{vB}} \tag{63}$$

The fuel rod total length is calculated with equation (35) as in the case of the homogeneous reactor.

The area available for the flowing water in the seed unit cell is:

$$A_S = A_{cS} - \frac{\pi}{8} d_S^2 \tag{64}$$

and the hydraulic diameter of the coolant channel

$$d_{hS} = \frac{8A_S}{\pi d_S} \tag{65}$$

If we assume that the fractional area available for the flowing water and the water average velocity are the
same in the "useful" and "not useful" region of the seed (the detailed design of fuel element /3/ has shown that this is possible) the average water enthalpy at the outlet of the seed coolant channels is:

$$H_{2uS} = H_1 + \frac{H_2 - H_1}{K_{2S}} \tag{66}$$

The average water temperature at the outlet of the seed coolant channels T_{2uS} and the average properties of the water in the seed coolant channels may be calculated with equations similar to equations (38) to (43). The average water velocity in the seed is:

$$u_S = \frac{q_{LS} \times L_c}{2\ \rho_{avS} \times A_S \times (H_{2uS} - H_1)} \qquad (67)$$

while the seed coolant channel Reynolds number is given by

$$Re_S = \frac{u_S\ d_{hS}}{\nu_{avS}} \qquad (68)$$

In the seed we do not use integral spiral ribs, but rather spacer grids in discrete axial positions of the fuel elements. The friction factor may be calculated with the correlation valid for the one-phase turbulent flow of a fluid in a regular triangular array of rods:

$$\lambda_S = \lambda_{TS}\ C_S \qquad (69)$$

where λ_{TS} is the friction factor for the flow inside a tube (Prandtl-Nikuradse relationship):

$$\lambda_{TS} = \frac{1}{\left[2\ \lg(Re_S \sqrt{\lambda_{TS}}) - 0.8\right]^2} \qquad (70)$$

and C_S is correction factor which takes account of the bundle geometry:

$$C_S = \left[1 - e^{-\frac{p_S/d_S - 1}{0.0265}}\right] \times \left[1.036 + 0.054\,(p_S/d_S - 1)\right] \qquad (71)\ /18/$$

The irreversible pressure drop in the seed is given by:

$$\Delta p_S = (K_I + \lambda_S \frac{L_R}{d_{hS}} + n_G\, C_v\, \varepsilon^2)\ \frac{\rho_{avS}\, u_S^2}{2}\ 10^{-5} \tag{72}$$

where n_G is the number of spacer grids, given by:

$$n_G = \frac{L_c}{L_{Sc}} + \frac{L_R - L_c}{L_{SR}} + 1 \tag{73}$$

where L_{Sc} is the grid axial spacing in the active core region and L_{SR} is the axial grid spacing in the plenum region of the seed rods. The present calculations have been performed with L_{Sc} = 0.15 m and L_{SR} = 0.20 m, which appear to be reasonable from a practical design point of view /19/. ε is the solidity of the spacer grid, i.e. the ratio of the cross section area of the grid to the cross section area of the coolant channel without grid. ε is mainly a function of the minimum distance between the rods $(p_S - d_S)$. From practical grid designs /19/ the following empirical relation is obtained:

$$\varepsilon = 0.6957 - 162.8\ (p_S - d_S) \tag{74}$$

Equation (74) is of course valid for small $(p_S - d_S)$ values (from 1 to a few millimeter). p_S and d_S must be given in meters in eq.(74). The factor K_I in equation (72) is chosen equal to 1.2 as in the calculations for the homogeneous reactor, while C_V, the modified drag coefficient of the grid, is chosen equal to 7. Reference /20/ suggests that for a well-made spark-eroded grid with smooth edges it is possible to achieve at high Reynolds numbers the favourable value C_V=7.

5.2 Pressure drop calculations in the blanket

The area of the unit blanket cell is given by:

$$A_{cB} = \frac{q_{LB}}{2q_{vB}} \tag{75}$$

with q_{LB} = average rod linear rating in the blanket (q_{LB} is not yet known at this stage of the calculation; it is calculated by iteration: see the end of this section beyond eq.(80))

q_{vB} = volumetric power density in the blanket, from eq.(61)

The blanket rod pitch is:

$$p_B = \sqrt{\frac{4}{\sqrt{3}} A_{cB}} \tag{76}$$

and the total number of blanket rods in the core:

$$n_B = \frac{A_{TB}}{2A_{cB}} \tag{77}$$

(A_{TB} from eq.(58))

The calculation now proceeds by iteration because the diameter of the blanket rods d_B is not yet known. Assuming a first iteration value for d_B, we calculate A_B (cell water flow area in the blanket) and d_{hB} (hydraulic diameter of the coolant channel) with equations similar to equations (27) to (29) and (30) because here, as in the homogeneous reactor, we have integral spiral rib spacers.

The average water enthalpy at the outlet of the blanket coolant channels is calculated with an equation similar to Eq.(66):

$$H_{2uB} = H_1 + \frac{H_2 - H_1}{K_{2B}} \tag{78}$$

The water temperatures, pressures and average physical properties are calculated with equations similar to Eqs.(38) to (43). The average water velocity in the blanket is:

$$u_B = \frac{q_{LB} \times L_c}{2\ \rho_{avB} \times A_B \times (H_{2uB} - H_1)} \qquad (79)$$

The Reynolds number Re_B, the friction factor λ_B and the irreversible pressure drop in the blanket Δp_B are calculated with the same method used for the homogeneous reactor (eqs.(45) to (52)). The iteration is stopped when the chosen d_B is such that the pressure drop in seed and blanket are the same:

$$\Delta p_S = \Delta p_B \qquad (80)$$

The determination of d_B allows the calculation of p_B/d_B and thus of q_{LB} as a function of p_B/d_B from equation (31). q_{LB} can then be used in equation (75) and this closes the second iteration loop.

The total core pressure drop is calculated with equations similar to equations (53) to (55). Finally the ratio between area occupied by the water (moderator) and the fuel (seed and blanket) rods is calculated:

$$\frac{V_M}{V_F} = \frac{2n_S A_S + 2n_B A_B + \left[K_1(1-K_{2S})\left(\frac{2\sqrt{3}}{\pi}\left(\frac{p_S}{d_S}\right)^2 - 1\right) + (1-K_1)(1-K_{2B})\left(\frac{2\sqrt{3}}{\pi}\left(\frac{p_B}{d_B}\right)^2 - 1\right)\right]\frac{\pi}{4} D_{eq}^2}{n_S \frac{\pi d_S^2}{4} + n_B \frac{\pi d_B^2}{4}} \qquad (81)$$

By means of equations (57) to (80) we obtain a value of $\Delta p_S = \Delta p_B$ for each pair of values of q_{VS} and d_S, and by putting Δp_C (pressure drop avaiable for the core: see section 3) equal to $\Delta p_S = \Delta p_B$ (pressure drop caused by the required flow of water through the chosen core characterized by q_{VS}, d_S and the condition that the average water enthalpy rise in seed and blanket are the same: the values of H_1 and H_2 used in eqs.(66) and (78) are the same), we obtain for each chosen case of heterogeneous core (d_S, q_{VS}) a certain value of Q and of the net electrical output of the plant (Eq.(24)).

6. Critical Heat Flux Calculations

With the choice of two parameters (p and d for the homogeneous cores; q_{VS} and d_S for the heterogeneous ones) we have now completely defined the reactor core (geometry, flow, temperature and pressure conditions). This was done in sections 3, 4 and 5 based not only on hydraulic considerations (pressure drop calculations), but also on heat transfer considerations. That is, we considered the limitation of the rod linear rating as a function of p/d (Eq. (31)) and the limitation of the water temperature at the outlet of the hot channel equal to the water saturation temperature at core outlet pressure (Eq.(11)). However there are two further heat transfer considerations:

- The maximum heat flux at the surface of the fuel rods, also under overperpower conditions, should always be lower than the local critical heat flux
- The nominal fuel rod surface temperature should be such that no subcooled boiling occurs over too large a portion of the coolant channels.

The first condition is self explaining. The second is due to the requirement of avoiding excessive formation of vapor in the coolant channels between the fuel rods, even in narrow regions near the fuel rod surface. This to avoid flow instability phenomena due to local decrease of coolant density and the resulting increase of the pressure drop (Ledinegg instability, see for instance Ref. /20/).

In the present section we will deal with the first requirement, while the second will be treated in the next section.
We can assume as a good approximation a chopped cosine axial power distribution in the core. Thus the water axial temperature distribution in the hot coolant channel is:

$$T_{HS}(x) = F_{\Delta H} O_P \frac{T_{2u}-T_1}{2} \left(1 + \frac{\sin \frac{\pi x}{L'_C}}{\sin \frac{\pi L_C}{2L'_C}}\right) \qquad (82)$$

where O_P=1 for nominal operating conditions, and O_P=1.12 for power plant overpower conditions. x is the axial distance of the considered section measured from the core center. We are here interested only in positive values of x (between 0 and $\frac{L_c}{2}$) because only in this portion of the core could a critical flux occur. L'_c (core extrapolated length) may be calculated once the axial power form factor φ_{ax} is known:

$$\frac{1}{\varphi_{ax}} = \frac{2L'_c}{\pi L_c} \sin \left(\frac{\pi L_c}{2L'_c}\right) \qquad (83)$$

φ_{ax} is calculated from the neutronic core calculations. For the present study we have assumed a constant value of φ_{ax}, obtained for a homogeneous APWR /2/, i.e. $\varphi_{ax} = 1.43$.

The pressure distribution along the cooling channels is assumed to be linear:

$$p(x) = \frac{p_1+p_2}{2} - (p_1-p_2)\frac{x}{L_c} \qquad (84)$$

The hot spot heat flux distribution at the surface of the fuel rods is:

$$\phi_{HS}(x) = F_q O_P \frac{q_L}{\pi d} \cos \frac{\pi x}{L'_c} \qquad (85)$$

where F_q is the hot channel factor for the heat flux at the fuel rod surface (it includes the product of the radial form factor times the axial form factor). For the present study we assume F_q=2.1 like in a PWR /5/.

In the literature one can find many critical heat flux correlations for rod clusters. For the present study we have used as a reference correlation the critical heat flux correlation of Dalle Donne and Hame /22/ which was developed especially for the APWR application. Calculations were performed using the Shippingport /23/, the WSC-2 /24/ and the B&W-VPI&SU /25/ correlations as well. The results reported here refer only to the correlation of Ref./22/. Comparison with the other correlations will be only shortly discussed in the conclusions of the present paper.

The calculations of the critical heat flux are performed as follows /22/:

$$G_B = 0.73735\times10^{-3}\ \rho_{av}u \tag{86}$$

$$d_{hB} = 39.37\ d_h \tag{87}$$

$$B = 0.25\ d_{hB}G_B \tag{88}$$

$$p_r = 14.504\times10^{-3}\ p(x) \tag{89}$$

$$F_1 = p_r^{0.982}\ e^{1.17(1-p_r)} \tag{90}$$

$$F_2 = p_r^{0.841}\ e^{1.424(1-p_r)} \tag{91}$$

$$F_3 = p_r^{1.851}\ e^{1.241(1-p_r)} \tag{92}$$

$$H_{fgB} = 4.299\times10^{-4}\ H_{fg}(p(x)) \tag{93}$$

where $H_{fg}(p(x))$ is the latent heat of vaporisation at the pressure p(x). Subscript B means that the parameters are given in British Thermal Units, while the quantities without subscript B are given in SI (Metric) Units with the exception of the pressures which are given in bars (10^5Pa).

$$A = \frac{1.763\times B\times H_{fgB}\times F_1}{1+9.157\ F_2G_Bd_{hB}} \tag{94}$$

$$C' = \frac{6.507\ F_3\sqrt{G_Bd_{hB}}}{d_{hB}} \tag{95}$$

$$Y = \frac{\sin\frac{\pi x}{L_c'} + \sin\frac{\pi L_c}{2L_c'}}{\frac{\pi}{L_c'}\left(\frac{L_c}{2} + x\right)\cos\frac{\pi x}{L_c'}} \tag{96}$$

$$V = 3.1 - 1.15\ G_B + 0.1188\ G_B^2 - 2.5\ \exp(-G_B) \tag{97}$$

for clusters with grid spacers (seed of heterogeneous reactor). For clusters with integral spiral rib spacers (homogeneous reactor and blanket of heterogeneous reactor) the following expression holds

$$V = 1-0.2589 \frac{F^{0.915}}{d_h^{0.17}} \left[0.25+0.1\ G_B + 2.75 \exp(-4G_B) - 3\exp(-3G_B) \right] \quad (98)$$

where F may be obtained from eq.(47)

$$C = C'V \left[1 + \frac{Y-1}{1+G_B} \right] \quad (99)$$

$$\Delta H_{S1B} = 0.4299\times10^{-3} \Delta H_{S1} \quad (100)$$

where ΔH_{S1} is the enthalpy difference between the enthalpy of saturated water at the core inlet pressure p_1 and the enthalpy H_1 of the water at core inlet. ΔH_{S1} is often called "inlet subcooling".

$$Z = 39.37 \left[\frac{L_C}{2} + x \right] \quad (101)$$

$$\phi_{CHF}(x) = 3.155\times10^{6} \frac{A+B\ \Delta H_{S1B}}{C+ZY} \quad (102)$$

Calculations are performed for 20 different values of x in the interval 0 to $\frac{L_C}{2}$ (upper part of the core). The minimum value of the ratio $\phi_{CHF}(x)/\phi_{HS}(x)$ is the "Departure from Nucleate Boiling Ratio" (DNBR).

Calculations are performed also to take account of the deformation in the axial heat flux distribution caused by the insertion of the control rods. In this case a method which holds with a good approximation is to still consider a chopped cosine axial power distribution, however for a shorter core length, which corresponds to the region of the core below the inserted control rods /26/:

$$L'_{CR} = L'_C - L_o \quad (103)$$

$$L_{CR} = L_C - L_o \quad (104)$$

Ref. /26/ suggests that $L_o = 0.1\ L_c$*. This is the value we will assume in the present study. The resulting hot spot heat flux distribution at the surface of the fuel rods is:

$$\phi_{HScR} = F_q O_P F_{cR} \cos \frac{\pi x}{L'_{cR}} \tag{105}$$

with

$$F_{cR} = \frac{L'_c}{L'_{cR}} \frac{\sin \frac{\pi L_c}{2L'_c}}{\sin \frac{\pi L_{cR}}{2L'_{cR}}} \tag{106}$$

while the temperature and pressure distributions in the hot coolant channels are:

$$T_{HS}(x) = T_1 + F_{\Delta H} O_p \frac{T_{2u} - T_1}{2} \left(1 + \frac{\sin \frac{\pi x}{L'_{cR}}}{\sin \frac{\pi L_{cR}}{2L'_{cR}}}\right) \tag{107}$$

$$p(x) = \frac{p_1 + p_2}{2} - (p_1 - p_2) \frac{x}{L_{cR}} \tag{108}$$

7. Fuel Rod Surface Temperature Calculations

In the present section we describe the method used to calculate the nominal fuel rod surface temperature.

The nominal water temperature axial distribution in the highest rated coolant channels is:

$$T_N(x) = T_1 + \varphi_{rad} O_P \frac{T_{2u} - T_1}{2} \left(1 + \frac{\sin \frac{\pi x}{L'_c}}{\sin \frac{\pi L_c}{2L'_c}}\right) \tag{109}$$

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* According to C. Broeders L_o should be considerably higher, possibly up to 0.4 L_c. This of course would reduce the DNBR too much. If the preliminary assessment of C. Broeders will be confirmed by subsequent more exact calculations, the major part of reactivity variations due to burn up has to be compensated by burnable poison in the fuel, such as instance gadolinium oxide.

where φ_{rad} is the radial power form factor. φ_{rad} depends on the radial neutron flux distribution and on the fuel enrichment in the various radial zones of the reactor. In the PWR for instance a three-cycle fuel management is normally used: the fresh fuel is introduced in the reactor in the outer region of the core and then after $\frac{1}{3}$ of the total burn-up moved successively into two further internal regions of the core. This has the advantage of reducing considerably φ_{rad}. For the present study we assume $\varphi_{rad}=1.34$, the same as for the German PWR of the 1300 MWe class /27/, because we envisage the use of the same fuel cycle system for the APWR.

The pressure distribution p(x) is given by equation (84). Equations (84) and (109) and the relationships of Ref./6/ allow the calculation of the water physical properties in the nominal highest rated coolant channels:

$$\mu = \mu(T_N(x), p(x)) \tag{110}$$

$$c_p = c_p(T_N(x), p(x)) \tag{111}$$

$$k = k(T_N(x), p(x)) \tag{112}$$

The heat transfer coefficient between fuel rod wall and cooling water is given by:

$$\alpha = 0.0211 \frac{k}{d_h}\left[1+0.0208\left(\frac{p}{d} - 1\right)\right] \left(1-e^{-\frac{p/d-1}{0.02}}\right) Re^{0.8} Pr^{0.4} \qquad (113) \ /28/$$

where the Reynolds and Prandtl numbers are calculated as:

$$Re = \frac{\rho_{av} u \, d_h}{\mu} \tag{113}$$

$$Pr = \frac{\mu \, c_p}{k} \tag{114}$$

The nominal heat flux distribution at the surface of the fuel rods in the highest rated channels is:

$$\phi_N(x) = \varphi_{ax}\ \varphi_{rad}\ O_p\ \frac{q_L}{\pi d} \cos \frac{\pi x}{L'_c} \qquad (115)$$

and the fuel rod wall temperature:

$$T_W(x) = T_N(x) + \frac{\Phi_N(x)}{\alpha} \qquad (116)$$

In the presence of subcooled boiling the wall temperature is given by:

$$T_{WB} = T_s\big(p(x)\big) + 25 \left[\phi_N(x) \times 10^{-6}\right]^{0.25} e^{-\frac{p(x)}{62}} \qquad (117)\ /29/$$

If $T_W(x)$ is less than $T_{WB}(x)$ for any value of x, then local boiling does not occur.

8. Calculation Results

8.1 Homogeneous reactors

Tables II to X show the results of the calculations for the homogeneous reactors. The calculations have been performed for the following cases:

p = 0.85 cm, d= 0.78 ÷ 0.82 cm (Table II)
p = 0.90 cm, d= 0.78 ÷ 0.87 cm (Table III)
p = 0.95 cm, d= 0.78 ÷ 0.93 cm (Table IV)
p = 1.00 cm, d= 0.78 ÷ 0.98 cm (Table V)
p = 1.05 cm, d= 0.82 ÷ 1.03 cm (Table VI)
p = 1.10 cm, d= 0.88 ÷ 1.07 cm (Table VII)
p = 1.15 cm, d= 0.94 ÷ 1.10 cm (Table VIII)
p = 1.20 cm, d= 0.96 ÷ 1.14 cm (Table IX)
p = 1.25 cm, d= 1.03 ÷ 1.09 cm (Table X).

Altogether 97 reactors. The symbols in the Tables are the same as those used in the text and explained in the List of Symbols. DNBR is the ratio between the critical heat flux and the hot channel heat flux at the axial point where this ratio is a minimum. Four values of DNBR are shown in the tables, namely for the case with and without inserted control rods and in nominal reactor power conditions (overpower factor = 1.00) and for an overpower factor of 1.12.

V_M/V_F is the ratio between the area occupied by the water (moderator) and by the fuel rods, and "CELL" is the same value for a single unit cell around a fuel rod.

X(BOIL) is the axial distance from the core center where subcooled boiling starts to occur in the highest rated channels. Two values of X(BOIL) are shown, for O_P=1.00 and O_P=1.12 respectively. The value 0 indicates that subcooled boiling occurs starting at the core center or below (that is for negative values of x). The stars indicate that no subcooled boiling occurs in the considered highest rated channels.

Figures 1 to 17 show the results of the calculations in diagrammatic form. Comparing these figures with the corresponding data of the standard German PWR of 1300 MWe (Table I) one can observe that for the parameters of the APWR:

- The rod linear power is always lower than that for the PWR value (208 W/cm); the reason for this is the smaller p/d ratio and the boundary condition due to reflooding (Eq. (31)).
- Nevertheless the core power density is higher than in the PWR case (102 W/cm^3) and it increases with decreasing fuel rod diameters.
- The water mass flow rate is lower than the PWR value (18800 kg/s).
- The water velocity is higher than for the PWR (4.5 m/s)
- The core height is lower than for the PWR (390 cm)
- Core pressure drops are higher than for the PWR (1.4 bar)

- Inlet and outlet water temperatures are lower than the PWR values. Variations in T_1 are considerably larger than in T_2.
- The primary water pumping power is never higher than 18.8 MW. This means at most about 10% more than the nominal PWR-pumping power (17 MW). Due to the fact that the primary circuit water pumps can operate at powers 25% higher than the nominal values, this 10% overpower is considered acceptable.
- The net electrical plant power decreases rapidly with d.
- The DNBR (departure from nucleate boiling ratio = ratio between critical heat flux and heat flux in the hot channel) is the smallest in the case of inserted control rods and overpower factor equal to 1.12. In this case the DNBR values for more than half of the investigated reactors (for low p and d values) are less than 1.3. Generally for PWR's the DNBR should be greater or equal to 1.3 /27/ and we assume the same safety margin for the APWR, although the standard deviation σ of the used critical heat flux correlation is only 6.2% in the case of integral spiral rib spacers /22/, and five time σ would correspond to a confidence limit of more than 99.99%, while a confidence limit of 95% is considered sufficient in this case. /27/.
- The water to fuel rod volume ratio V_M/V_F is an important parameter for the neutronic calculations: the conversion ratio is higher for lower values of V_M/V_F. Fig.15 shows that this parameter decreases with increasing fuel rod diameter d. Of course for a constant d value, V_M/V_F decreases with decreasing values of the fuel rod pitch p.
- Figures 16 and 17 show that for almost all the calculated reactors subcooled (or local) boiling occurs in the highest rated channels over a considerable length of the upper part of the core. This length is of course greater in the case of an overpower factor equal to 1.12. Subcooled boiling is normally allowed in a PWR, even to a greater extent than we have allowed here for the calculated APWR's. Indeed even saturated boiling is allowed at the outlet of the hot channels in the PWR's /27/ while in the present study for the APWR it is not (see eq.(12)). However, as discussed in section 6, even the very small amount of vapor at the fuel rod wall caused by subcooled boiling could possibly

produce flow instabilities for very narrow coolant channels in parallel. In our opinion this point can be clarified only by out-of-pile experiments with tight lattice rod bundles.

8.2 Heterogeneous reactors

Tables XI to XVII show the results of the calculations for the heterogeneous reactors. The calculations have been performed for the following cases:

d_S = 1.00 cm q_{vS} = 128 ÷ 148 W/cm^3 (Table XI)
d_S = 0.95 cm q_{vS} = 140 ÷ 164 W/cm^3 (Table XII)
d_S = 0.90 cm q_{vS} = 148 ÷ 182 W/cm^3 (Table XIII)
d_S = 0.85 cm q_{vS} = 160 ÷ 206 W/cm^3 (Table XIV)
d_S = 0.80 cm q_{vS} = 180 ÷ 228 W/cm^3 (Table XV)
d_S = 0.75 cm q_{vS} = 204 ÷ 272 W/cm^3 (Table XVI)
d_S = 0.70 cm q_{vS} = 228 ÷ 288 W/cm^3 (Table XVII)

Altogether 101 reactors. For each calculated reactor the first four DNBR values are for the seed (without and with insertion of the control rods) and the second four values for the blanket. Figures 18 to 46 show the results of the calculations in diagrammatic form. The comparison of these values with the corresponding data of the standard German PWR of 1300 MWe results in conclusions qualitatively similar to those for the homogeneous reactors (see Section 8.1), here we shall discuss only the special features of the results for the heterogeneous reactors.

- The pitch to diameter ratios of the fuel rods are always higher for the seed than for the blanket (Figures 21 and 22).
- Contrary to the case of the homogeneous reactors, the heterogeneous reactors can, in certain cases, be even higher than the PWR (Fig.25).

- The DNBR's are always greater than 1.3 in the seed (Figures 34 to 37), however, for certain reactors, they can be lower than 1.3 in the blanket especially for the 12% overpower factor case (Figures 40 and 41). Although the power density in the blanket is only half that in the seed, the DNBR's are lower in the blanket because the fuel rod cluster is much tighter.

9. Conclusions

Based on the present parametric thermohydraulic study of Advanced Pressurized Light Water Reactors both homogeneous and heterogeneous with control rods, we conclude the following:

1. It possible to place either a homogeneous or a heterogeneous APWR core inside the reactor vessel of a modern German 1300 MWe PWR.

2. There are however limitations caused by the size of the reactor vessel, of the heat exchangers and of the turbines, and by the power of the primary circuit water pumps. A tigher fuel rod lattice in the core offers the benefit of a smaller water to fuel rod volume ratio V_M/V_F and thus a higher conversion ratio. This must be paid for by a decrease of the net electrical output of the plant. The decrease is however different for the homogeneous and the heterogeneous type of APWR. Fig.47 shows the ratio V_M/V_F versus the net electrical output of the plant for all the calculated reactors of the present study; for the same V_M/V_F ratio the decrease of power is greater for the heterogeneous reactors than for the homogeneous reactors. For instance for $V_M/V_F = 0.3$, $Q_{el.net} = 1027$ MWe and 1130 MWe for the heterogeneous and the homogeneous reactors respectively, which means a decrease of 21% and 13% from the PWR power (1300 MWe for $V_M/V_F = 1.25$).

3. The APWR reactors require higher water velocities (5 to 9.5 m/s) than for the PWR case (4.5 m/s). These higher velocities could possibly cause vibration and/or corrosion and erosion problems in the core. Velocities of this order have been achieved in the KWU reactor of Atucha in Argentina.

4. The pressure drop across the core is higher in the APWR's than in the PWR (up to 9 bar as against 1.4 bar). This implies the necessity of a redesign of the core hold-down system.

5. The APWR cores tend to be shorter than in the PWR case, with the exception of some heterogeneous reactors. This has the advantage of making the reflooding of the reactor after a LOCA easier. However the hydraulic resistances of the APWR cores are always higher than that of the PWR, and this probably outweighs the advantage given by the shorter core.

6. The number of fuel rods is generally higher than for the PWR (n_T = 46413) especially for the reactors with low V_M/V_F values. This means higher fuel cycle costs for the APWR.

7. The DNB (or the critical heat flux) has been calculated in the present study with the correlation suggested in Ref. /22/. This correlation was developed especially for tight lattice rod bundles and takes account of the effect on DNB of the spiral integral rib spacers, which is not taken into account by other correlations. The DNB predicted by the Shippingport correlation /23/ would be higher and those predicted by the Edlund /25/ and WSC2 /24/ correlations would be lower than the DNB predicted by correlation of Ref. /21/.

8. The DNB ratio for about half of the homogeneous reactors is smaller than 1.3. This is true for the reactors with small fuel rod diameters and pitches (Fig.14). These reactors have generally high values of V_M/V_F, i.e. relatively large values of p/d. This means that at high p/d ratios the DNB ratio limitation is more stringent than the limitation on the fuel rod linear rating given by the reflooding (eq.(31)). On the

contrary at low p/d values the condition DNBR $\geq$ 1.3 is less stringent than the boundary condition given by equation (31). This emphasizes the importance of the limitation given by Eq. (31) for the design of a APWR and demonstrates that further work should be performed in this area.

9. The DNB ratio for some of the heterogeneous reactors is smaller than 1.3 in the blanket (Fig.41). In the seed of all the calculated reactors the DNB ratio is greater than 1.3. Also here the blanket DNBR is smaller than 1.3 for reactors with relatively high V_M/V_F ratios and the same considerations made for the homogeneous reactors are valid for the blankets of the heterogeneous reactors as well.

10. For most of the calculated reactors subcooled (local) boiling occurs in the highest rated coolant channels. The extent of the axial region where subcooled boiling occurs is generally lower than in the PWR case, because we have imposed the condition that no saturation boiling should occur, not even at outlet of the hot channels. However, due to the fact that the coolant channels are considerably smaller than in the PWR, even this small amount of vapor at the wall could possibly cause flow instabilities of the Ledinegg type. Also in this area further work is required.

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List of Symbols

Geometrical Parameters

A = cell water flow area (m^2)

A_c = cross section area of the unit cell of the fuel rod array (m^2)

A_T = useful total cross section area of the core (area occupied by fuel rods and relative water cooling channels) (m^2)

b = thickness of the integral spiral ribs (m)

d = fuel rod diameter (m)

d_h = hydraulic diameter of the coolant channel (m)

D_{eq} = equivalent diameter of the core = diameter of the circle which has the same cross section area of the actual core (m)

H = axial pitch of the integral spiral ribs (m)

L_c = core active length (m)

L'_c = core extrapolated length (m)

L_R = fuel rod total length (m)

L_o = shortening of the core active length due to insertion of the control rods (m)

L_{CR} = core active length with inserted control rods (m)

L'_{CR} = core extrapolated length with inserted control rods (m)

L_{SC} = spacer grid axial spacing in the active core region (m)

L_{SR} = spacer grid axial spacing in fission gas plenum region (m)

n_B = total number of fuel rods in the blanket

n_G = number of spacer grids along the length of the fuel rods

n_S = total number of fuel rods in the seed

n_T = total number of fuel rods

p = fuel rod pitch (m)

V_M/V_F = ratio between area occupied by the water (moderator) and the fuel rods.

x = axial distance of the considered section measured from the core center (m)

α = water fraction of the unit cell of the fuel rod array (in the tables indicated as "CELL")

ε = spacer grid solidity = ratio of the cross section area of the grid to the cross section area of the coolant channel

Water Physical Properties

c_p = water specific heat (J/kg°C)

k = water thermal conductivity (J/ms°C)

H_1 = average water enthalpy at the inlet of the reactor (J/kg)

H_2 = average water enthalpy at the outlet of the reactor (J/kg)

H_{2u} = average water enthalpy at the outlet of the fuel rod coolant channels (J/kg)

ΔH_{S1} = difference between the enthalpy of the saturated water at the core inlet pressure p_1 and the enthalpy H_1 of the water at core inlet (J/kg)

ρ = water density (kg/m^3)

η = water dynamic viscosity (kg/ms)

ν = water kinematic viscosity (m^2/s)

Temperatures

T_1 = water temperature at reactor inlet (°C)

T_2 = average water temperature at reactor outlet (°C)

T_o = equivalent reject heat temperature (eq.(24)) (°C)

T_{2u} = average water temperature at the outlet of the fuel rod coolant channels (°C)

T_{2H} = water temperature at the outlet of the hot coolant channels (°C)

T_s = steam saturation temperature at the turbine pressure p_s (°C)

T_N = nominal water temperature in the most rated coolant channels (°C)

T_W = fuel rod wall temperature in the most rated coolant channels without boiling (^oC)

T_{WB} = fuel rod wall temperature in the most rated coolant channels with subcooled boiling (^oC)

T_{HS} = water temperature in the hot coolant channels (^oC)

<u>Other Physical Parameters</u>

H_c = pressure head available for the core (m)

H_T = total pressure head of the primary circuit water pumps (m)

H_R = $H_T - H_c$ = pressure head available for the rest of the primary circuit (m)

KF = average total heat transfer coefficient times the total surface of the heat exchangers ($W/^oC$)

M = total water mass flow in the primary circuit (kg/s)

M_u = useful total water mass flow = mass flow of water which actually cools the fuel rods (kg/s)

N = power required to pump the water in the primary circuit (W)

N_{el} = total electrical power for internal use in the plant (inclusive of N) (W)

p = water pressure (bar)

p_1 = water pressure at reactor inlet (bar)

p_2 = water pressure at reactor outlet (bar)

p_s = steam saturation pressure at the turbine (bar)

p_{av} = average water pressure in the core (bar)

Q = reactor thermal output (W)

$Q_{el.net}$ = net electrical power of the plant (W)

q_L = average fuel rod linear rating (W/m)

q_v = average volume power density (W/m^3)

u = average water velocity (m/s)

V = water volume flow for each pump in the primary circuit (m^3/s)

α = convective heat transfer coefficient between fuel rod wall and cooling water ($W/m^2\ ^oC$)

ϕ_{CHF} = critical heat flux at the surface of the fuel rods (W/m^2)

ϕ_{HS} = hot spot heat flux at the surface of the fuel rods (W/m^2)

ϕ_{HSCR} = hot spot heat flux at the surface of the fuel rods with inserted control rods (W/m^2)

ϕ_N = nominal heat flux at the surface of the fuel rods in the most rated coolant channels (W/m^2)

Δp = friction pressure drop caused by the required flow of water through the core (bar)

Δp_c = irreversible pressure drop available for the core (bar)

Δp_{acc} = core pressure drop due to the acceleration caused by the change of water temperature (bar)

Δp_{el} = core pressure drop due to the elevation difference (bar)

Δp_{tot} = total core pressure drop (bar)

Dimensionless Parameters

C = friction factor correction number for low p/d values (eq.(50) and (51))

C_S = friction factor correction number for bundle geometry (eq.(71))

C_V = modified drag coefficient of the spacer grid

DNBR = departure from nucleate boiling ratio = minimum ratio between critical heat flux and heat flux in the hot channel

F = friction factor correction number for spiral ribs (eq.(47))

$F_{\Delta H}$ = hot channel factor for the enthalpy rise in the core

F_q = hot channel factor for the heat flux at the fuel rod surface

K = ratio of the turbine pressure for the APWR case to the turbine pressure for the PWR reference case

K_I = inlet pressure drop coefficient

O_P = power plant overpower factor

Pr	=	Prandtl number
Re	=	Reynolds number
Re'	=	modified Reynolds number (eq.(46))
φ_{ax}	=	axial power distribution form factor
φ_{rad}	=	radial power distribution form factor
λ	=	friction factor
λ_T	=	friction factor for flow in a tube

Subscripts

av	=	average
B	=	relative to the blanket
S	=	relative to the seed
o	=	relative to the reference 1300 MWe PWR
1	=	at the core inlet
2	=	at the core outlet

Table I: Parameters of the reference PWR

$Q_{el,net,o}$	=	1300 MWe
Q_o	=	3765 MW
N_o	=	17 MWe
$N_{el,o}$	=	54 MWe
$T_{1,o}$	=	291.14°C
$T_{2,o}$	=	326.16°C
$T_{s,o}$	=	280.31°C
T_o	=	355.32 K
$p_{1,o}$	=	159.65 bar
$p_{2,o}$	=	158.26 bar
$p_{s,o}$	=	64.5 bar
M_o	=	18800 kg/s
KF_o	=	155.927 MW/°C
$H_{T,o}$	=	89.6 m
$H_{R,o}$	=	70.6 m
$F_{\Delta H}$	=	1.6
F_q	=	2.1

Table II

H O M O G E N E O U S   C O R E

P = 0.850 CM N = 160925

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
0.780	1.090	157.7	252.0	16364.	8.6	139.	4.57	4.76	285.2	323.6	0.936	3525.	18.75	1197.	0.921	1.47	1.43	0.349	0.309	42.	1
											OPF =	1.12				1.32	1.28			24.	
0.790	1.076	154.5	246.9	15770.	8.8	139.	5.22	5.42	283.7	323.0	0.920	3465.	18.78	1171.	0.901	1.48	1.44	0.317	0.277	45.	2
											OPF =	1.12				1.33	1.28			28.	
0.800	1.062	151.3	241.8	15052.	9.1	139.	5.96	6.17	281.7	322.2	0.900	3388.	18.66	1138.	0.876	1.49	1.44	0.287	0.245	45.	3
											OPF =	1.12				1.33	1.29			28.	
0.810	1.049	148.1	236.7	14185.	9.2	138.	6.77	6.99	279.2	321.3	0.874	3291.	18.32	1097.	0.844	1.48	1.44	0.258	0.214	41.	4
											OPF =	1.12				1.33	1.28			28.	
0.820	1.037	144.9	231.5	13152.	9.3	136.	7.64	7.87	275.9	320.1	0.841	3167.	17.65	1044.	0.803	1.47	1.42	0.230	0.185	37.	5
											OPF =	1.12				1.31	1.26			24.	

Table III

H O M O G E N E O U S   C O R E

P = 0.900 CM N = 143541

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
0.780	1.154	171.4	244.3	17898.	7.3	149.	2.71	2.89	288.9	324.9	0.975	3670.	18.09	1259.	0.969	1.43	1.39	0.502	0.468	30.	6
											OPF =	1.12				1.27	1.24			19.	
0.800	1.125	165.4	235.9	17348.	7.8	152.	3.41	3.60	287.6	324.5	0.961	3620.	18.43	1238.	0.952	1.46	1.43	0.432	0.396	42.	7
											OPF =	1.12				1.31	1.27			23.	
0.810	1.111	162.5	231.6	16991.	8.1	154.	3.84	4.04	286.8	324.1	0.952	3586.	18.58	1223.	0.941	1.48	1.44	0.400	0.361	46.	8
											OPF =	1.12				1.32	1.29			27.	
0.820	1.098	159.5	227.3	16565.	8.3	155.	4.34	4.54	285.7	323.7	0.941	3545.	18.71	1206.	0.927	1.50	1.46	0.368	0.328	50.	9
											OPF =	1.12				1.34	1.30			27.	
0.830	1.084	156.4	223.0	16054.	8.6	156.	4.91	5.12	284.4	323.3	0.928	3494.	18.78	1184.	0.910	1.51	1.47	0.337	0.296	51.	10
											OPF =	1.12				1.35	1.31			31.	
0.840	1.071	153.4	218.7	15442.	8.8	156.	5.56	5.78	282.8	322.6	0.911	3430.	18.75	1156.	0.890	1.52	1.48	0.308	0.266	51.	11
											OPF =	1.12				1.36	1.32			31.	
0.850	1.059	150.4	214.4	14711.	9.0	155.	6.29	6.51	280.7	321.9	0.890	3351.	18.55	1122.	0.863	1.52	1.48	0.279	0.236	50.	12
											OPF =	1.12				1.36	1.32			31.	
0.860	1.047	147.4	210.1	13843.	9.2	154.	7.07	7.31	278.1	320.9	0.863	3251.	18.13	1080.	0.831	1.52	1.47	0.252	0.208	46.	13
											OPF =	1.12				1.35	1.31			31.	
0.870	1.034	144.3	205.8	12826.	9.2	151.	7.89	8.13	274.8	319.7	0.830	3126.	17.39	1027.	0.790	1.50	1.45	0.225	0.180	41.	14
											OPF =	1.12				1.34	1.30			26.	

Table IV

H O M O G E N E O U S   C O R E

P = 0.950 CM N = 128829

D CM	P/D -	QL W/CM	QV W/CCM	M KG/S	U M/S	LC CM	DP BAR	DPT BAR	T1 C	T2 C	K -	Q MW	NP MW	QEL MW	QR -	DNBR -	VM/VF -	CELL -	X(BOIL.) CM	
0.780	1.218	183.1	234.3	18556.	6.4	158.	1.84	2.01	290.4	325.5	0.990	3728.	17.52	1284.	0.988	1.36 1.33	0.664	0.636	16.	15
											OPF =	1.12				1.21 1.19			8.	
0.800	1.187	177.8	227.4	18285.	6.8	162.	2.20	2.38	289.8	325.3	0.984	3704.	17.77	1274.	0.980	1.40 1.37	0.587	0.555	24.	16
											OPF =	1.12				1.25 1.22			12.	
0.820	1.159	172.3	220.4	17920.	7.2	165.	2.68	2.87	289.0	325.0	0.975	3672.	18.07	1260.	0.969	1.44 1.41	0.515	0.480	37.	17
											OPF =	1.12				1.28 1.26			21.	
0.840	1.131	166.7	213.3	17419.	7.7	169.	3.32	3.52	287.8	324.5	0.963	3626.	18.39	1241.	0.954	1.48 1.44	0.448	0.410	46.	18
											OPF =	1.12				1.32 1.29			25.	
0.850	1.118	163.9	209.7	17100.	7.9	170.	3.71	3.92	287.1	324.2	0.955	3596.	18.54	1228.	0.944	1.49 1.46	0.416	0.377	51.	19
											OPF =	1.12				1.33 1.30			30.	
0.860	1.105	161.0	206.0	16723.	8.2	172.	4.16	4.37	286.1	323.9	0.946	3560.	18.67	1212.	0.932	1.51 1.48	0.385	0.346	56.	20
											OPF =	1.12				1.35 1.32			34.	
0.870	1.092	158.2	202.4	16276.	8.4	173.	4.67	4.89	285.0	323.5	0.934	3516.	18.76	1193.	0.918	1.53 1.49	0.356	0.315	60.	21
											OPF =	1.12				1.36 1.33			35.	
0.880	1.080	155.3	198.7	15746.	8.6	173.	5.25	5.47	283.6	323.0	0.920	3462.	18.78	1170.	0.900	1.54 1.50	0.327	0.285	61.	22
											OPF =	1.12				1.37 1.34			35.	
0.890	1.067	152.5	195.1	15119.	8.8	173.	5.89	6.12	281.9	322.3	0.902	3396.	18.68	1142.	0.878	1.55 1.51	0.299	0.256	61.	23
											OPF =	1.12				1.38 1.35			35.	
0.900	1.056	149.6	191.4	14381.	9.0	172.	6.60	6.84	279.8	321.5	0.880	3314.	18.42	1106.	0.851	1.55 1.51	0.273	0.229	56.	24
											OPF =	1.12				1.38 1.35			34.	
0.910	1.044	146.7	187.7	13517.	9.1	170.	7.35	7.59	277.1	320.5	0.853	3212.	17.92	1063.	0.818	1.54 1.50	0.247	0.202	55.	25
											OPF =	1.12				1.38 1.34			34.	
0.920	1.033	143.9	184.1	12518.	9.1	167.	8.12	8.37	273.8	319.3	0.820	3086.	17.12	1010.	0.777	1.52 1.48	0.221	0.176	50.	26
											OPF =	1.12				1.36 1.32			33.	

H O M O G E N E O U S   C O R E

P = 0.950 CM N = 128829

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR	VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-	-	-	CM	
0.930	1.022	141.0	180.4	11714.	9.4	164.	8.67	8.93	270.9	318.2	0.791	2978.	16.33	964.	0.742	1.50 1.46	0.197	0.151	41.	27
											OPF = 1.12					1.34 1.30			25.	

Table V

H O M O G E N E O U S   C O R E

P = 1.000 CM N = 116268

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
0.780	1.282	192.9	222.7	18884.	5.8	167.	1.38	1.55	291.1	325.8	0.998	3756.	17.17	1296.	0.997	1.28	1.26	0.836	0.812	0.	28
											OPF =	1.12				1.15	1.13			0.	
0.800	1.250	188.2	217.3	18732.	6.0	171.	1.59	1.77	290.8	325.6	0.994	3743.	17.34	1291.	0.993	1.32	1.30	0.750	0.723	9.	29
											OPF =	1.12				1.18	1.16			4.	
0.820	1.220	183.4	211.7	18535.	6.4	175.	1.86	2.05	290.3	325.5	0.990	3726.	17.54	1284.	0.987	1.36	1.34	0.670	0.640	17.	30
											OPF =	1.12				1.22	1.20			9.	
0.840	1.190	178.3	205.9	18277.	6.7	179.	2.21	2.40	289.8	325.3	0.984	3704.	17.78	1274.	0.980	1.40	1.38	0.596	0.563	31.	31
											OPF =	1.12				1.25	1.23			18.	
0.860	1.163	173.1	199.9	17935.	7.1	182.	2.66	2.86	289.0	325.0	0.976	3673.	18.06	1261.	0.970	1.44	1.42	0.527	0.491	41.	32
											OPF =	1.12				1.29	1.27			23.	
0.880	1.136	167.8	193.8	17475.	7.5	186.	3.25	3.46	287.9	324.6	0.965	3631.	18.36	1243.	0.956	1.48	1.45	0.462	0.424	56.	33
											OPF =	1.12				1.32	1.30			28.	
0.890	1.124	165.1	190.7	17186.	7.8	188.	3.61	3.82	287.3	324.3	0.957	3604.	18.50	1231.	0.947	1.50	1.47	0.431	0.392	61.	34
											OPF =	1.12				1.34	1.31			33.	
0.900	1.111	162.5	187.6	16848.	8.0	189.	4.01	4.23	286.4	324.0	0.949	3572.	18.63	1217.	0.936	1.52	1.49	0.402	0.361	66.	35
											OPF =	1.12				1.36	1.33			38.	
0.910	1.099	159.8	184.5	16452.	8.2	190.	4.47	4.70	285.4	323.6	0.939	3534.	18.73	1201.	0.924	1.53	1.50	0.373	0.332	67.	36
											OPF =	1.12				1.37	1.34			38.	
0.920	1.087	157.0	181.3	15987.	8.4	191.	4.99	5.22	284.3	323.2	0.926	3487.	18.78	1181.	0.908	1.55	1.52	0.345	0.303	72.	37
											OPF =	1.12				1.38	1.35			38.	
0.930	1.075	154.3	178.2	15442.	8.6	191.	5.56	5.81	282.8	322.6	0.911	3430.	18.75	1156.	0.890	1.56	1.53	0.318	0.275	67.	38
											OPF =	1.12				1.39	1.36			43.	
0.940	1.064	151.6	175.1	14805.	8.8	191.	6.20	6.45	281.0	322.0	0.893	3361.	18.59	1127.	0.867	1.57	1.53	0.292	0.248	67.	39
											OPF =	1.12				1.40	1.37			43.	

H O M O G E N E O U S   C O R E

P = 1.000 CM N = 116268

D CM	P/D -	QL W/CM	QV W/CCM	M KG/S	U M/S	LC CM	DP BAR	DPT BAR	T1 C	T2 C	K -	Q MW	NP MW	QEL MW	QR -	DNBR -	VM/VF -	CELL -	X(BOIL.) CM	
0.950	1.053	148.9	171.9	14063.	8.9	189.	6.88	7.14	278.8	321.2	0.870	3277.	18.26	1091.	0.839	1.57 1.53	0.266	0.222	66.	40
											OPF = 1.12					1.40 1.37			43.	
0.960	1.042	146.1	168.8	13206.	9.0	187.	7.60	7.86	276.1	320.1	0.843	3174.	17.70	1047.	0.805	1.56 1.52	0.242	0.196	61.	41
											OPF = 1.12					1.39 1.36			37.	
0.980	1.020	140.7	162.5	11510.	9.3	180.	8.80	9.07	270.1	317.9	0.783	2949.	16.11	952.	0.732	1.52 1.48	0.195	0.148	45.	42
											OPF = 1.12					1.36 1.32			27.	

Table VI

H O M O G E N E O U S   C O R E

P = 1.050 CM N = 105459

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
0.820	1.280	192.7	201.8	18854.	5.7	185.	1.42	1.61	291.0	325.7	0.997	3753.	17.20	1295.	0.996	1.29	1.27	0.834	0.808	5.	43
											OPF = 1.12					1.15	1.13			0.	
0.840	1.250	188.2	197.1	18705.	6.0	188.	1.63	1.82	290.7	325.6	0.993	3740.	17.36	1290.	0.992	1.33	1.31	0.752	0.723	14.	44
											OPF = 1.12					1.19	1.17			5.	
0.860	1.221	183.6	192.3	18514.	6.3	192.	1.89	2.09	290.3	325.5	0.989	3724.	17.56	1283.	0.987	1.37	1.35	0.676	0.644	24.	45
											OPF = 1.12					1.22	1.20			14.	
0.880	1.193	178.8	187.3	18267.	6.7	196.	2.23	2.43	289.7	325.3	0.983	3703.	17.79	1274.	0.980	1.41	1.38	0.605	0.570	34.	46
											OPF = 1.12					1.26	1.24			20.	
0.900	1.167	173.9	182.1	17945.	7.0	200.	2.65	2.86	289.0	325.0	0.976	3674.	18.05	1261.	0.970	1.45	1.42	0.538	0.501	50.	47
											OPF = 1.12					1.29	1.27			25.	
0.920	1.141	168.8	176.8	17519.	7.4	204.	3.19	3.42	288.0	324.6	0.966	3635.	18.33	1245.	0.957	1.48	1.46	0.475	0.436	61.	48
											OPF = 1.12					1.32	1.30			36.	
0.930	1.129	166.3	174.2	17255.	7.6	206.	3.52	3.75	287.4	324.4	0.959	3611.	18.47	1234.	0.949	1.50	1.48	0.445	0.406	67.	49
											OPF = 1.12					1.34	1.32			36.	
0.940	1.117	163.7	171.5	16949.	7.8	207.	3.89	4.13	286.7	324.1	0.951	3582.	18.60	1222.	0.940	1.52	1.49	0.417	0.376	73.	50
											OPF = 1.12					1.36	1.33			41.	
0.950	1.105	161.2	168.8	16594.	8.0	209.	4.31	4.55	285.8	323.8	0.942	3548.	18.71	1207.	0.928	1.54	1.51	0.389	0.347	78.	51
											OPF = 1.12					1.37	1.35			42.	
0.960	1.094	158.6	166.1	16181.	8.2	210.	4.77	5.02	284.8	323.4	0.931	3507.	18.77	1189.	0.915	1.55	1.52	0.362	0.319	79.	52
											OPF = 1.12					1.38	1.36			47.	
0.970	1.082	156.0	163.4	15701.	8.4	210.	5.29	5.55	283.5	322.9	0.918	3457.	18.77	1168.	0.899	1.56	1.54	0.335	0.292	79.	53
											OPF = 1.12					1.40	1.37			47.	
0.980	1.071	153.4	160.7	15144.	8.6	210.	5.87	6.13	282.0	322.3	0.903	3398.	18.69	1143.	0.879	1.57	1.55	0.310	0.266	79.	54
											OPF = 1.12					1.41	1.38			47.	

H O M O G E N E O U S   C O R E

P = 1.050 CM N = 105459

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
0.990	1.061	150.8	158.0	14499.	8.7	209.	6.49	6.75	280.1	321.6	0.884	3327.	18.47	1112.	0.856	1.58	1.55	0.285	0.240	73.	55
											OPF =	1.12				1.41	1.38			47.	
1.000	1.050	148.2	155.2	13757.	8.8	207.	7.15	7.42	277.9	320.8	0.861	3241.	18.08	1075.	0.827	1.58	1.55	0.261	0.216	73.	56
											OPF =	1.12				1.41	1.38			47.	
1.010	1.040	145.6	152.5	12910.	8.9	204.	7.83	8.10	275.1	319.8	0.833	3137.	17.46	1031.	0.793	1.58	1.54	0.238	0.192	66.	57
											OPF =	1.12				1.41	1.38			41.	
1.030	1.019	140.4	147.1	11318.	9.2	197.	8.91	9.20	269.4	317.6	0.776	2922.	15.90	941.	0.724	1.54	1.50	0.193	0.146	49.	58
											OPF =	1.12				1.37	1.34			35.	

Table VII

H O M O G E N E O U S   C O R E

P = 1.100 CM N = 96089

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
0.880	1.250	188.2	179.6	18678.	6.0	207.	1.67	1.87	290.6	325.6	0.993	3738.	17.39	1289.	0.991	1.33	1.31	0.754	0.723	21.	59
											OPF =	1.12				1.19	1.17			10.	
0.900	1.222	183.8	175.4	18492.	6.3	211.	1.92	2.14	290.2	325.4	0.989	3722.	17.58	1282.	0.986	1.37	1.35	0.681	0.647	32.	60
											OPF =	1.12				1.22	1.20			16.	
0.920	1.196	179.2	171.0	18255.	6.6	215.	2.24	2.46	289.7	325.2	0.983	3702.	17.80	1273.	0.979	1.41	1.39	0.612	0.576	43.	61
											OPF =	1.12				1.26	1.24			21.	
0.940	1.170	174.5	166.6	17951.	6.9	219.	2.64	2.87	289.0	325.0	0.976	3675.	18.05	1261.	0.970	1.44	1.42	0.548	0.510	55.	62
											OPF =	1.12				1.29	1.27			33.	
0.960	1.146	169.8	162.0	17553.	7.3	223.	3.15	3.39	288.1	324.6	0.966	3639.	18.31	1246.	0.958	1.48	1.46	0.487	0.448	72.	63
											OPF =	1.12				1.32	1.30			39.	
0.980	1.122	164.9	157.4	17031.	7.7	227.	3.79	4.04	286.9	324.2	0.953	3590.	18.57	1225.	0.942	1.52	1.49	0.431	0.389	85.	64
											OPF =	1.12				1.35	1.33			45.	
0.990	1.111	162.5	155.0	16709.	7.9	228.	4.17	4.43	286.1	323.9	0.945	3559.	18.68	1212.	0.932	1.53	1.51	0.403	0.361	91.	65
											OPF =	1.12				1.37	1.35			46.	
1.000	1.100	160.0	152.7	16338.	8.1	229.	4.60	4.86	285.2	323.5	0.936	3522.	18.75	1196.	0.920	1.55	1.53	0.377	0.334	92.	66
											OPF =	1.12				1.38	1.36			52.	
1.010	1.089	157.5	150.3	15911.	8.2	230.	5.07	5.34	284.1	323.1	0.924	3479.	18.78	1177.	0.906	1.56	1.54	0.351	0.308	92.	67
											OPF =	1.12				1.40	1.37			52.	
1.020	1.078	155.1	148.0	15418.	8.4	230.	5.59	5.86	282.7	322.6	0.910	3428.	18.74	1155.	0.889	1.58	1.55	0.326	0.282	92.	68
											OPF =	1.12				1.41	1.38			52.	
1.030	1.068	152.6	145.6	14851.	8.6	230.	6.15	6.43	281.1	322.0	0.894	3366.	18.60	1129.	0.868	1.59	1.56	0.302	0.258	86.	69
											OPF =	1.12				1.42	1.39			52.	
1.040	1.058	150.1	143.3	14203.	8.7	228.	6.76	7.04	279.2	321.3	0.875	3293.	18.33	1098.	0.844	1.59	1.56	0.279	0.234	80.	70
											OPF =	1.12				1.42	1.40			51.	

H O M O G E N E O U S   C O R E

P = 1.100 CM N = 96089

D CM	P/D -	QL W/CM	QV W/CCM	M KG/S	U M/S	LC CM	DP BAR	DPT BAR	T1 C	T2 C	K -	Q MW	NP MW	QEL MW	QR -	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
1.050	1.048	147.6	140.9	13464.	8.8	226.	7.39	7.68	276.9	320.4	0.851	3205.	17.88	1060.	0.816	1.59	1.56	0.256	0.210	79.	71
											OPF =	1.12				1.42	1.40			51.	
1.060	1.038	145.2	138.5	12629.	8.8	222.	8.04	8.33	274.2	319.4	0.823	3100.	17.22	1016.	0.781	1.59	1.56	0.234	0.187	72.	72
											OPF =	1.12				1.42	1.39			44.	
1.070	1.028	142.7	136.2	11767.	8.8	218.	8.64	8.93	271.1	318.3	0.793	2985.	16.39	967.	0.744	1.57	1.54	0.212	0.165	65.	73
											OPF =	1.12				1.40	1.37			44.	

Table VIII

HOMOGENEOUS CORE

P = 1.150 CM N = 87915

D CM	P/D -	QL W/CM	QV W/CCM	M KG/S	U M/S	LC CM	DP BAR	DPT BAR	T1 C	T2 C	K -	Q MW	NP MW	QEL MW	QR -	DNBR -	DNBR -	VM/VF -	CELL -	X(BOIL.) CM	
0.940	1.223	184.0	160.7	18470.	6.2	230.	1.95	2.18	290.2	325.4	0.988	3720.	17.60	1281.	0.986	1.36	1.35	0.686	0.650	34.	74
											OPF =	1.12				1.22	1.20			17.	
0.960	1.198	179.6	156.8	18242.	6.5	234.	2.26	2.49	289.7	325.2	0.983	3700.	17.81	1273.	0.979	1.40	1.38	0.620	0.582	47.	75
											OPF =	1.12				1.25	1.24			29.	
0.980	1.173	175.2	152.9	17952.	6.9	239.	2.64	2.88	289.0	325.0	0.976	3675.	18.05	1262.	0.970	1.44	1.42	0.557	0.518	66.	76
											OPF =	1.12				1.28	1.27			36.	
1.000	1.150	170.6	148.9	17580.	7.2	243.	3.12	3.37	288.2	324.7	0.967	3641.	18.30	1247.	0.959	1.48	1.46	0.499	0.458	79.	77
											OPF =	1.12				1.32	1.30			42.	
1.020	1.127	166.0	144.9	17098.	7.6	246.	3.71	3.98	287.0	324.2	0.955	3596.	18.54	1228.	0.944	1.51	1.49	0.443	0.402	*****	78
											OPF =	1.12				1.35	1.33			49.	
1.040	1.106	161.3	140.8	16468.	7.9	249.	4.45	4.73	285.5	323.7	0.939	3535.	18.73	1201.	0.924	1.54	1.52	0.391	0.348	*****	79
											OPF =	1.12				1.38	1.36			56.	
1.060	1.085	156.6	136.7	15643.	8.2	251.	5.36	5.64	283.3	322.8	0.917	3451.	18.77	1165.	0.897	1.57	1.55	0.342	0.298	107.	80
											OPF =	1.12				1.40	1.38			56.	
1.080	1.065	151.8	132.6	14566.	8.5	250.	6.42	6.72	280.3	321.7	0.886	3335.	18.50	1115.	0.858	1.59	1.57	0.295	0.250	94.	81
											OPF =	1.12				1.42	1.40			56.	
1.090	1.055	149.5	130.5	13916.	8.6	248.	7.01	7.31	278.4	321.0	0.866	3260.	18.17	1083.	0.833	1.60	1.57	0.273	0.227	93.	82
											OPF =	1.12				1.43	1.41			56.	
1.100	1.045	147.1	128.4	13182.	8.7	245.	7.62	7.92	276.0	320.1	0.842	3171.	17.68	1046.	0.804	1.60	1.57	0.251	0.205	86.	83
											OPF =	1.12				1.43	1.40			55.	

Table IX

H O M O G E N E O U S   C O R E

P = 1.200 CM N = 80742

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR	VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-	-	-	CM	
0.960	1.250	188.2	150.9	18624.	5.9	246.	1.74	1.98	290.5	325.5	0.992	3734.	17.45	1287.	0.990	1.32 1.31	0.758	0.723	31.	84
											OPF =	1.12				1.18 1.17			18.	
0.980	1.224	184.2	147.7	18448.	6.2	250.	1.98	2.23	290.1	325.4	0.988	3718.	17.62	1280.	0.985	1.36 1.35	0.690	0.653	44.	85
											OPF =	1.12				1.21 1.20			25.	
1.000	1.200	180.0	144.3	18228.	6.5	255.	2.28	2.53	289.7	325.2	0.983	3699.	17.82	1272.	0.979	1.40 1.38	0.626	0.588	57.	86
											OPF =	1.12				1.25 1.23			32.	
1.020	1.176	175.7	140.9	17951.	6.8	259.	2.64	2.90	289.0	325.0	0.976	3675.	18.05	1262.	0.970	1.43 1.42	0.566	0.526	71.	87
											OPF =	1.12				1.28 1.26			39.	
1.040	1.154	171.4	137.4	17601.	7.1	263.	3.09	3.36	288.2	324.7	0.968	3643.	18.29	1248.	0.960	1.47 1.45	0.509	0.468	92.	88
											OPF =	1.12				1.31 1.30			46.	
1.060	1.132	166.9	133.9	17152.	7.4	267.	3.65	3.92	287.2	324.3	0.957	3601.	18.52	1230.	0.946	1.50 1.48	0.456	0.413	*****	89
											OPF =	1.12				1.34 1.33			53.	
1.080	1.111	162.5	130.3	16575.	7.8	270.	4.33	4.62	285.8	323.8	0.942	3546.	18.71	1206.	0.928	1.53 1.52	0.405	0.361	*****	90
											OPF =	1.12				1.37 1.35			61.	
1.100	1.091	157.9	126.7	15829.	8.1	272.	5.16	5.46	283.8	323.0	0.922	3471.	18.78	1174.	0.903	1.56 1.55	0.357	0.312	*****	91
											OPF =	1.12				1.40 1.38			61.	
1.120	1.071	153.4	123.0	14867.	8.4	272.	6.14	6.45	281.2	322.0	0.895	3368.	18.61	1130.	0.869	1.59 1.57	0.311	0.266	109.	92
											OPF =	1.12				1.42 1.40			68.	
1.140	1.053	148.9	119.4	13639.	8.6	268.	7.25	7.56	277.5	320.7	0.857	3227.	18.00	1069.	0.823	1.60 1.58	0.268	0.222	101.	93
											OPF =	1.12				1.43 1.41			60.	

Table X

H O M O G E N E O U S   C O R E
==============================

P = 1.250 CM N = 74412

D	P/D	QL	QV	M	U	LC	DP	DPT	T1	T2	K	Q	NP	QEL	QR	DNBR		VM/VF	CELL	X(BOIL.)	
CM	-	W/CM	W/CCM	KG/S	M/S	CM	BAR	BAR	C	C	-	MW	MW	MW	-	-		-	-	CM	
1.030	1.214	182.4	134.8	18324.	6.3	273.	2.15	2.41	289.9	325.3	0.985	3708.	17.74	1276.	0.981	1.37	1.36	0.663	0.624	61.	94
											OPF =	1.12				1.22	1.21			34.	
1.050	1.190	178.3	131.8	18088.	6.6	278.	2.46	2.74	289.3	325.1	0.979	3687.	17.94	1267.	0.974	1.41	1.39	0.603	0.563	76.	95
											OPF =	1.12				1.26	1.24			42.	
1.070	1.168	174.2	128.7	17792.	6.9	282.	2.85	3.13	288.7	324.8	0.972	3660.	18.16	1255.	0.966	1.44	1.43	0.546	0.505	92.	96
											OPF =	1.12				1.29	1.27			49.	
1.090	1.147	169.9	125.6	17419.	7.2	287.	3.32	3.61	287.8	324.5	0.963	3626.	18.39	1241.	0.954	1.48	1.46	0.493	0.450	*****	97
											OPF =	1.12				1.32	1.30			57.	

Table XI

H E T E R O G E N E O U S   C O R E

DS = 1.000 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
128.	1.345		1.345	200.6	20482	44261	450.0	7.08	18223.	2.28	289.6	0.982	3699.	17.83	1272.	1.54	1.53	0.746	0.657	45.	1
												OPF = 1.12				1.37	1.37			23.	
64.	1.766	1.521	1.161	172.8	23779			5.78		2.69	325.2					1.45	1.44			*****	
												OPF = 1.12				1.29	1.29			90.	
130.	1.329		1.329	198.8	20995	45798	439.9	7.13	17919.	2.68	289.0	0.975	3672.	18.07	1260.	1.55	1.55	0.679	0.602	55.	2
												OPF = 1.12				1.39	1.38			22.	
65.	1.729	1.519	1.139	168.3	24803			6.12		3.09	325.0					1.50	1.50			*****	
												OPF = 1.12				1.34	1.34			99.	
132.	1.312		1.312	196.8	21534	47382	429.1	7.16	17537.	3.17	288.1	0.966	3637.	18.32	1245.	1.57	1.56	0.618	0.552	64.	3
												OPF = 1.12				1.40	1.40			32.	
66.	1.694	1.515	1.118	163.9	25848			6.47		3.57	324.6					1.56	1.55			*****	
												OPF = 1.12				1.39	1.38			107.	
134.	1.295		1.295	194.6	22104	48939	418.2	7.18	17119.	3.69	287.1	0.956	3598.	18.53	1229.	1.59	1.58	0.566	0.508	63.	4
												OPF = 1.12				1.42	1.41			42.	
67.	1.662	1.509	1.101	160.3	26835			6.80		4.08	324.3					1.60	1.59			*****	
												OPF = 1.12				1.43	1.42			115.	
136.	1.278		1.278	192.3	22708	50529	406.8	7.20	16642.	4.25	285.9	0.943	3552.	18.69	1209.	1.60	1.60	0.519	0.468	71.	5
												OPF = 1.12				1.43	1.43			41.	
68.	1.632	1.503	1.087	156.9	27821			7.11		4.64	323.8					1.65	1.64			*****	
												OPF = 1.12				1.47	1.46			122.	
138.	1.260		1.260	189.7	23352	52090	394.8	7.20	16102.	4.86	284.6	0.929	3499.	18.78	1186.	1.62	1.62	0.477	0.432	89.	6
												OPF = 1.12				1.45	1.45			49.	
69.	1.606	1.495	1.075	154.2	28738			7.40		5.24	323.3					1.69	1.68			*****	
												OPF = 1.12				1.51	1.50			118.	
140.	1.242		1.242	187.0	24041	53696	382.2	7.19	15494.	5.51	282.9	0.913	3436.	18.75	1159.	1.65	1.64	0.439	0.398	96.	7
												OPF = 1.12				1.47	1.46			57.	
70.	1.581	1.487	1.064	151.6	29655			7.66		5.88	322.7					1.72	1.71			*****	
												OPF = 1.12				1.54	1.53			124.	
142.	1.223		1.223	183.9	24786	55411	367.8	7.12	14732.	6.27	280.8	0.891	3353.	18.56	1123.	1.67	1.66	0.400	0.364	101.	8
												OPF = 1.12				1.49	1.48			55.	
71.	1.556	1.478	1.053	148.9	30625			7.92		6.63	321.9					1.76	1.75			*****	
												OPF = 1.12				1.57	1.56			120.	

H E T E R O G E N E O U S   C O R E

DS = 1.000 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
144.	1.203		1.203	180.6	25598	57103	354.0	7.11	14033.	6.91	278.7	0.869	3273.	18.24	1089.	1.69	1.68	0.366	0.334	124.	9
												OPF = 1.12				1.51	1.50			62.	
72.	1.534	1.469	1.044	146.7	31505			8.10		7.26	321.1					1.79	1.78			*****	
												OPF = 1.12				1.60	1.58			115.	
146.	1.183		1.183	176.9	26495	58950	337.8	7.04	13152.	7.64	275.9	0.841	3167.	17.65	1044.	1.71	1.71	0.331	0.301	*****	10
												OPF = 1.12				1.53	1.52			68.	
73.	1.511	1.461	1.035	144.4	32455			8.26		7.99	320.1					1.82	1.80			*****	
												OPF = 1.12				1.63	1.61			110.	
148.	1.161		1.161	172.8	27503	60976	320.9	7.01	12245.	8.32	272.8	0.810	3050.	16.87	995.	1.74	1.73	0.295	0.268	*****	11
												OPF = 1.12				1.55	1.54			72.	
74.	1.488	1.452	1.025	141.9	33473			8.51		8.65	318.9					1.85	1.83			*****	
												OPF = 1.12				1.65	1.63			104.	

Table XII

H E T E R O G E N E O U S   C O R E

DS = 0.950 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
140.	1.291		1.359	202.0	22246	48113	412.5	6.98	18325.	2.15	289.9	0.985	3708.	17.74	1276.	1.54	1.54	0.770	0.678	31.	12
												OPF = 1.12				1.38	1.37			10.	
70.	1.693	1.452	1.166	173.8	25867			5.74		2.53	325.3					1.45	1.44			*****	
												OPF = 1.12				1.30	1.29			82.	
142.	1.277		1.344	200.5	22737	49621	404.2	7.03	18071.	2.49	289.3	0.979	3685.	17.96	1266.	1.56	1.55	0.707	0.628	30.	13
												OPF = 1.12				1.39	1.39			10.	
71.	1.661	1.450	1.145	169.6	26884			6.04		2.86	325.1					1.50	1.49			*****	
												OPF = 1.12				1.34	1.33			91.	
144.	1.263		1.329	198.8	23251	51095	395.9	7.07	17798.	2.84	288.7	0.972	3661.	18.16	1256.	1.57	1.57	0.655	0.584	40.	14
												OPF = 1.12				1.40	1.40			20.	
72.	1.632	1.447	1.128	166.0	27844			6.32		3.21	324.9					1.54	1.53			*****	
												OPF = 1.12				1.38	1.37			99.	
146.	1.248		1.314	197.0	23789	52626	387.2	7.10	17459.	3.27	287.9	0.964	3630.	18.37	1242.	1.58	1.58	0.605	0.543	48.	15
												OPF = 1.12				1.42	1.41			19.	
73.	1.603	1.443	1.111	162.5	28837			6.63		3.63	324.6					1.59	1.58			*****	
												OPF = 1.12				1.42	1.41			97.	
150.	1.219		1.283	193.0	24948	55686	369.1	7.14	16674.	4.21	286.0	0.944	3555.	18.69	1210.	1.62	1.61	0.520	0.471	55.	16
												OPF = 1.12				1.44	1.44			28.	
75.	1.553	1.431	1.085	156.7	30738			7.18		4.57	323.8					1.66	1.65			*****	
												OPF = 1.12				1.48	1.47			111.	
152.	1.204		1.267	190.8	25576	57129	360.5	7.18	16295.	4.65	285.1	0.934	3518.	18.76	1194.	1.63	1.63	0.488	0.442	63.	17
												OPF = 1.12				1.46	1.45			36.	
76.	1.533	1.424	1.077	154.7	31553			7.40		5.00	323.5					1.69	1.68			*****	
												OPF = 1.12				1.51	1.50			108.	
154.	1.189		1.251	188.4	26244	58667	350.9	7.20	15822.	5.17	283.8	0.922	3470.	18.78	1173.	1.65	1.65	0.454	0.413	70.	18
												OPF = 1.12				1.47	1.47			44.	
77.	1.512	1.417	1.068	152.5	32423			7.63		5.51	323.0					1.72	1.70			*****	
												OPF = 1.12				1.54	1.52			105.	
158.	1.156		1.217	183.0	27723	61964	329.3	7.17	14623.	6.37	280.5	0.887	3341.	18.52	1118.	1.69	1.68	0.389	0.354	91.	19
												OPF = 1.12				1.51	1.50			49.	
79.	1.471	1.402	1.050	148.1	34241			8.06		6.70	321.8					1.78	1.76			*****	
												OPF = 1.12				1.59	1.57			107.	

H E T E R O G E N E O U S   C O R E

DS = 0.950 CM

QVS	PS		PS/DS	QLS	NS	NT	LC	US	M	DP	T1	K	Q	NP	QEL	DNBR		VM/VF	CELL	X(BOIL.)	
QVB	PB	DB	PB/DB	QLB	NB			UB		DPT	T2										
W/CCM	CM	CM	-	W/CM	-	-	CM	M/S	KG/S	BAR	C	-	MW	MW	MW	-		-	-	CM	
160.	1.139		1.199	179.9	28554	63693	317.8	7.15	13958.	6.97	278.5	0.867	3264.	18.20	1086.	1.71	1.70	0.358	0.327	103.	20
												OPF = 1.12				1.53	1.52			56.	
80.	1.453	1.394	1.042	146.2	35139			8.23		7.30	321.0					1.80	1.78			*****	
												OPF = 1.12				1.61	1.59			103.	
162.	1.122		1.181	176.5	29465	65523	305.1	7.12	13206.	7.60	276.1	0.843	3174.	17.70	1047.	1.73	1.72	0.328	0.298	*****	21
												OPF = 1.12				1.54	1.54			61.	
81.	1.434	1.387	1.034	144.2	36058			8.37		7.92	320.1					1.83	1.81			*****	
												OPF = 1.12				1.63	1.61			99.	
164.	1.103		1.161	172.7	30480	67600	290.9	7.08	12345.	8.24	273.2	0.814	3063.	16.96	1000.	1.75	1.74	0.294	0.267	*****	22
												OPF = 1.12				1.56	1.55			65.	
82.	1.413	1.379	1.025	141.8	37120			8.63		8.56	319.0					1.85	1.83			*****	
												OPF = 1.12				1.65	1.63			95.	

Table XIII

H E T E R O G E N E O U S   C O R E

DS = 0.900 CM

QVS	PS		PS/DS	QLS	NS	NT	LC	US	M	DP	T1	K	Q	NP	QEL	DNBR		VM/VF	CELL	X(BOIL.)	
QVB	PB	DB	PB/DB	QLB	NB			UB		DPT	T2										
W/CCM	CM	CM	-	W/CM	-	-	CM	M/S	KG/S	BAR	C	-	MW	MW	MW	-		-	-	CM	
148.	1.270		1.411	206.7	22990	48491	394.8	6.72	18840.	1.44	291.0	0.997	3752.	17.22	1295.	1.52	1.52	0.992	0.858	0.	23
												OPF = 1.12				1.36	1.35			0.	
74.	1.705	1.378	1.238	186.3	25501			5.01		1.80	325.7					1.32	1.31			79.	
												OPF = 1.12				1.18	1.17			39.	
150.	1.258		1.398	205.6	23417	49901	388.4	6.78	18708.	1.63	290.7	0.994	3741.	17.36	1290.	1.53	1.53	0.913	0.796	0.	24
												OPF = 1.12				1.37	1.36			0.	
75.	1.673	1.382	1.211	181.8	26484			5.25		1.98	325.6					1.37	1.36			97.	
												OPF = 1.12				1.22	1.22			49.	
152.	1.246		1.385	204.5	23859	51287	382.0	6.83	18565.	1.82	290.4	0.990	3728.	17.51	1285.	1.54	1.54	0.847	0.743	10.	25
												OPF = 1.12				1.38	1.37			0.	
76.	1.644	1.384	1.188	177.9	27428			5.48		2.17	325.5					1.41	1.41			115.	
												OPF = 1.12				1.26	1.26			57.	
154.	1.235		1.372	203.3	24316	52727	375.5	6.88	18387.	2.07	290.0	0.986	3713.	17.68	1278.	1.55	1.55	0.785	0.694	9.	26
												OPF = 1.12				1.39	1.38			0.	
77.	1.615	1.384	1.167	174.0	28411			5.73		2.41	325.3					1.46	1.45			*****	
												OPF = 1.12				1.30	1.30			66.	
156.	1.223		1.359	202.0	24789	54178	368.9	6.92	18181.	2.34	289.6	0.981	3695.	17.86	1270.	1.56	1.56	0.730	0.649	18.	27
												OPF = 1.12				1.40	1.39			0.	
78.	1.588	1.382	1.149	170.4	29389			6.00		2.68	325.2					1.50	1.49			*****	
												OPF = 1.12				1.34	1.33			74.	
158.	1.211		1.345	200.7	25280	55578	362.4	6.97	17973.	2.61	289.1	0.977	3677.	18.03	1262.	1.57	1.57	0.684	0.611	18.	28
												OPF = 1.12				1.41	1.40			9.	
79.	1.564	1.379	1.134	167.4	30298			6.23		2.95	325.0					1.54	1.53			*****	
												OPF = 1.12				1.37	1.36			82.	
160.	1.199		1.332	199.2	25790	56981	355.9	7.02	17746.	2.91	288.6	0.971	3656.	18.19	1254.	1.59	1.58	0.643	0.577	27.	29
												OPF = 1.12				1.42	1.41			9.	
80.	1.542	1.375	1.121	164.7	31191			6.46		3.24	324.8					1.57	1.56			*****	
												OPF = 1.12				1.40	1.39			80.	
162.	1.187		1.319	197.6	26322	58389	349.3	7.06	17497.	3.22	288.0	0.965	3633.	18.35	1244.	1.60	1.59	0.605	0.545	35.	30
												OPF = 1.12				1.43	1.42			17.	
81.	1.521	1.370	1.110	162.2	32067			6.69		3.55	324.6					1.60	1.59			*****	
												OPF = 1.12				1.43	1.42			87.	

H E T E R O G E N E O U S   C O R E

DS = 0.900 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
166.	1.162		1.291	194.1	27457	61316	335.5	7.13	16882.	3.97	286.5	0.950	3575.	18.62	1219.	1.63	1.62	0.534	0.484	42.	31
												OPF = 1.12				1.45	1.45			25.	
83.	1.480	1.359	1.088	157.4	33859			7.16		4.30	324.0					1.66	1.65			*****	
												OPF = 1.12				1.48	1.47			92.	
168.	1.149		1.277	192.2	28066	62816	328.0	7.14	16494.	4.42	285.6	0.940	3538.	18.73	1203.	1.64	1.63	0.501	0.455	49.	32
												OPF = 1.12				1.46	1.46			25.	
84.	1.461	1.354	1.079	155.2	34750			7.40		4.74	323.7					1.69	1.68			*****	
												OPF = 1.12				1.51	1.50			98.	
170.	1.136		1.263	190.1	28707	64279	320.8	7.17	16133.	4.83	284.6	0.930	3502.	18.77	1187.	1.65	1.65	0.472	0.430	56.	33
												OPF = 1.12				1.48	1.47			32.	
85.	1.444	1.347	1.071	153.4	35572			7.59		5.15	323.3					1.71	1.70			*****	
												OPF = 1.12				1.53	1.52			96.	
172.	1.123		1.248	187.9	29384	65857	312.7	7.17	15660.	5.34	283.4	0.917	3453.	18.77	1166.	1.67	1.66	0.442	0.403	63.	34
												OPF = 1.12				1.49	1.49			31.	
86.	1.426	1.341	1.063	151.4	36473			7.81		5.65	322.9					1.74	1.72			*****	
												OPF = 1.12				1.55	1.54			94.	
174.	1.110		1.233	185.6	30104	67409	304.9	7.20	15220.	5.79	282.2	0.905	3407.	18.70	1146.	1.69	1.68	0.415	0.379	69.	35
												OPF = 1.12				1.51	1.50			38.	
87.	1.410	1.335	1.056	149.7	37305			7.99		6.10	322.4					1.76	1.74			*****	
												OPF = 1.12				1.57	1.56			91.	
176.	1.096		1.218	183.0	30872	69098	295.8	7.17	14639.	6.36	280.5	0.888	3343.	18.53	1119.	1.70	1.70	0.386	0.353	74.	36
												OPF = 1.12				1.52	1.51			44.	
88.	1.393	1.328	1.048	147.8	38226			8.18		6.66	321.8					1.79	1.76			*****	
												OPF = 1.12				1.59	1.58			96.	
178.	1.081		1.202	180.3	31698	70782	287.0	7.18	14096.	6.85	278.9	0.871	3281.	18.27	1092.	1.72	1.71	0.360	0.329	79.	37
												OPF = 1.12				1.54	1.53			43.	
89.	1.377	1.322	1.042	146.2	39084			8.32		7.15	321.2					1.80	1.78			*****	
												OPF = 1.12				1.61	1.59			93.	
182.	1.051		1.167	174.0	33576	74593	265.8	7.12	12675.	8.01	274.3	0.825	3106.	17.26	1018.	1.76	1.75	0.303	0.277	*****	38
												OPF = 1.12				1.57	1.56			53.	
91.	1.344	1.309	1.027	142.5	41017			8.65		8.30	319.5					1.84	1.82			*****	
												OPF = 1.12				1.65	1.62			86.	

Table XIV

HETEROGENEOUS CORE

DS = 0.850 CM

QVS QVB W/CCM	PS PB CM	 DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
160.	1.228		1.445	209.0	24578	51155	366.7	6.54	19021.	1.19	291.4	1.001	3767.	17.00	1301.	1.52	1.51	1.145	0.981	0.	39
												OPF = 1.12				1.36	1.35			0.	
80.	1.670	1.300	1.285	193.3	26577			4.70		1.52	325.9					1.25	1.25			46.	
												OPF = 1.12				1.12	1.11			18.	
165.	1.204		1.416	207.1	25581	54474	353.8	6.66	18793.	1.51	290.9	0.995	3748.	17.27	1293.	1.54	1.53	0.953	0.830	0.	40
												OPF = 1.12				1.37	1.37			0.	
83.	1.602	1.314	1.219	183.3	28893			5.18		1.83	325.7					1.37	1.36			71.	
												OPF = 1.12				1.22	1.21			44.	
170.	1.179		1.387	204.7	26657	57849	340.9	6.78	18482.	1.94	290.2	0.988	3721.	17.59	1282.	1.56	1.55	0.812	0.718	0.	41
												OPF = 1.12				1.39	1.39			0.	
85.	1.542	1.315	1.173	175.0	31192			5.69		2.25	325.4					1.46	1.45			102.	
												OPF = 1.12				1.30	1.29			60.	
176.	1.149		1.352	201.4	28060	61953	325.4	6.90	17983.	2.60	289.1	0.977	3678.	18.02	1263.	1.59	1.58	0.682	0.612	8.	42
												OPF = 1.12				1.42	1.41			0.	
88.	1.479	1.308	1.131	166.7	33893			6.31		2.91	325.0					1.56	1.54			*****	
												OPF = 1.12				1.39	1.38			73.	
180.	1.129		1.328	198.7	29077	64771	315.0	6.98	17579.	3.12	288.2	0.967	3641.	18.30	1247.	1.61	1.60	0.612	0.552	16.	43
												OPF = 1.12				1.44	1.43			8.	
90.	1.441	1.300	1.109	161.9	35694			6.72		3.42	324.7					1.61	1.60			*****	
												OPF = 1.12				1.44	1.43			79.	
182.	1.119		1.316	197.3	29613	66130	309.6	7.01	17326.	3.43	287.6	0.961	3618.	18.44	1237.	1.62	1.61	0.580	0.526	23.	44
												OPF = 1.12				1.45	1.44			8.	
91.	1.425	1.295	1.100	160.0	36517			6.93		3.73	324.4					1.64	1.62			*****	
												OPF = 1.12				1.46	1.45			77.	
184.	1.108		1.304	195.8	30171	67488	304.4	7.06	17104.	3.71	287.1	0.955	3597.	18.54	1228.	1.63	1.62	0.553	0.502	23.	45
												OPF = 1.12				1.46	1.45			8.	
92.	1.410	1.290	1.092	158.3	37317			7.11		4.00	324.2					1.66	1.64			*****	
												OPF = 1.12				1.48	1.47			84.	
186.	1.098		1.292	194.2	30751	68924	298.8	7.08	16805.	4.06	286.3	0.948	3568.	18.65	1216.	1.64	1.64	0.524	0.478	30.	46
												OPF = 1.12				1.47	1.46			15.	
93.	1.394	1.285	1.084	156.4	38173			7.32		4.36	324.0					1.68	1.66			*****	
												OPF = 1.12				1.50	1.49			82.	

H E T E R O G E N E O U S   C O R E

DS = 0.850 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
188.	1.087		1.279	192.5	31357	70389	292.9	7.10	16476.	4.44	285.5	0.939	3536.	18.73	1202.	1.66	1.65	0.496	0.453	37.	47
												OPF = 1.12				1.48	1.47			15.	
94.	1.378	1.280	1.077	154.6	39032			7.52		4.74	323.7					1.70	1.69			*****	
												OPF = 1.12				1.52	1.51			81.	
190.	1.076		1.266	190.7	31991	71797	287.5	7.14	16192.	4.76	284.8	0.932	3508.	18.77	1190.	1.67	1.66	0.473	0.432	43.	48
												OPF = 1.12				1.49	1.48			22.	
95.	1.365	1.275	1.071	153.2	39806			7.68		5.05	323.4					1.72	1.70			*****	
												OPF = 1.12				1.54	1.52			86.	
192.	1.065		1.253	188.8	32656	73333	281.3	7.15	15802.	5.19	283.8	0.921	3468.	18.78	1173.	1.68	1.67	0.447	0.409	42.	49
												OPF = 1.12				1.50	1.49			21.	
96.	1.350	1.269	1.064	151.5	40677			7.87		5.47	323.0					1.74	1.72			*****	
												OPF = 1.12				1.56	1.54			84.	
194.	1.054		1.240	186.7	33357	74818	275.6	7.20	15467.	5.54	282.9	0.912	3433.	18.75	1158.	1.70	1.69	0.424	0.388	48.	50
												OPF = 1.12				1.51	1.51			28.	
97.	1.337	1.264	1.058	150.2	41461			8.02		5.82	322.7					1.76	1.74			*****	
												OPF = 1.12				1.57	1.55			83.	
196.	1.043		1.227	184.5	34099	76450	268.8	7.19	15002.	6.01	281.6	0.898	3383.	18.65	1136.	1.71	1.70	0.399	0.366	54.	51
												OPF = 1.12				1.53	1.52			34.	
98.	1.323	1.258	1.051	148.6	42351			8.19		6.29	322.2					1.78	1.75			*****	
												OPF = 1.12				1.59	1.57			81.	
198.	1.031		1.213	182.2	34886	78077	262.2	7.22	14559.	6.43	280.3	0.885	3334.	18.49	1115.	1.72	1.71	0.376	0.345	59.	52
												OPF = 1.12				1.54	1.53			33.	
99.	1.310	1.253	1.046	147.2	43191			8.33		6.71	321.7					1.79	1.77			*****	
												OPF = 1.12				1.60	1.58			85.	
200.	1.019		1.198	179.7	35728	79806	254.9	7.22	14034.	6.91	278.7	0.869	3273.	18.24	1089.	1.74	1.73	0.353	0.323	64.	53
												OPF = 1.12				1.55	1.54			38.	
100.	1.297	1.247	1.040	145.7	44078			8.46		7.18	321.1					1.81	1.78			*****	
												OPF = 1.12				1.61	1.59			83.	
202.	1.006		1.183	177.0	36635	81558	247.8	7.25	13533.	7.34	277.2	0.854	3214.	17.93	1064.	1.75	1.74	0.331	0.302	74.	54
												OPF = 1.12				1.57	1.55			43.	
101.	1.285	1.242	1.035	144.4	44923			8.57		7.61	320.5					1.82	1.79			*****	
												OPF = 1.12				1.62	1.60			81.	

H E T E R O G E N E O U S   C O R E

DS = 0.850 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -	VM/VF -	CELL -	X(BOIL.) CM	
204.	0.993		1.168	174.1	37621	83442	240.0	7.29	12970.	7.78	275.3	0.835	3144.	17.51	1034.	1.77 1.76	0.307	0.280	84.	55
												OPF =	1.12			1.58 1.57			42.	
102.	1.272	1.236	1.029	142.9	45821			8.69		8.05	319.8					1.83 1.80			*****	
												OPF =	1.12			1.63 1.61			78.	
206.	0.979		1.151	170.9	38707	85656	231.4	7.32	12326.	8.26	273.1	0.813	3061.	16.95	999.	1.78 1.77	0.279	0.254	*****	56
												OPF =	1.12			1.59 1.58			46.	
103.	1.257	1.231	1.021	140.9	46949			9.04		8.52	319.0					1.85 1.81			*****	
												OPF =	1.12			1.65 1.62			69.	

Table XV

H E T E R O G E N E O U S   C O R E

DS = 0.800 CM

QVS	PS		PS/DS	QLS	NS	NT	LC	US	M	DP	T1	K	Q	NP	QEL	DNBR		VM/VF	CELL	X(BOIL.)	
QVB	PB	DB	PB/DB	QLB	NB			UB		DPT	T2										
W/CCM	CM	CM	-	W/CM	-	-	CM	M/S	KG/S	BAR	C	-	MW	MW	MW	-		-	-	CM	
180.	1.158		1.448	209.2	27625	58277	325.5	6.50	18959.	1.28	291.2	0.999	3762.	17.08	1299.	1.54	1.53	1.066	0.923	0.	57
												OPF = 1.12				1.37	1.37			0.	
90.	1.555	1.242	1.252	188.5	30652			4.92		1.57	325.8					1.32	1.31			41.	
												OPF = 1.12				1.18	1.17			24.	
184.	1.142		1.428	207.9	28414	60816	317.3	6.58	18800.	1.50	290.9	0.996	3749.	17.26	1293.	1.55	1.54	0.949	0.831	0.	58
												OPF = 1.12				1.38	1.38			0.	
92.	1.513	1.247	1.213	182.3	32402			5.24		1.79	325.7					1.39	1.38			63.	
												OPF = 1.12				1.24	1.23			32.	
188.	1.126		1.407	206.4	29242	63445	309.1	6.66	18595.	1.78	290.5	0.991	3731.	17.48	1286.	1.56	1.56	0.849	0.752	0.	59
												OPF = 1.12				1.40	1.39			0.	
94.	1.472	1.247	1.180	176.5	34203			5.60		2.07	325.5					1.45	1.44			77.	
												OPF = 1.12				1.30	1.29			46.	
192.	1.110		1.387	204.7	30113	66005	301.1	6.74	18371.	2.09	290.0	0.986	3712.	17.70	1277.	1.58	1.57	0.771	0.689	0.	60
												OPF = 1.12				1.41	1.40			0.	
96.	1.437	1.244	1.156	171.7	35892			5.93		2.37	325.3					1.51	1.49			98.	
												OPF = 1.12				1.35	1.33			53.	
196.	1.093		1.366	202.8	31031	68678	292.9	6.81	18081.	2.47	289.3	0.979	3686.	17.95	1266.	1.60	1.59	0.699	0.630	0.	61
												OPF = 1.12				1.42	1.42			0.	
98.	1.403	1.239	1.133	167.1	37647			6.30		2.75	325.1					1.56	1.55			*****	
												OPF = 1.12				1.39	1.38			59.	
200.	1.076		1.345	200.6	32003	71365	284.9	6.89	17780.	2.86	288.6	0.972	3659.	18.17	1255.	1.61	1.61	0.639	0.578	7.	62
												OPF = 1.12				1.44	1.43			0.	
100.	1.372	1.232	1.114	163.1	39362			6.63		3.14	324.8					1.61	1.59			*****	
												OPF = 1.12				1.44	1.42			64.	
204.	1.059		1.324	198.2	33036	73916	277.0	6.97	17439.	3.29	287.9	0.964	3628.	18.38	1241.	1.63	1.62	0.589	0.535	14.	63
												OPF = 1.12				1.46	1.45			0.	
102.	1.347	1.223	1.101	160.2	40880			6.95		3.57	324.5					1.64	1.62			*****	
												OPF = 1.12				1.47	1.45			69.	
208.	1.042		1.303	195.6	34140	76674	268.5	7.03	16985.	3.85	286.8	0.952	3585.	18.59	1223.	1.65	1.64	0.538	0.492	20.	64
												OPF = 1.12				1.47	1.47			7.	
104.	1.320	1.215	1.087	157.0	42534			7.31		4.12	324.1					1.68	1.66			*****	
												OPF = 1.12				1.50	1.48			74.	

H E T E R O G E N E O U S   C O R E

DS = 0.800 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
212.	1.024		1.280	192.7	35327	79405	260.2	7.11	16532.	4.38	285.7	0.941	3541.	18.72	1204.	1.67	1.66	0.495	0.453	26.	65
												OPF = 1.12				1.49	1.48			13.	
106.	1.297	1.206	1.076	154.4	44078			7.61		4.64	323.7					1.71	1.69			*****	
												OPF = 1.12				1.53	1.51			72.	
216.	1.006		1.258	189.4	36612	82250	251.6	7.19	16012.	4.96	284.3	0.927	3489.	18.78	1182.	1.69	1.68	0.454	0.416	31.	66
												OPF = 1.12				1.51	1.50			19.	
108.	1.275	1.196	1.065	151.9	45638			7.90		5.22	323.2					1.74	1.71			*****	
												OPF = 1.12				1.55	1.53			75.	
220.	0.987		1.234	185.8	38019	85246	242.6	7.27	15409.	5.60	282.7	0.910	3427.	18.74	1155.	1.72	1.71	0.414	0.379	42.	67
												OPF = 1.12				1.53	1.52			24.	
110.	1.253	1.187	1.055	149.6	47227			8.17		5.86	322.6					1.76	1.74			*****	
												OPF = 1.12				1.57	1.55			73.	
224.	0.968		1.210	181.7	39579	88570	231.9	7.28	14568.	6.42	280.3	0.886	3335.	18.50	1116.	1.74	1.73	0.371	0.339	46.	68
												OPF = 1.12				1.55	1.54			29.	
112.	1.230	1.178	1.044	146.8	48991			8.46		6.68	321.7					1.79	1.76			*****	
												OPF = 1.12				1.60	1.57			70.	
228.	0.947		1.184	177.1	41339	92035	220.8	7.34	13690.	7.20	277.7	0.859	3233.	18.03	1072.	1.76	1.75	0.331	0.302	61.	69
												OPF = 1.12				1.57	1.56			33.	
114.	1.209	1.169	1.035	144.4	50696			8.68		7.45	320.7					1.81	1.77			*****	
												OPF = 1.12				1.61	1.58			66.	

Table XVI

H E T E R O G E N E O U S   C O R E

DS = 0.750 CM

QVS	PS		PS/DS	QLS	NS	NT	LC	US	M	DP	T1	K	Q	NP	QEL	DNBR		VM/VF	CELL	X(BOIL.)	
QVB	PB	DB	PB/DB	QLB	NB			UB		DPT	T2										
W/CCM	CM	CM	-	W/CM	-	-	CM	M/S	KG/S	BAR	C	-	MW	MW	MW	-		-	-	CM	
204.	1.089		1.452	209.4	31277	66828	286.8	6.45	18891.	1.37	291.1	0.998	3756.	17.16	1297.	1.55	1.55	1.001	0.877	0.	70
												OPF = 1.12				1.39	1.38			0.	
102.	1.444	1.179	1.225	184.2	35551			5.15		1.64	325.8					1.38	1.37			43.	
												OPF = 1.12				1.23	1.22			22.	
208.	1.075		1.434	208.3	32058	69332	280.3	6.51	18740.	1.58	290.8	0.994	3743.	17.33	1291.	1.56	1.56	0.910	0.806	0.	71
												OPF = 1.12				1.40	1.39			0.	
104.	1.410	1.180	1.195	179.1	37274			5.44		1.85	325.6					1.43	1.42			56.	
												OPF = 1.12				1.28	1.27			28.	
212.	1.062		1.416	207.0	32872	71737	274.0	6.59	18587.	1.79	290.4	0.991	3730.	17.49	1286.	1.58	1.57	0.840	0.749	0.	72
												OPF = 1.12				1.41	1.40			0.	
106.	1.381	1.177	1.173	175.1	38865			5.71		2.05	325.5					1.48	1.46			69.	
												OPF = 1.12				1.32	1.31			34.	
220.	1.035		1.380	204.1	34610	76697	261.7	6.73	18194.	2.32	289.6	0.982	3696.	17.85	1271.	1.60	1.60	0.718	0.649	0.	73
												OPF = 1.12				1.43	1.42			0.	
110.	1.327	1.168	1.136	167.8	42087			6.27		2.58	325.2					1.56	1.54			*****	
												OPF = 1.12				1.39	1.38			46.	
228.	1.007		1.343	200.4	36524	81787	249.4	6.88	17698.	2.97	288.5	0.970	3652.	18.22	1252.	1.63	1.62	0.621	0.565	0.	74
												OPF = 1.12				1.46	1.45			0.	
114.	1.280	1.155	1.108	161.7	45263			6.83		3.22	324.8					1.63	1.61			*****	
												OPF = 1.12				1.45	1.43			56.	
228.	1.007		1.343	200.4	36524	81787	249.4	6.88	17698.	2.97	288.5	0.970	3652.	18.22	1252.	1.63	1.62	0.621	0.565	0.	75
												OPF = 1.12				1.46	1.45			0.	
114.	1.280	1.155	1.108	161.7	45263			6.83		3.22	324.8					1.63	1.61			*****	
												OPF = 1.12				1.45	1.43			56.	
236.	0.979		1.306	196.0	38657	86928	237.1	7.03	17070.	3.75	287.0	0.954	3593.	18.55	1227.	1.66	1.65	0.540	0.495	12.	76
												OPF = 1.12				1.49	1.48			0.	
118.	1.239	1.141	1.087	157.0	48271			7.37		3.99	324.2					1.68	1.65			*****	
												OPF = 1.12				1.50	1.48			59.	
240.	0.965		1.286	193.5	39825	89544	231.1	7.12	16739.	4.14	286.2	0.946	3562.	18.67	1213.	1.68	1.67	0.505	0.463	17.	77
												OPF = 1.12				1.50	1.49			6.	
120.	1.221	1.133	1.078	155.0	49719			7.61		4.38	323.9					1.70	1.67			*****	
												OPF = 1.12				1.52	1.49			64.	

H E T E R O G E N E O U S   C O R E

DS = 0.750 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
244.	0.950		1.267	190.7	41076	92414	224.4	7.18	16267.	4.68	285.0	0.934	3515.	18.76	1193.	1.70	1.69	0.466	0.428	22.	78
												OPF = 1.12				1.52	1.51			11.	
122.	1.202	1.125	1.068	152.6	51338			7.90		4.92	323.5					1.72	1.70			*****	
												OPF = 1.12				1.54	1.51			62.	
248.	0.935		1.246	187.7	42425	95334	217.6	7.25	15778.	5.21	283.7	0.920	3465.	18.78	1172.	1.72	1.71	0.431	0.396	27.	79
												OPF = 1.12				1.53	1.52			11.	
124.	1.184	1.118	1.059	150.5	52909			8.15		5.45	323.0					1.74	1.71			*****	
												OPF = 1.12				1.56	1.53			65.	
252.	0.919		1.225	184.3	43893	98414	210.4	7.32	15208.	5.80	282.1	0.904	3405.	18.70	1146.	1.74	1.72	0.396	0.363	32.	80
												OPF = 1.12				1.55	1.54			16.	
126.	1.166	1.110	1.051	148.4	54521			8.40		6.04	322.4					1.76	1.73			*****	
												OPF = 1.12				1.57	1.54			63.	
256.	0.903		1.203	180.6	45508	101776	202.2	7.35	14464.	6.52	280.0	0.883	3323.	18.46	1111.	1.76	1.74	0.359	0.329	40.	81
												OPF = 1.12				1.57	1.56			20.	
128.	1.148	1.102	1.041	146.1	56268			8.65		6.75	321.6					1.78	1.74			*****	
												OPF = 1.12				1.59	1.55			61.	
256.	0.903		1.203	180.6	45508	101776	202.2	7.35	14464.	6.52	280.0	0.883	3323.	18.46	1111.	1.76	1.74	0.359	0.329	40.	82
												OPF = 1.12				1.57	1.56			20.	
128.	1.148	1.102	1.041	146.1	56268			8.65		6.75	321.6					1.78	1.74			*****	
												OPF = 1.12				1.59	1.55			61.	
260.	0.885		1.180	176.4	47314	105237	194.0	7.44	13735.	7.17	277.8	0.860	3238.	18.06	1074.	1.78	1.76	0.326	0.297	48.	83
												OPF = 1.12				1.59	1.57			29.	
130.	1.131	1.095	1.034	144.1	57923			8.83		7.39	320.8					1.79	1.75			*****	
												OPF = 1.12				1.60	1.56			58.	
264.	0.866		1.155	171.6	49381	109299	184.4	7.53	12832.	7.89	274.9	0.830	3127.	17.40	1027.	1.79	1.77	0.286	0.260	60.	84
												OPF = 1.12				1.60	1.58			32.	
132.	1.112	1.087	1.023	141.5	59918			9.21		8.11	319.7					1.80	1.76			*****	
												OPF = 1.12				1.61	1.57			55.	
272.	0.821		1.095	158.9	54958	120687	156.2	7.59	10027.	9.61	264.1	0.725	2728.	14.32	860.	1.80	1.78	0.179	0.163	*****	85
												OPF = 1.12				1.61	1.58			39.	
136.	1.062	1.072	0.991	132.9	65729			11.86		9.84	315.6					1.93	1.88			*****	
												OPF = 1.12				1.73	1.68			78.	

Table XVII

H E T E R O G E N E O U S   C O R E

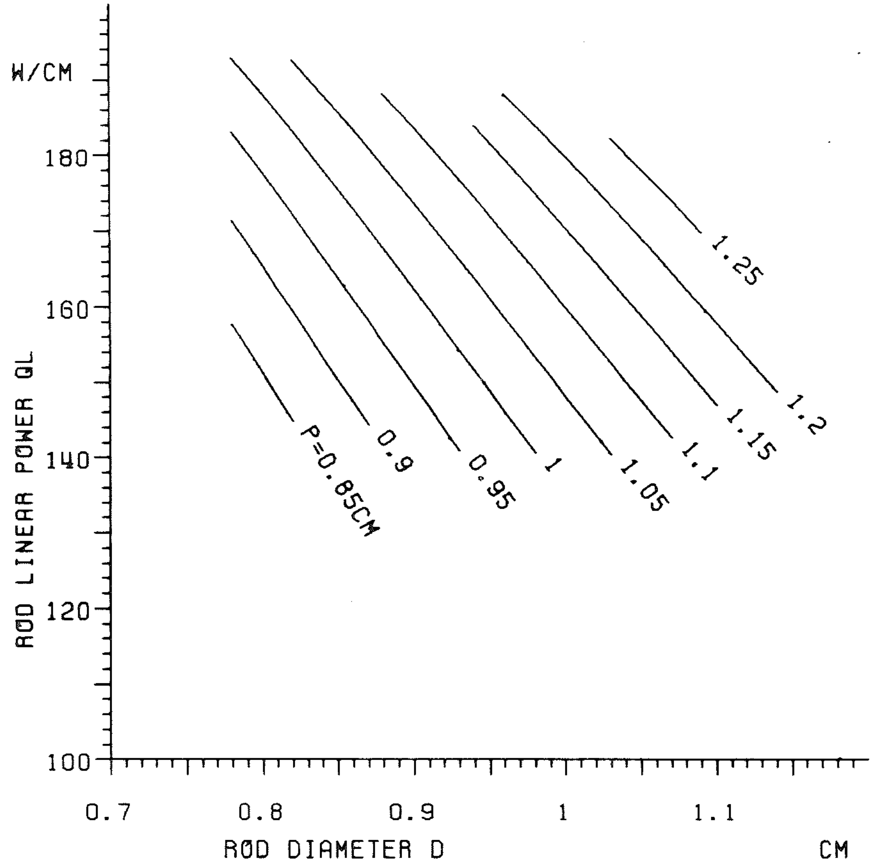
DS = 0.700 CM

QVS QVB W/CCM	PS PB CM	DB CM	PS/DS PB/DB -	QLS QLB W/CM	NS NB -	NT -	LC CM	US UB M/S	M KG/S	DP DPT BAR	T1 T2 C	K -	Q MW	NP MW	QEL MW	DNBR -		VM/VF -	CELL -	X(BOIL.) CM	
228.	1.033		1.475	210.6	34752	74220	257.0	6.32	18959.	1.28	291.2	0.999	3762.	17.08	1299.	1.56	1.55	1.044	0.917	0.	86
												OPF = 1.12				1.39	1.38			0.	
114.	1.371	1.112	1.232	185.5	39468			5.09		1.52	325.8					1.37	1.36			32.	
												OPF = 1.12				1.23	1.21			13.	
232.	1.022		1.460	209.9	35491	76458	252.0	6.38	18865.	1.41	291.0	0.997	3754.	17.19	1296.	1.57	1.56	0.973	0.860	0.	87
												OPF = 1.12				1.40	1.39			0.	
116.	1.345	1.111	1.210	181.8	40967			5.30		1.65	325.7					1.41	1.40			38.	
												OPF = 1.12				1.26	1.25			19.	
236.	1.011		1.445	209.0	36256	78688	247.2	6.45	18766.	1.55	290.8	0.995	3746.	17.30	1292.	1.58	1.57	0.912	0.811	0.	88
												OPF = 1.12				1.41	1.40			0.	
118.	1.322	1.109	1.192	178.6	42432			5.49		1.78	325.7					1.45	1.43			43.	
												OPF = 1.12				1.29	1.28			25.	
240.	1.000		1.429	208.0	37047	81080	242.3	6.51	18632.	1.73	290.5	0.992	3734.	17.44	1287.	1.59	1.58	0.850	0.761	0.	89
												OPF = 1.12				1.42	1.41			0.	
120.	1.298	1.107	1.173	175.0	44033			5.73		1.96	325.6					1.49	1.47			55.	
												OPF = 1.12				1.33	1.31			30.	
244.	0.989		1.413	206.9	37868	83493	237.5	6.57	18482.	1.94	290.2	0.988	3721.	17.59	1282.	1.60	1.59	0.794	0.716	0.	90
												OPF = 1.12				1.43	1.42			0.	
122.	1.275	1.103	1.156	171.7	45625			5.98		2.17	325.4					1.52	1.50			59.	
												OPF = 1.12				1.36	1.34			36.	
248.	0.978		1.398	205.6	38720	85928	232.8	6.62	18313.	2.16	289.8	0.985	3707.	17.75	1275.	1.61	1.60	0.744	0.674	0.	91
												OPF = 1.12				1.44	1.43			0.	
124.	1.253	1.099	1.140	168.7	47208			6.22		2.39	325.3					1.55	1.53			70.	
												OPF = 1.12				1.39	1.37			41.	
252.	0.967		1.382	204.3	39606	88209	228.3	6.70	18171.	2.35	289.5	0.981	3694.	17.87	1270.	1.62	1.61	0.705	0.640	0.	92
												OPF = 1.12				1.45	1.44			0.	
126.	1.235	1.093	1.130	166.5	48603			6.42		2.58	325.2					1.58	1.56			80.	
												OPF = 1.12				1.41	1.39			40.	
256.	0.956		1.366	202.8	40530	90745	223.6	6.76	17966.	2.62	289.1	0.976	3676.	18.04	1262.	1.63	1.62	0.661	0.603	0.	93
												OPF = 1.12				1.46	1.45			0.	
128.	1.215	1.088	1.117	163.7	50215			6.66		2.85	325.0					1.61	1.58			*****	
												OPF = 1.12				1.43	1.41			45.	

H E T E R O G E N E O U S   C O R E

DS = 0.700 CM

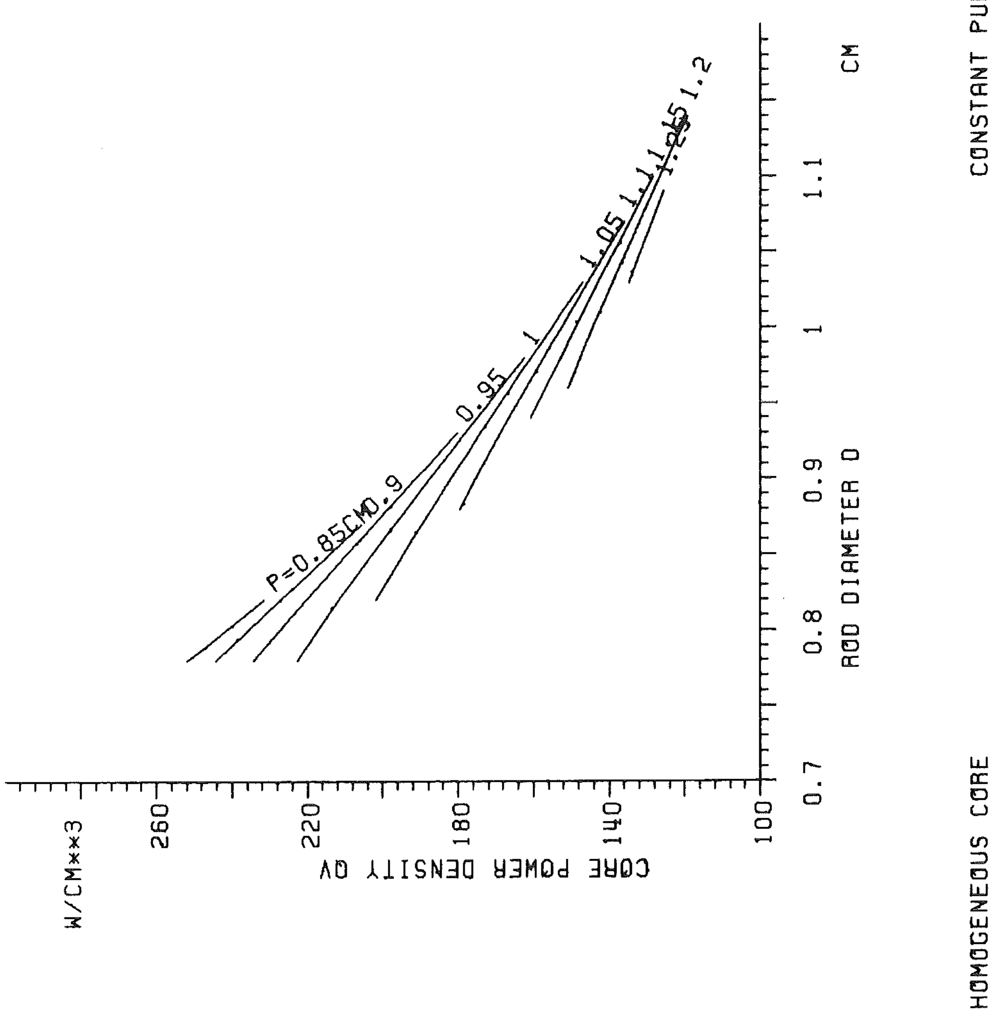
QVS	PS		PS/DS	QLS	NS	NT	LC	US	M	DP	T1	K	Q	NP	QEL	DNBR		VM/VF	CELL	X(BOIL.)	
QVB	PB	DB	PB/DB	QLB	NB			UB		DPT	T2										
W/CCM	CM	CM	-	W/CM	-	-	CM	M/S	KG/S	BAR	C	-	MW	MW	MW	-		-	-	CM	
260.	0.945		1.350	201.2	41495	93205	219.0	6.82	17738.	2.92	288.6	0.971	3655.	18.20	1253.	1.64	1.63	0.622	0.570	0.	94
												OPF =	1.12			1.47	1.46			0.	
130.	1.197	1.082	1.106	161.4	51710			6.91		3.14	324.8					1.63	1.60			*****	
												OPF =	1.12			1.45	1.43			44.	
264.	0.934		1.334	199.4	42506	95540	214.6	6.91	17553.	3.15	288.1	0.966	3639.	18.31	1246.	1.66	1.65	0.592	0.542	0.	95
												OPF =	1.12			1.48	1.47			0.	
132.	1.182	1.076	1.099	159.8	53034			7.10		3.37	324.6					1.64	1.62			*****	
												OPF =	1.12			1.47	1.44			48.	
268.	0.922		1.318	197.5	43567	98118	209.9	6.97	17275.	3.50	287.5	0.960	3613.	18.46	1235.	1.67	1.66	0.557	0.512	0.	96
												OPF =	1.12			1.49	1.48			0.	
134.	1.166	1.070	1.090	157.7	54551			7.34		3.72	324.4					1.66	1.64			*****	
												OPF =	1.12			1.49	1.46			47.	
272.	0.911		1.301	195.4	44685	100770	205.2	7.03	16962.	3.88	286.7	0.952	3583.	18.60	1222.	1.68	1.67	0.523	0.482	5.	97
												OPF =	1.12			1.50	1.49			0.	
136.	1.150	1.063	1.081	155.7	56085			7.59		4.09	324.1					1.68	1.65			*****	
												OPF =	1.12			1.50	1.47			51.	
276.	0.899		1.284	193.2	45866	103307	200.8	7.14	16712.	4.17	286.1	0.945	3559.	18.68	1212.	1.70	1.68	0.495	0.456	10.	98
												OPF =	1.12			1.52	1.50			0.	
138.	1.136	1.057	1.075	154.3	57441			7.77		4.39	323.9					1.69	1.66			*****	
												OPF =	1.12			1.51	1.48			50.	
280.	0.887		1.267	190.8	47121	106138	195.8	7.20	16324.	4.61	285.1	0.935	3521.	18.75	1195.	1.71	1.70	0.463	0.427	15.	99
												OPF =	1.12			1.53	1.52			5.	
140.	1.121	1.051	1.067	152.3	59017			8.02		4.83	323.5					1.71	1.68			*****	
												OPF =	1.12			1.53	1.50			54.	
284.	0.875		1.249	188.1	48461	109083	190.6	7.25	15882.	5.10	284.0	0.923	3476.	18.78	1176.	1.73	1.71	0.432	0.398	19.	100
												OPF =	1.12			1.54	1.53			5.	
142.	1.106	1.044	1.059	150.4	60622			8.25		5.31	323.1					1.73	1.69			*****	
												OPF =	1.12			1.54	1.51			52.	
288.	0.862		1.231	185.3	49900	111960	185.9	7.38	15516.	5.49	283.0	0.913	3438.	18.76	1160.	1.74	1.73	0.406	0.372	23.	101
												OPF =	1.12			1.56	1.54			9.	
144.	1.093	1.038	1.053	149.0	62060			8.43		5.70	322.7					1.73	1.70			*****	
												OPF =	1.12			1.55	1.51			51.	



HOMOGENEOUS CORE

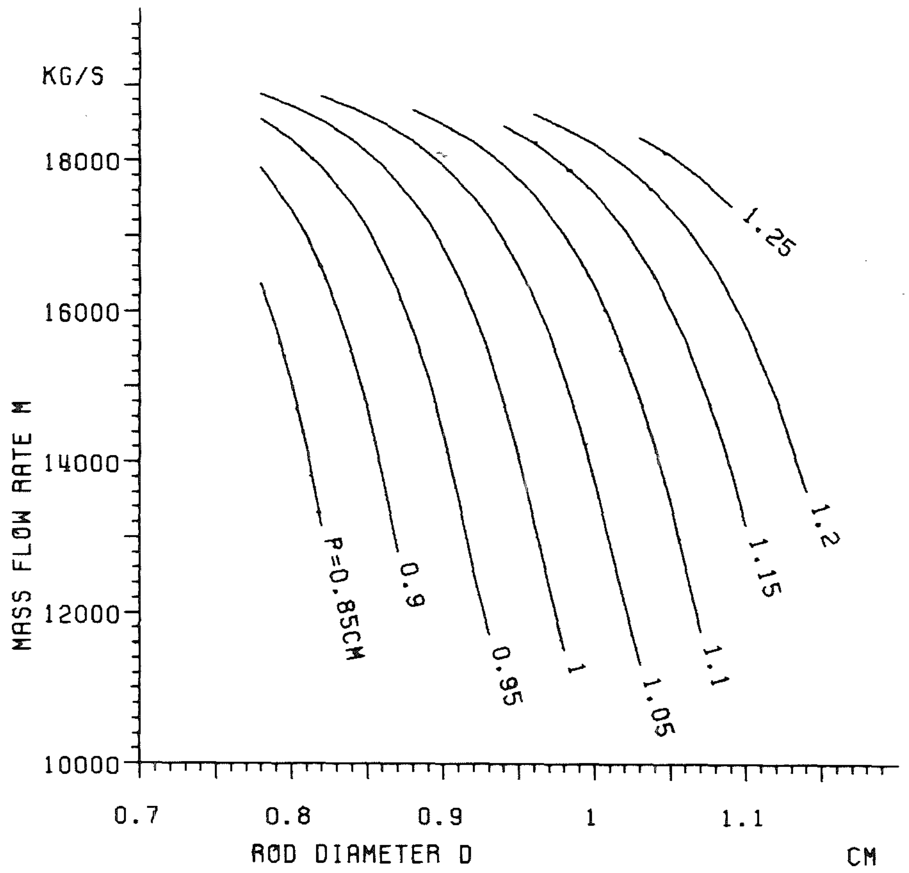
CONSTANT PUMP CHARACTERISTICS

Fig. 1



CONSTANT PUMP CHARACTERISTICS
HOMOGENEOUS CORE
W/CM**3
CORE POWER DENSITY QV
260
220
180
140
100
0.7
0.8
0.9
1
1.1
CM
ROD DIAMETER D
P=0.85CM
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25

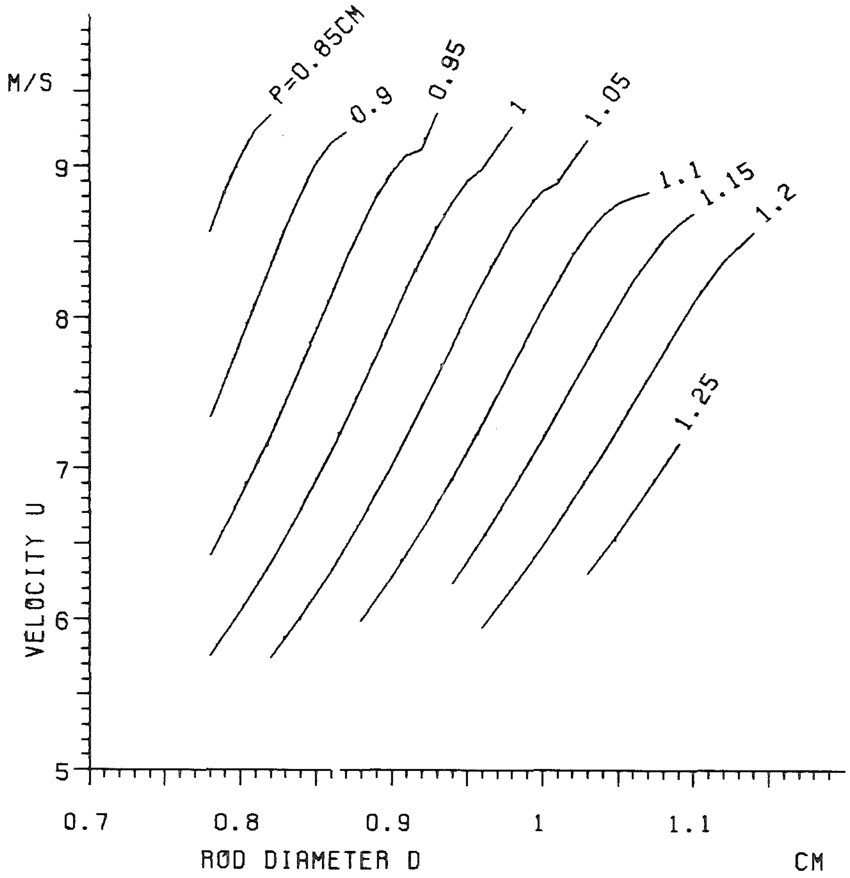
Fig. 2



HOMOGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 3



HOMOGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 4

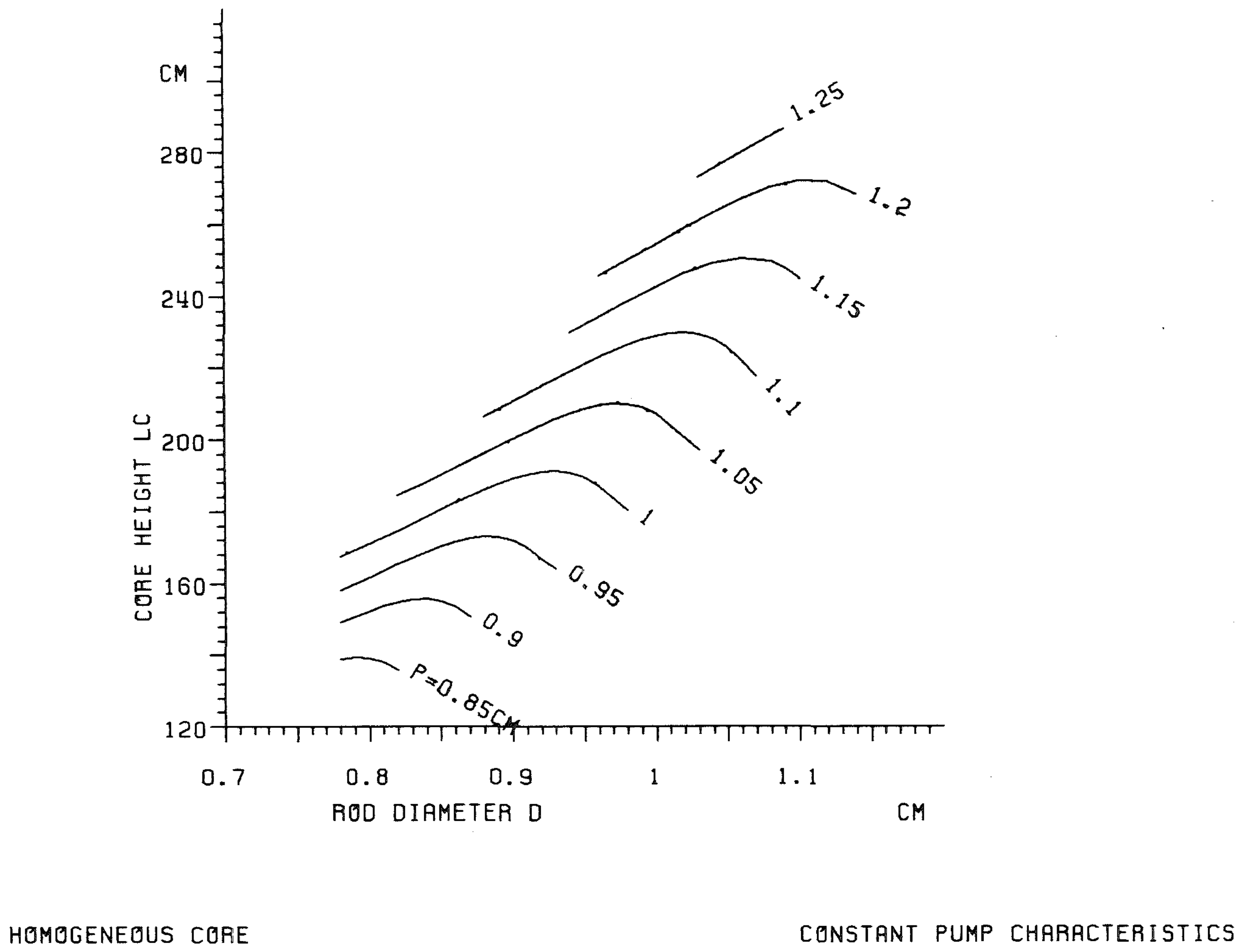
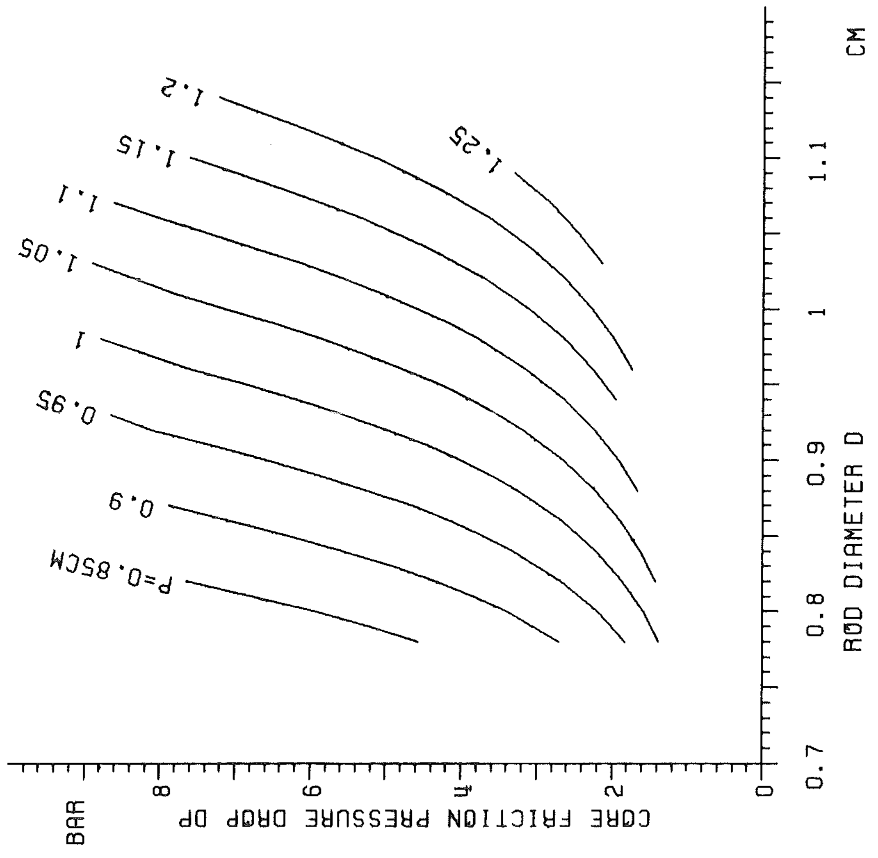

CM
280
240
200
160
120
CORE HEIGHT LC
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
P=0.85CM
0.7
0.8
0.9
1
1.1
ROD DIAMETER D
CM
HOMOGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

Fig. 5



HOMOGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 6

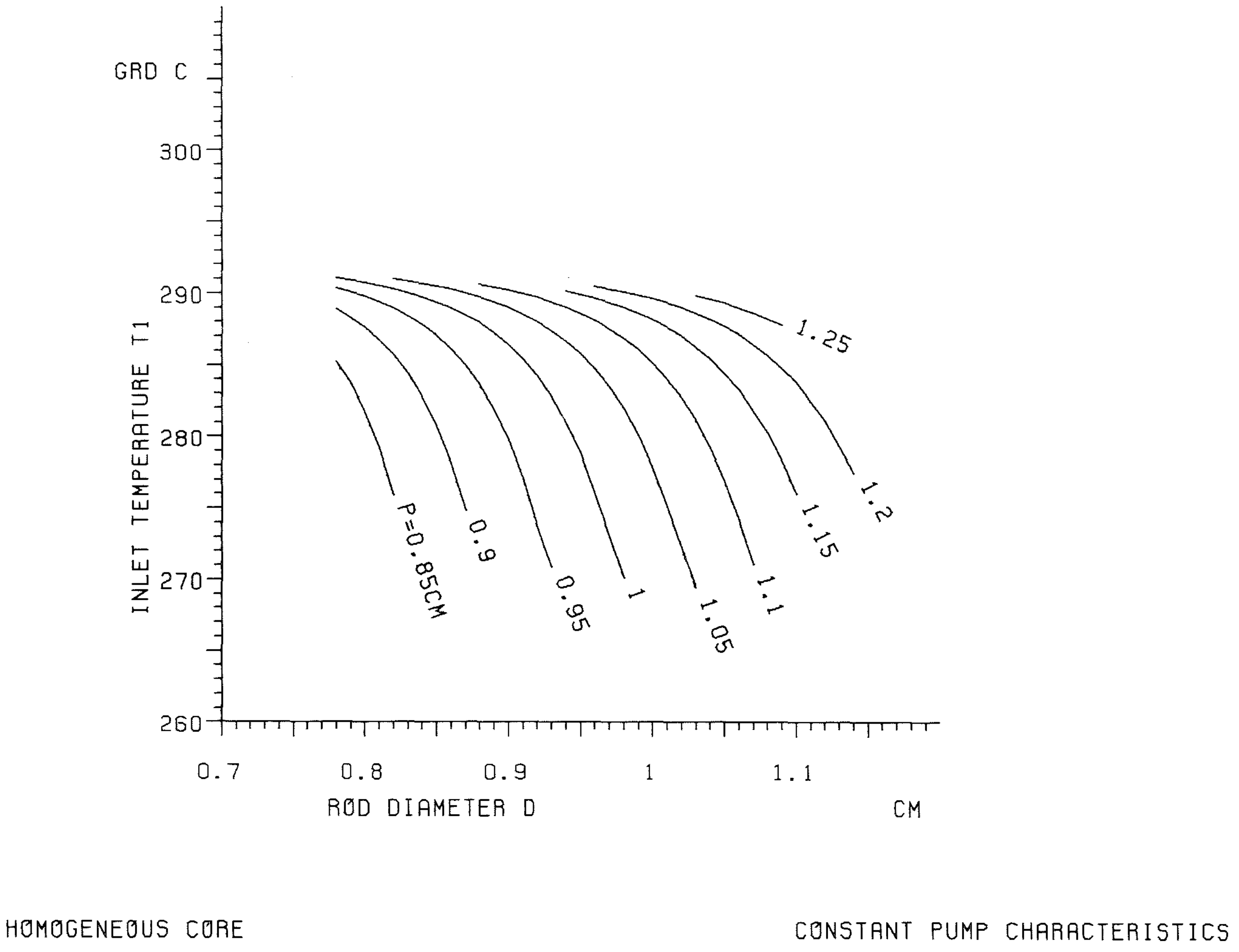

GRD C
300
290
280
270
260
INLET TEMPERATURE T1
0.7
0.8
0.9
1
1.1
RØD DIAMETER D
CM
P=0.85CM
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
HØMOGENEØUS CØRE
CØNSTANT PUMP CHARACTERISTICS

Fig. 7

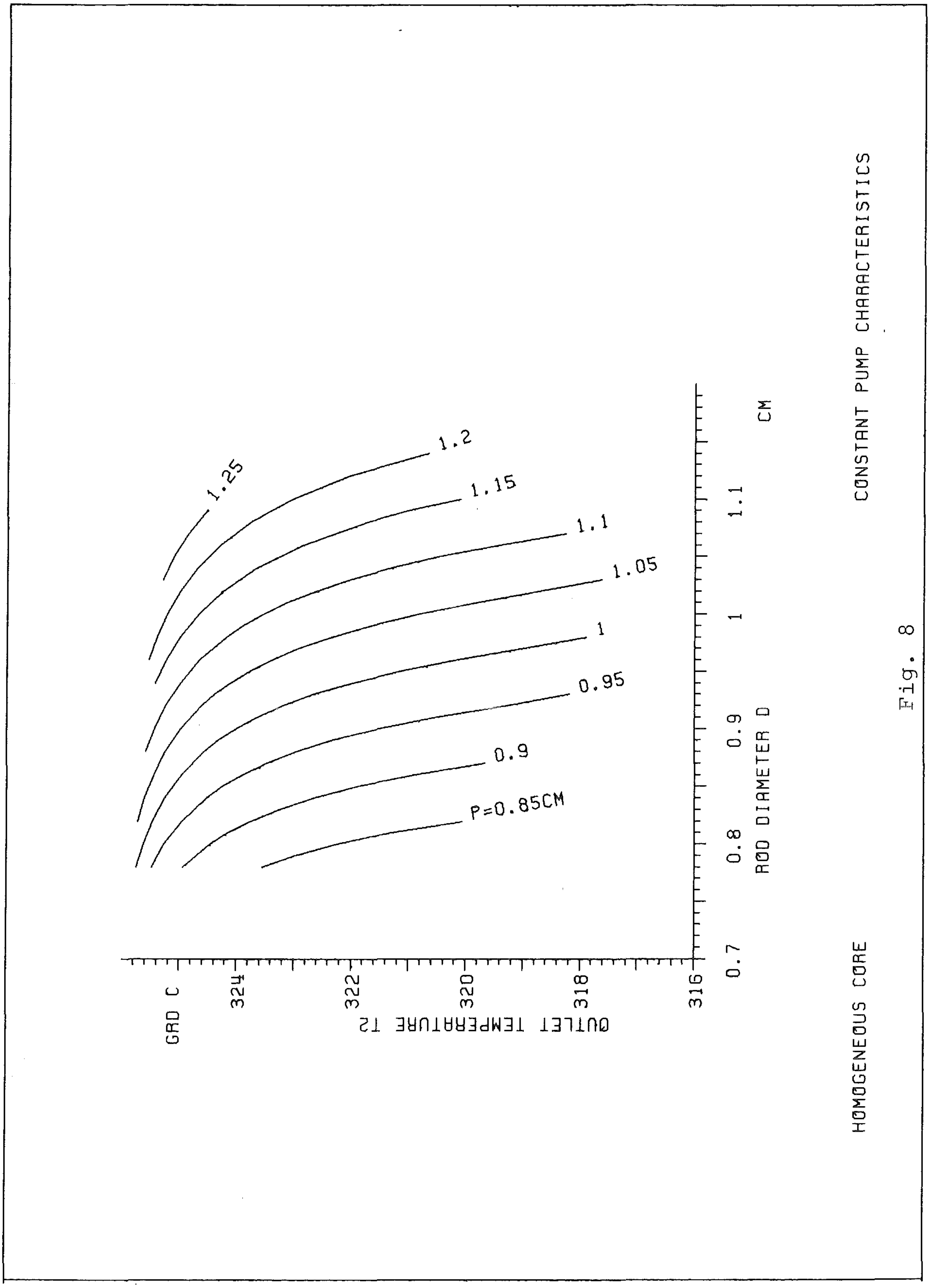

CONSTANT PUMP CHARACTERISTICS
HOMOGENEOUS CORE
OUTLET TEMPERATURE T2
GRD C
324
322
320
318
316
ROD DIAMETER D
CM
0.7
0.8
0.9
1
1.1
P=0.85CM
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25

Fig. 8

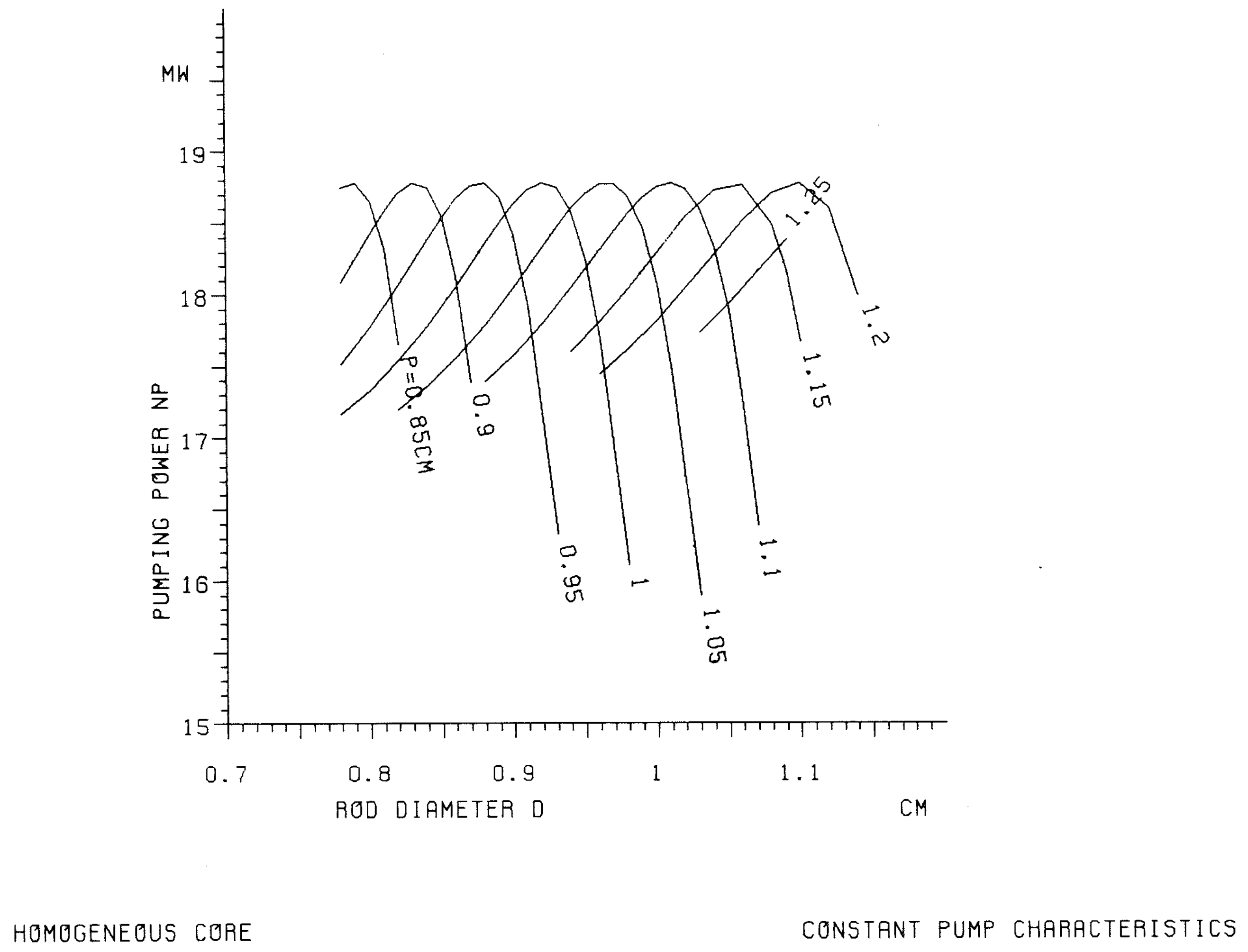
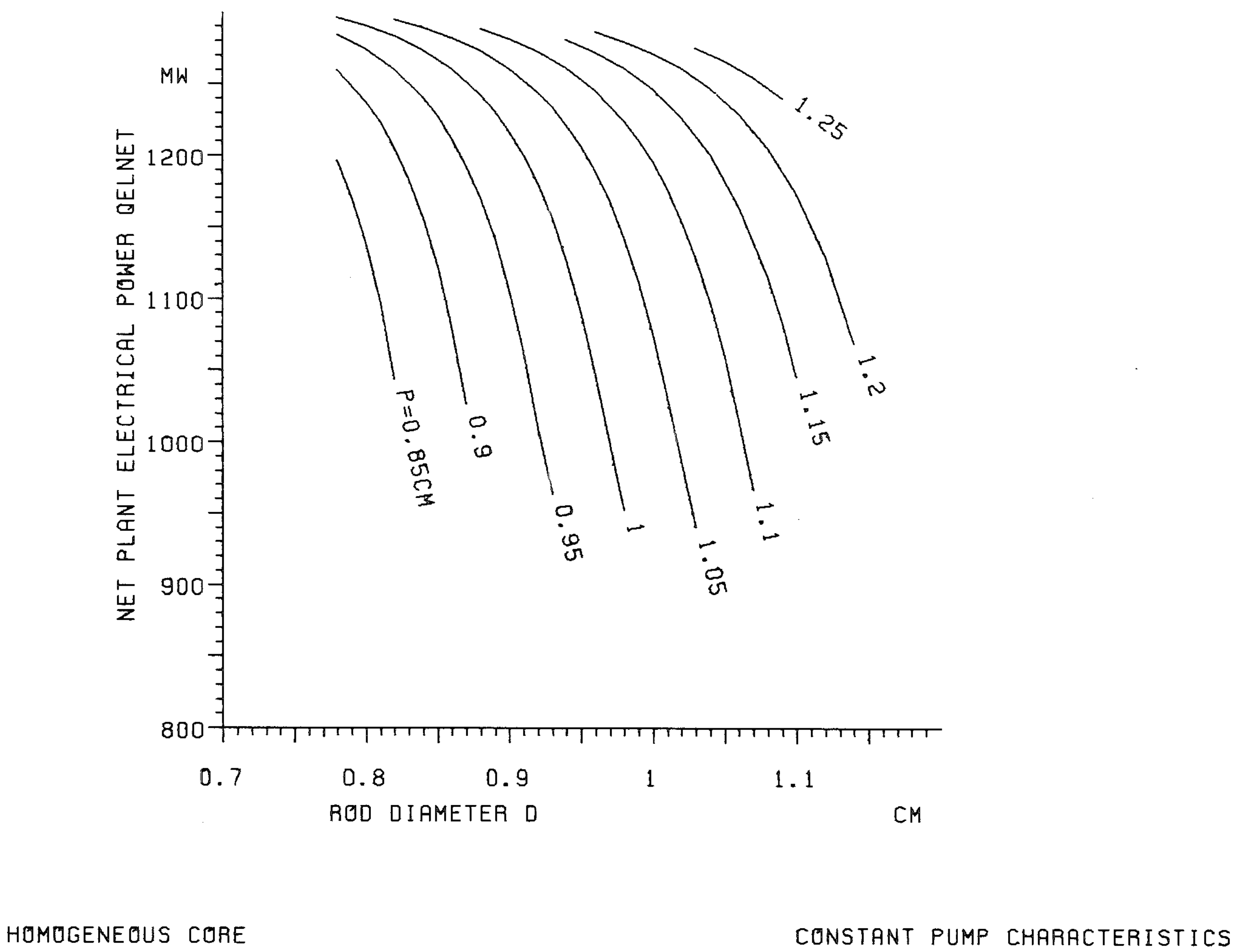
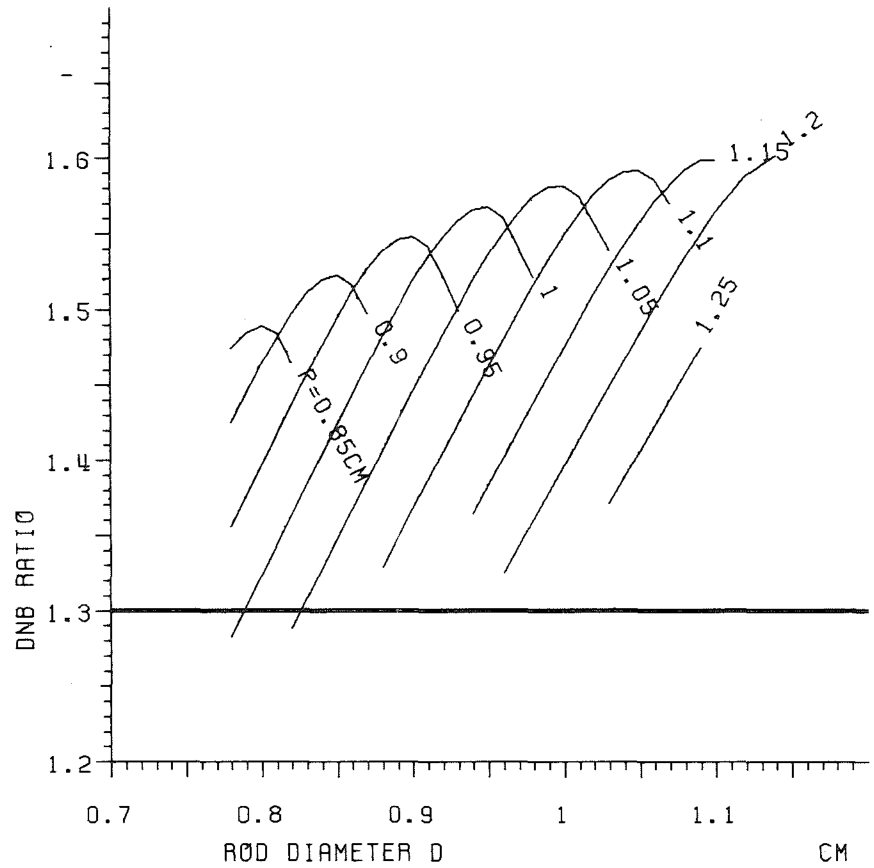

MW
19
18
17
16
15
PUMPING POWER NP
0.7
0.8
0.9
1
1.1
ROD DIAMETER D
CM
P=0.85CM
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
HOMOGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

Fig. 9



MW
NET PLANT ELECTRICAL POWER QELNET
1200
1100
1000
900
800
0.7
0.8
0.9
1
1.1
ROD DIAMETER D
CM
P=0.85CM
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
HOMOGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

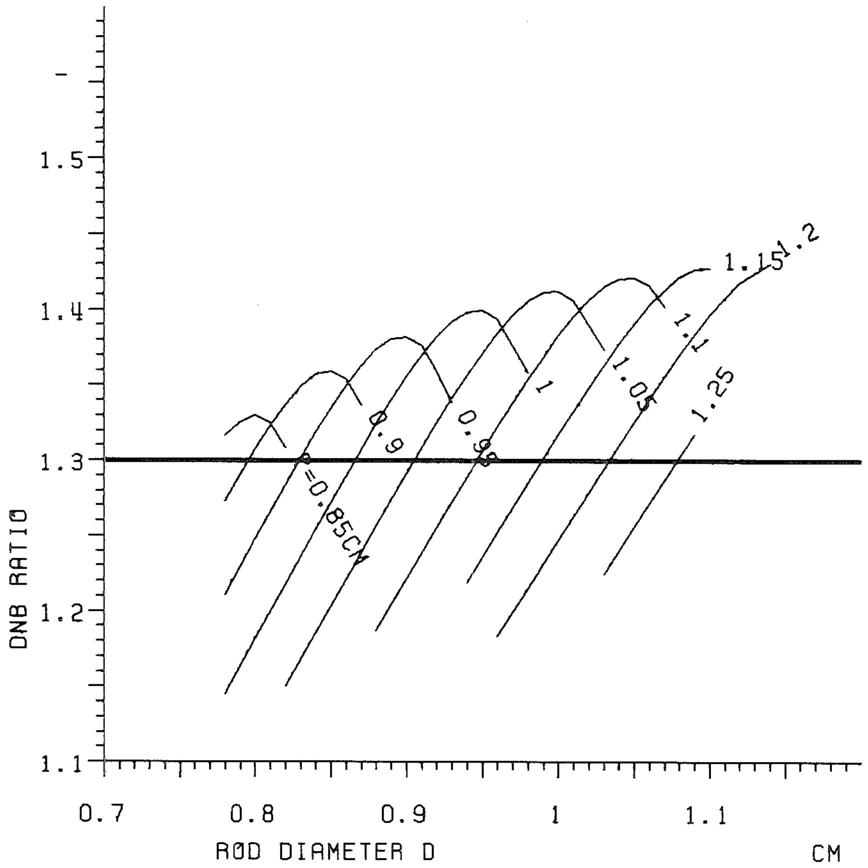
Fig. 10



HOMOGENEOUS CORE

OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

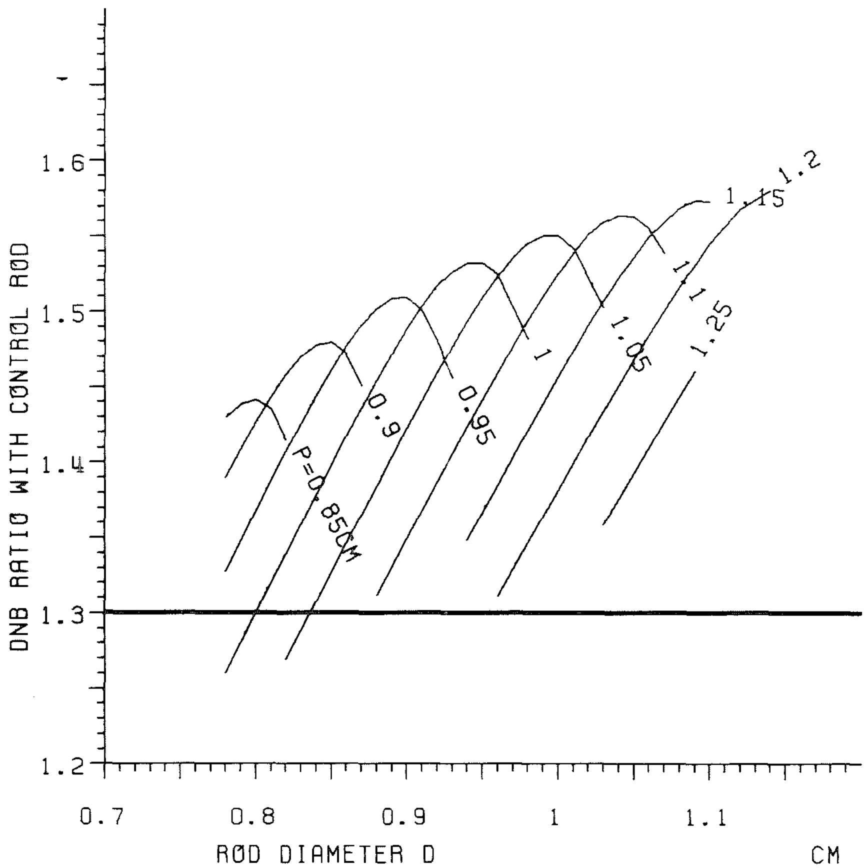
Fig. 11



HOMOGENEOUS CORE

OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

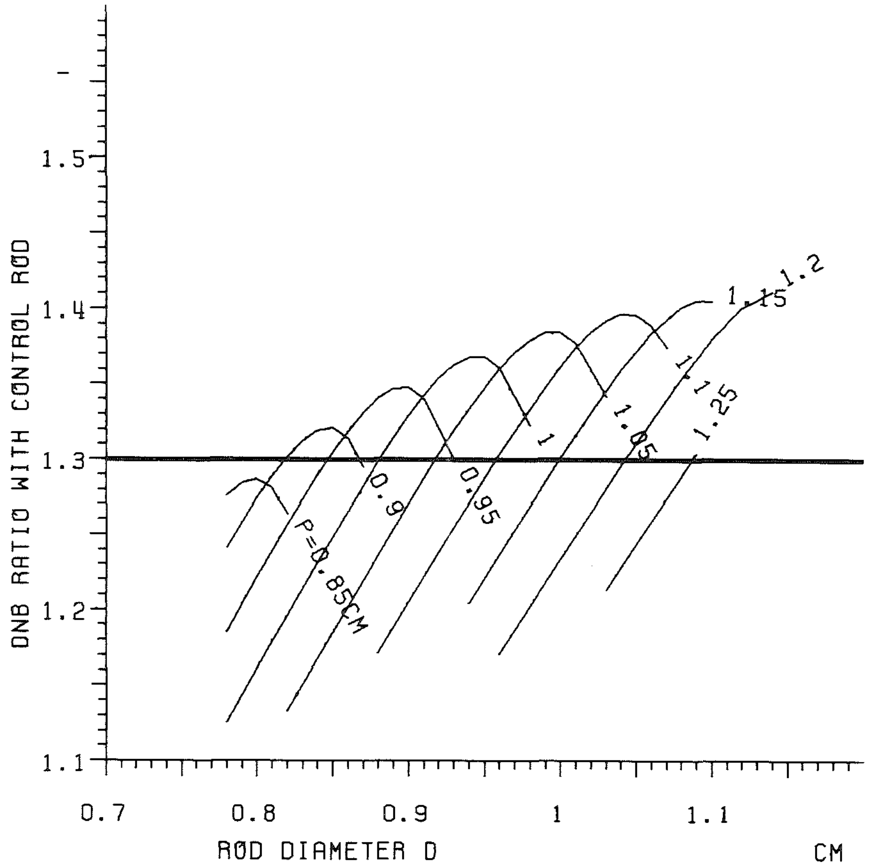
Fig. 12



HOMOGENEOUS CORE

OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

Fig. 13



HOMOGENEOUS CORE

OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

Fig. 14

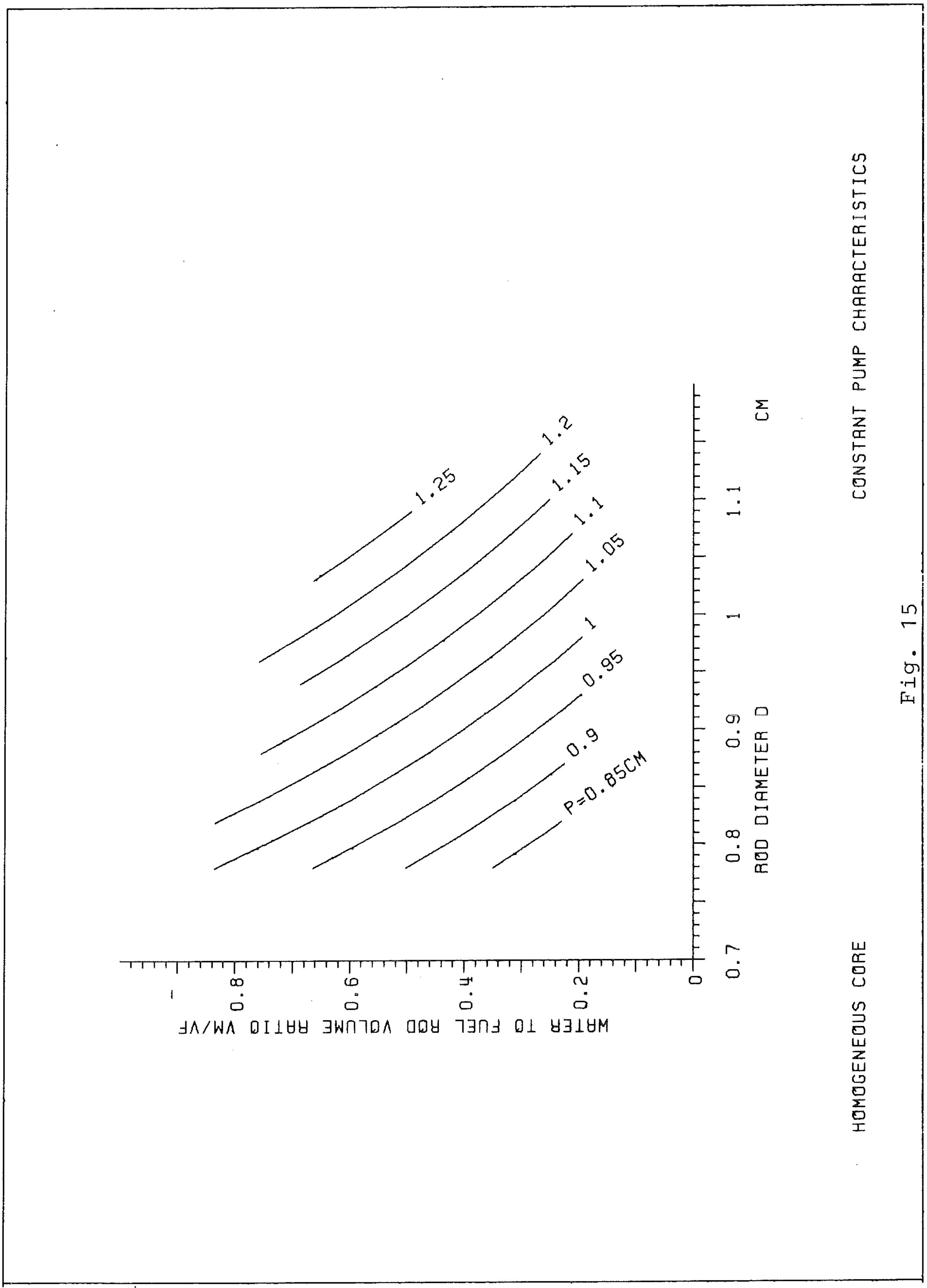

CONSTANT PUMP CHARACTERISTICS
HOMOGENEOUS CORE
ROD DIAMETER D
CM
WATER TO FUEL ROD VOLUME RATIO VM/VF
0.7
0.8
0.9
1
1.1
0
0.2
0.4
0.6
0.8
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
P=0.85CM

Fig. 15

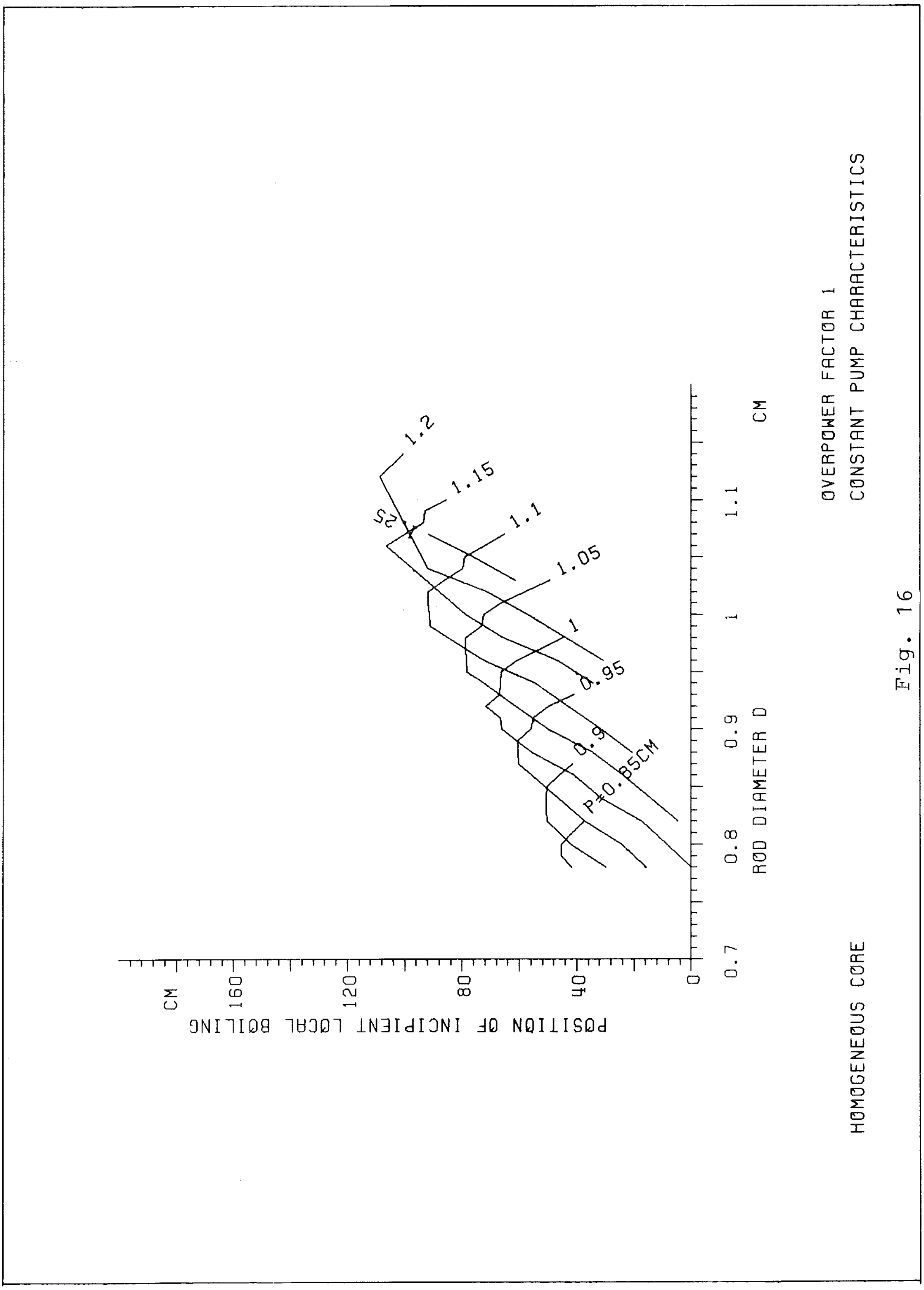
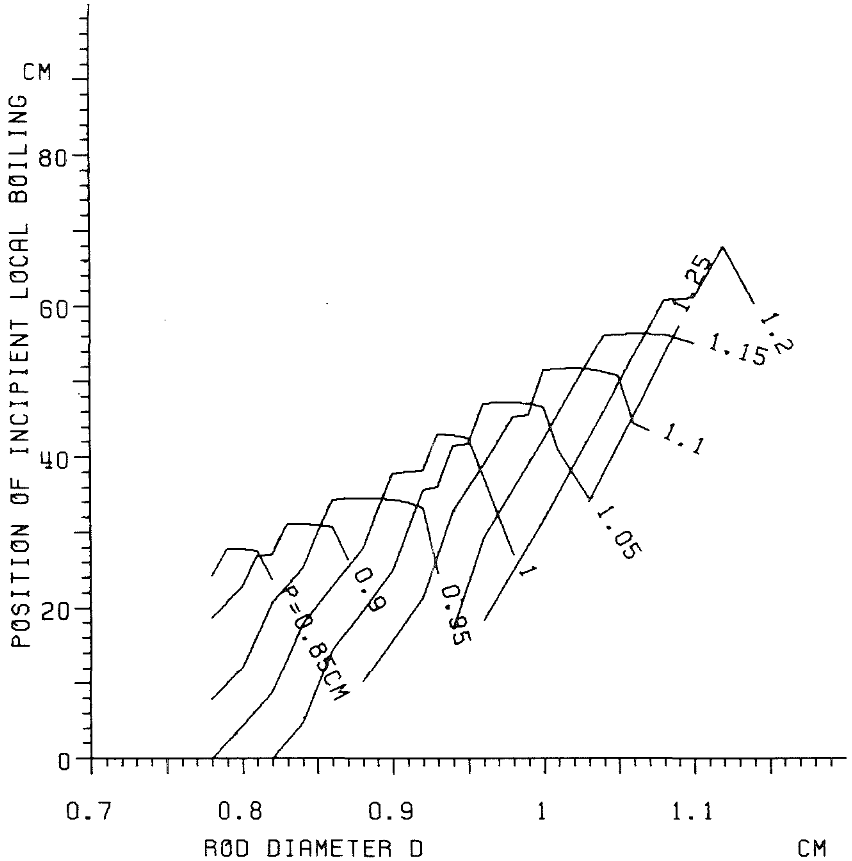

POSITION OF INCIPIENT LOCAL BOILING
CM
160
120
80
40
0
0.7
0.8
0.9
1
1.1
ROD DIAMETER D
CM
1.2
1.15
1.1
1.05
1
0.95
0.9
P=0.85CM
HOMOGENEOUS CORE
OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

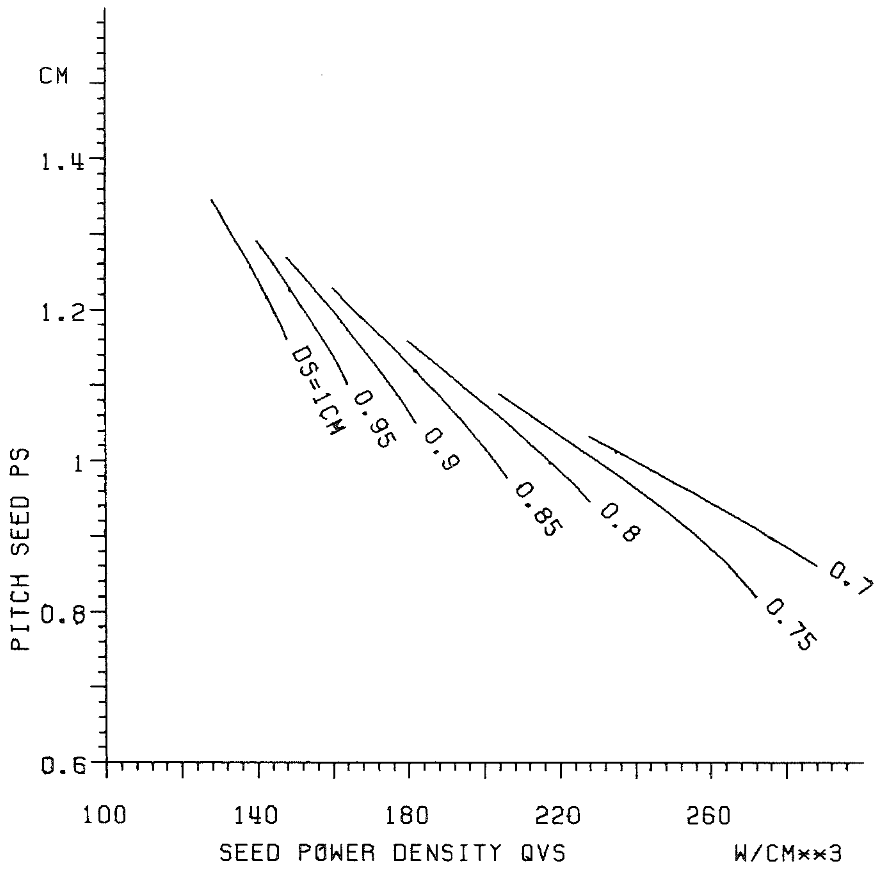
Fig. 16



HOMOGENEOUS CORE

OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

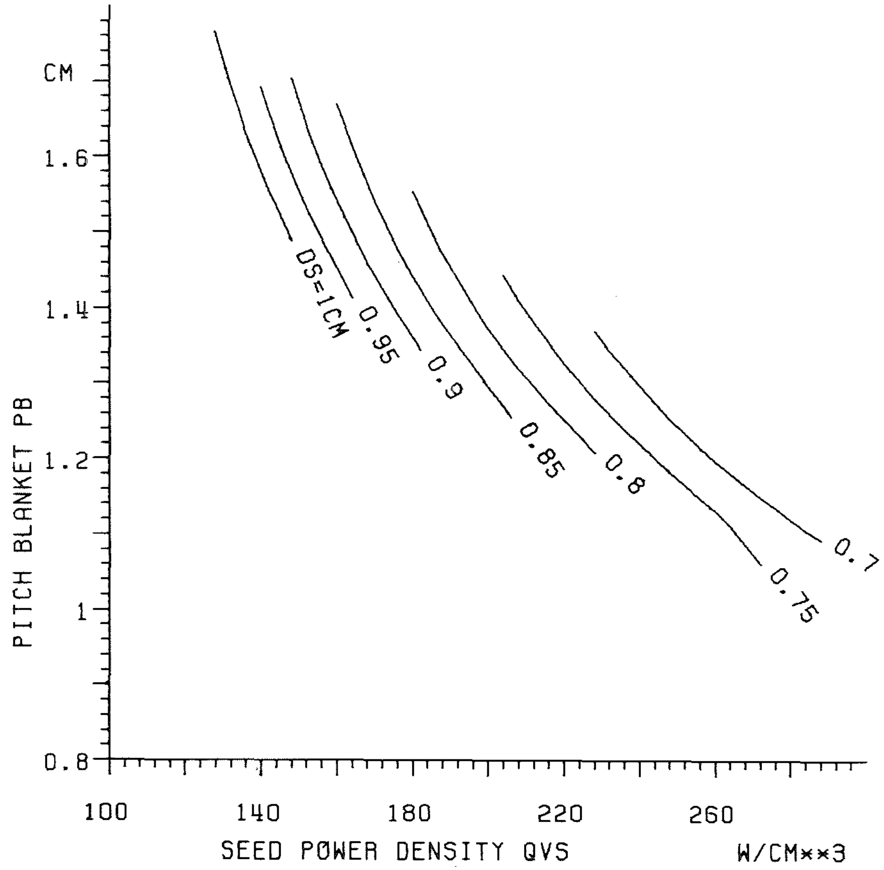
Fig. 17



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 18



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 19

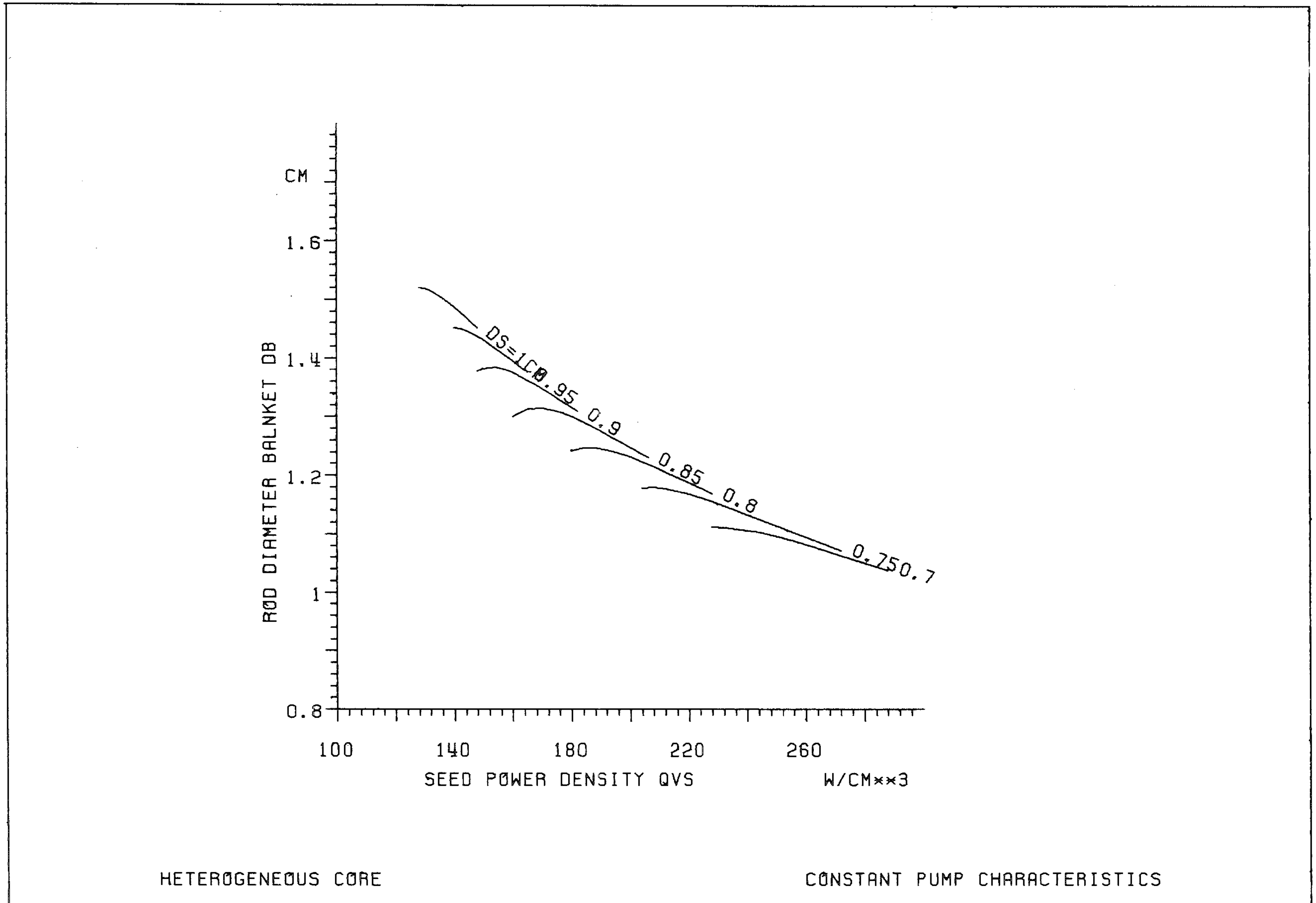

CM
1.6
1.4
1.2
1
0.8
ROD DIAMETER BALNKET DB
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
HETEROGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

Fig. 20

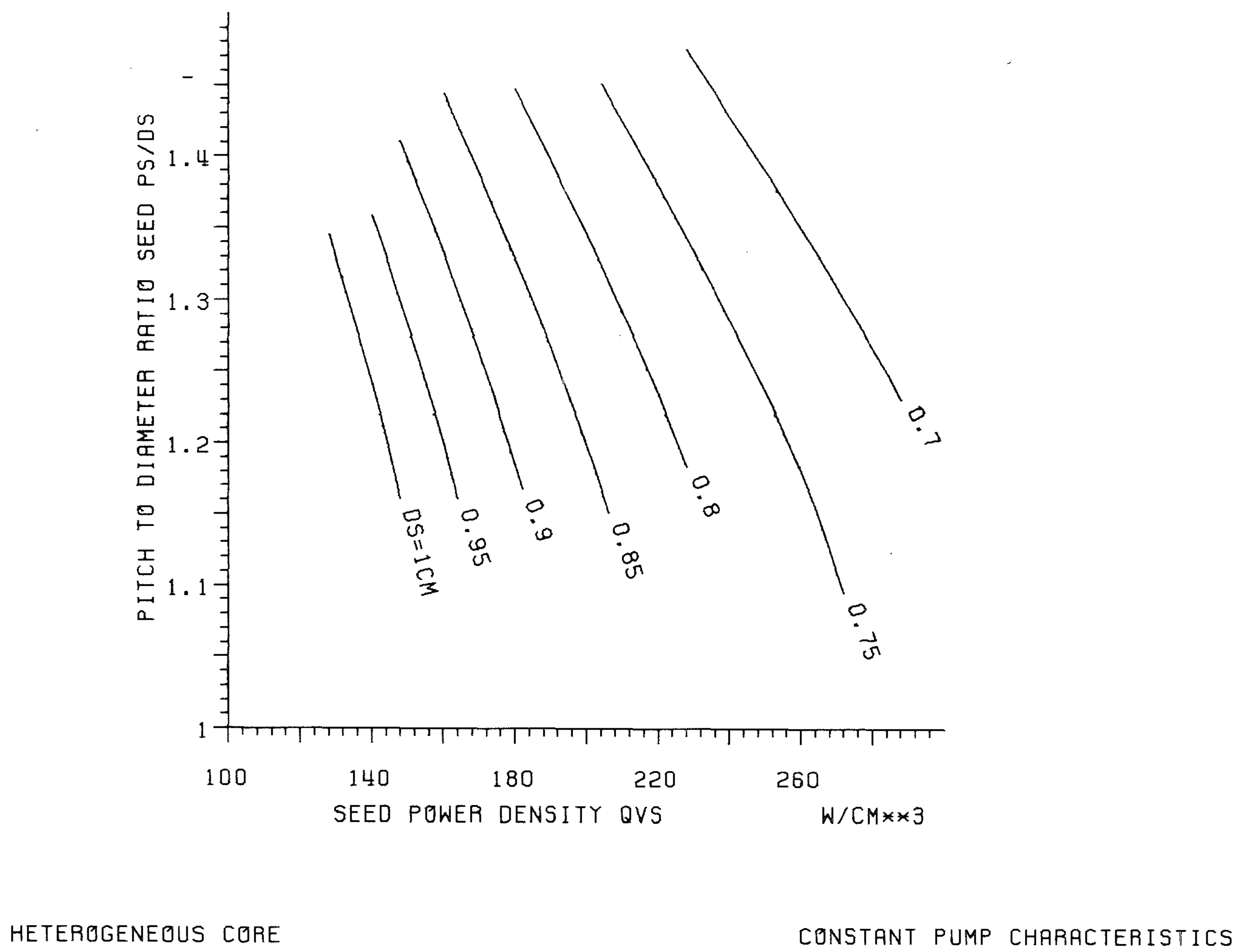
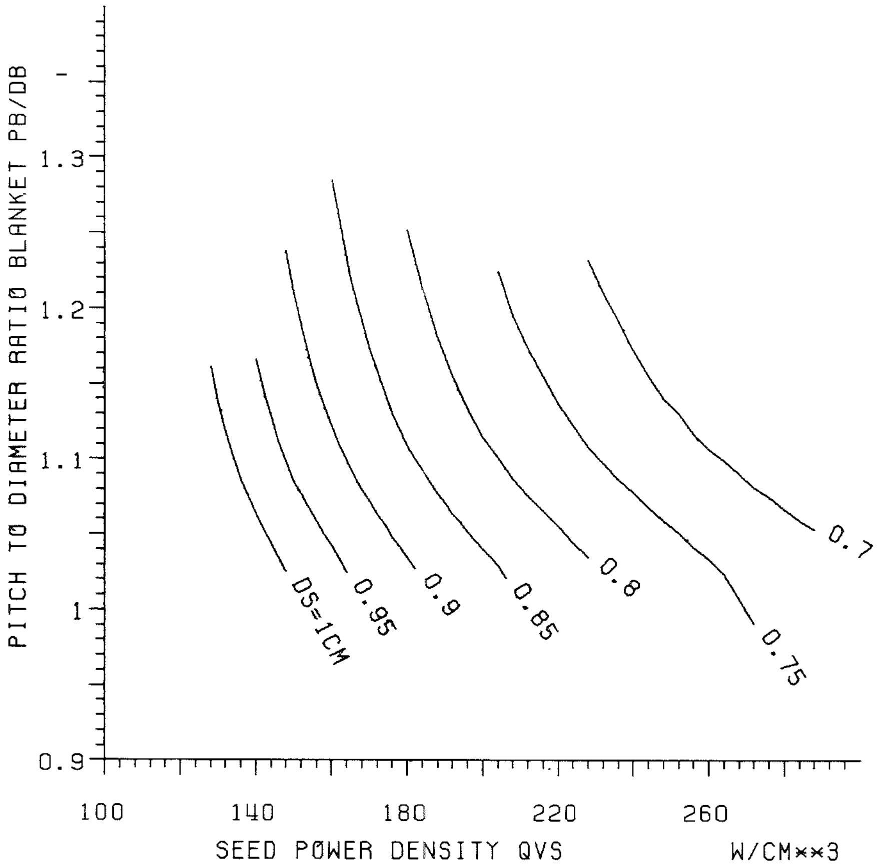

PITCH TO DIAMETER RATIO SEED PS/DS
1.4
1.3
1.2
1.1
1
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

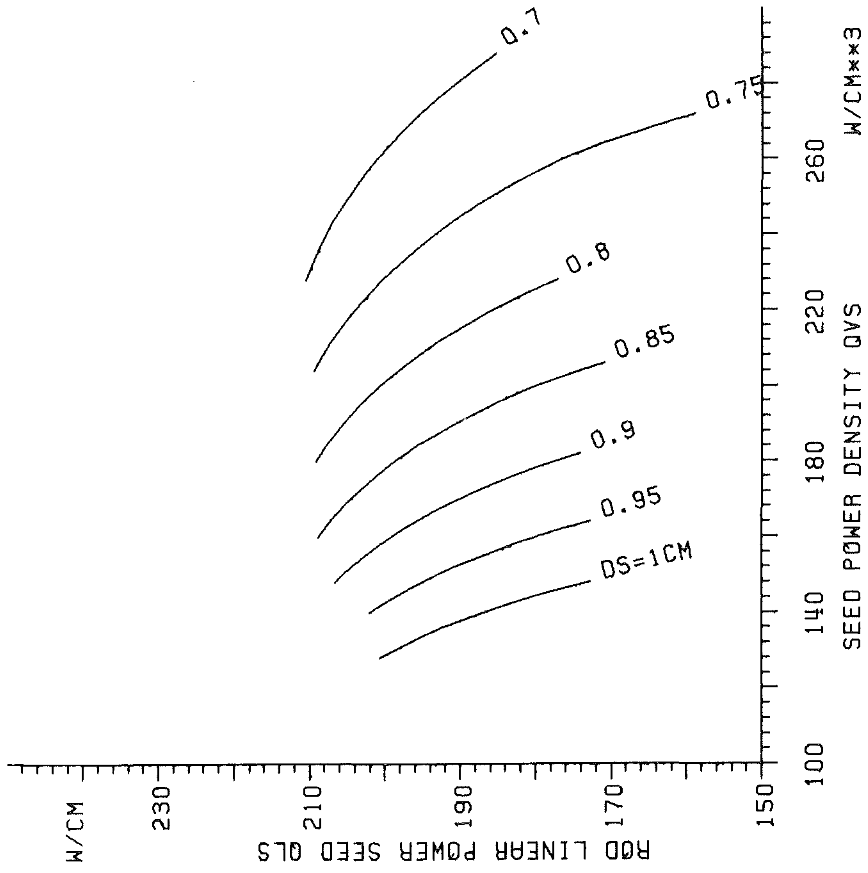
Fig. 21



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

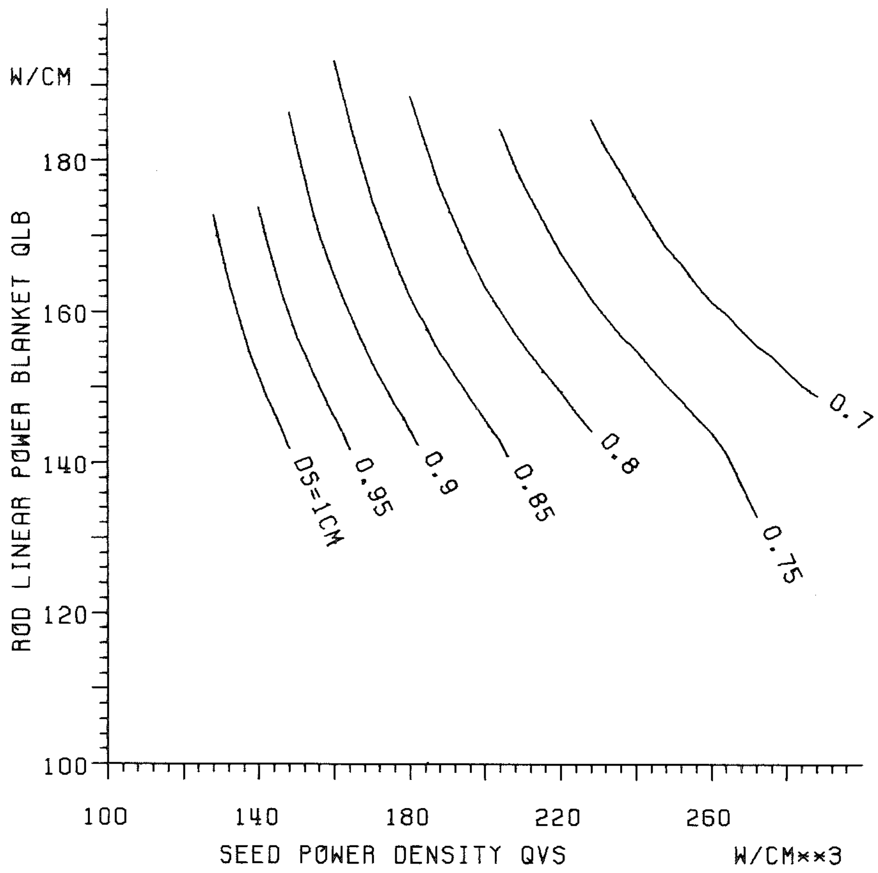
Fig. 22



CONSTANT PUMP CHARACTERISTICS

HETEROGENEOUS CORE

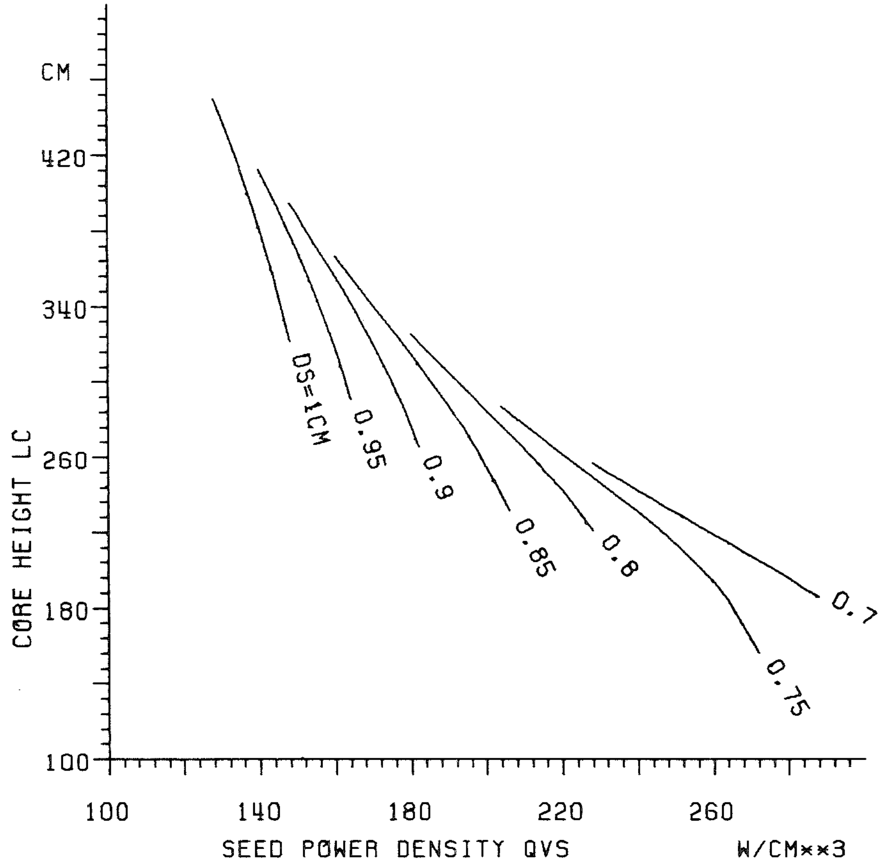
Fig. 23



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 24



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 25

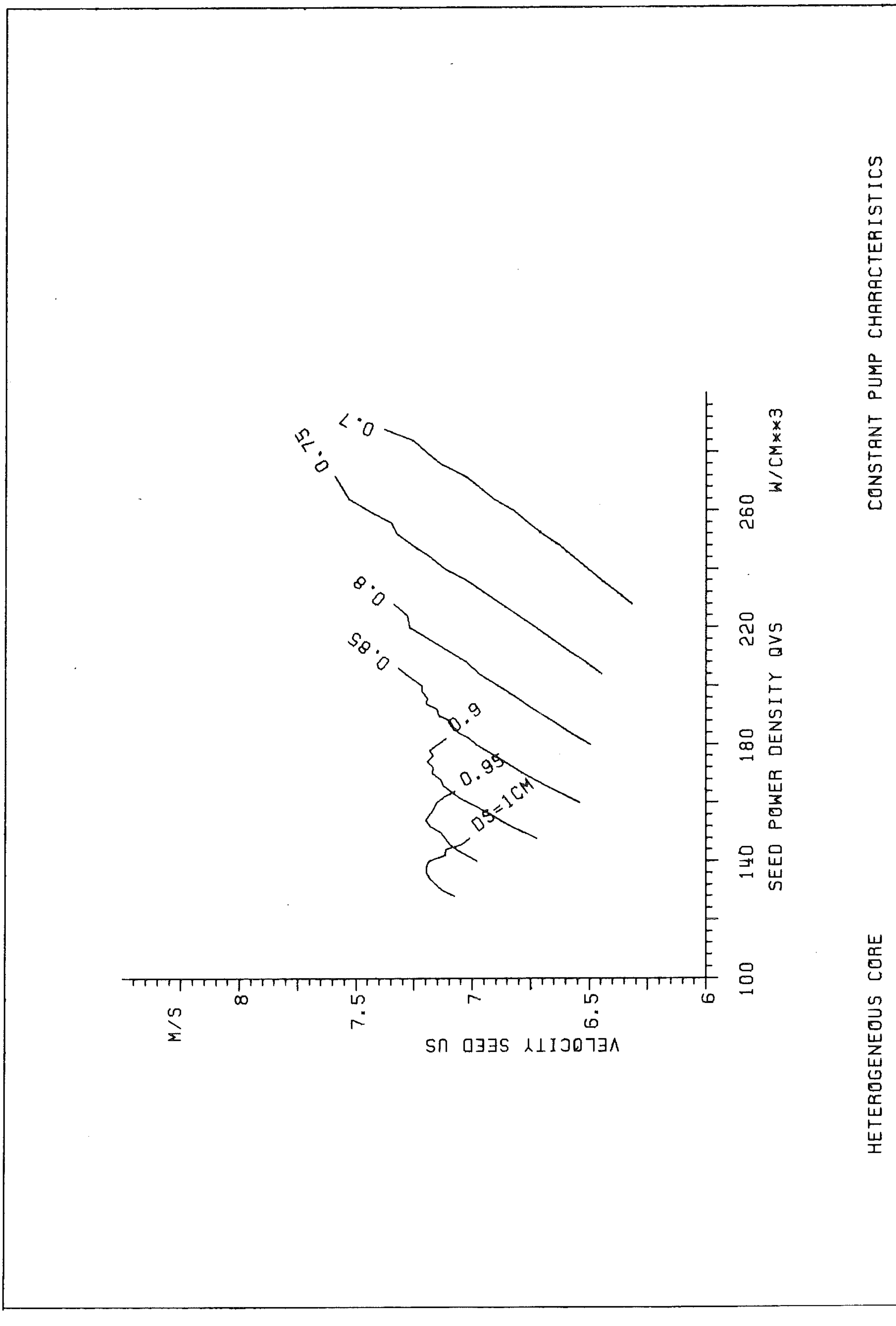
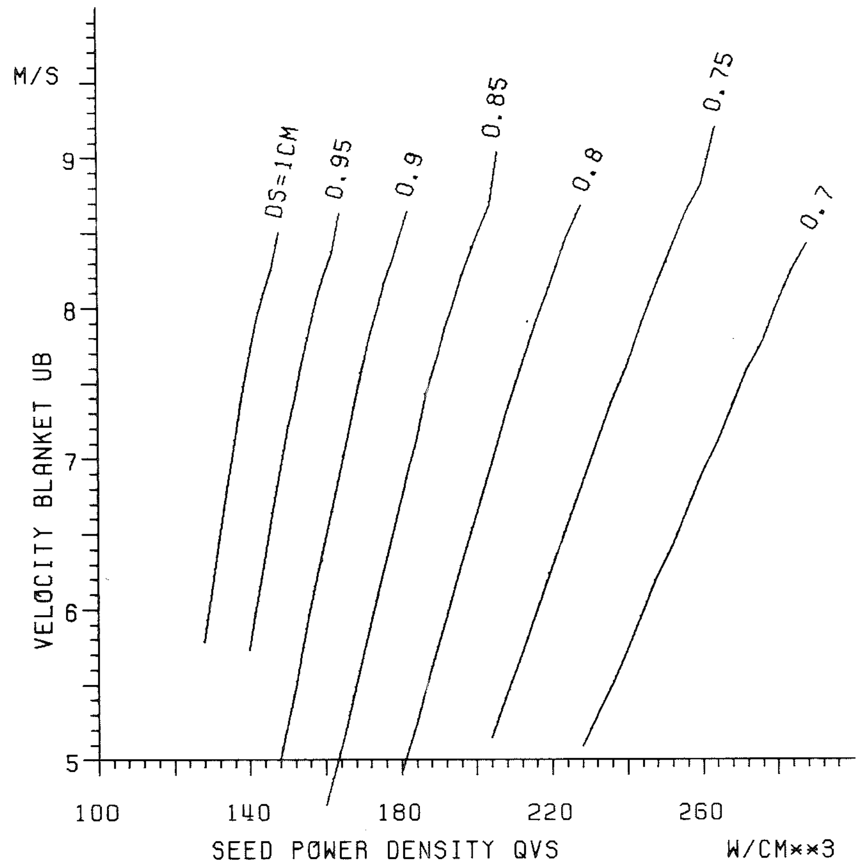

CONSTANT PUMP CHARACTERISTICS
HETEROGENEOUS CORE
VELOCITY SEED US
M/S
8
7.5
7
6.5
6
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
0.7
0.75
0.8
0.85
0.9
0.95
DS=1CM

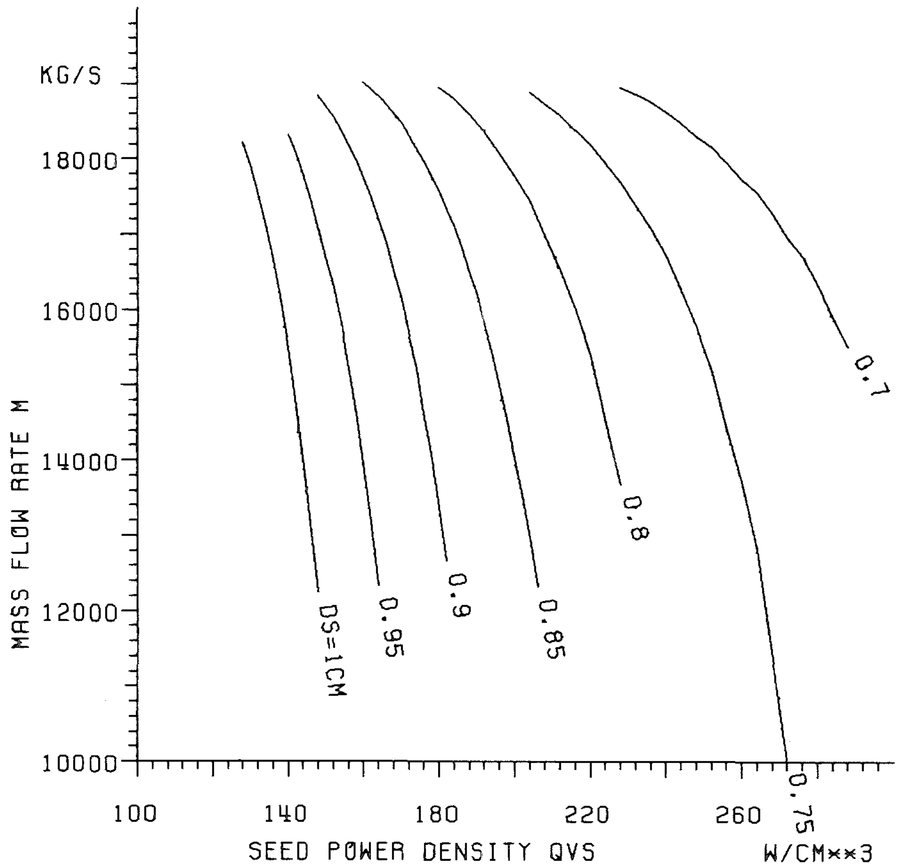
Fig. 26



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 27



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 28

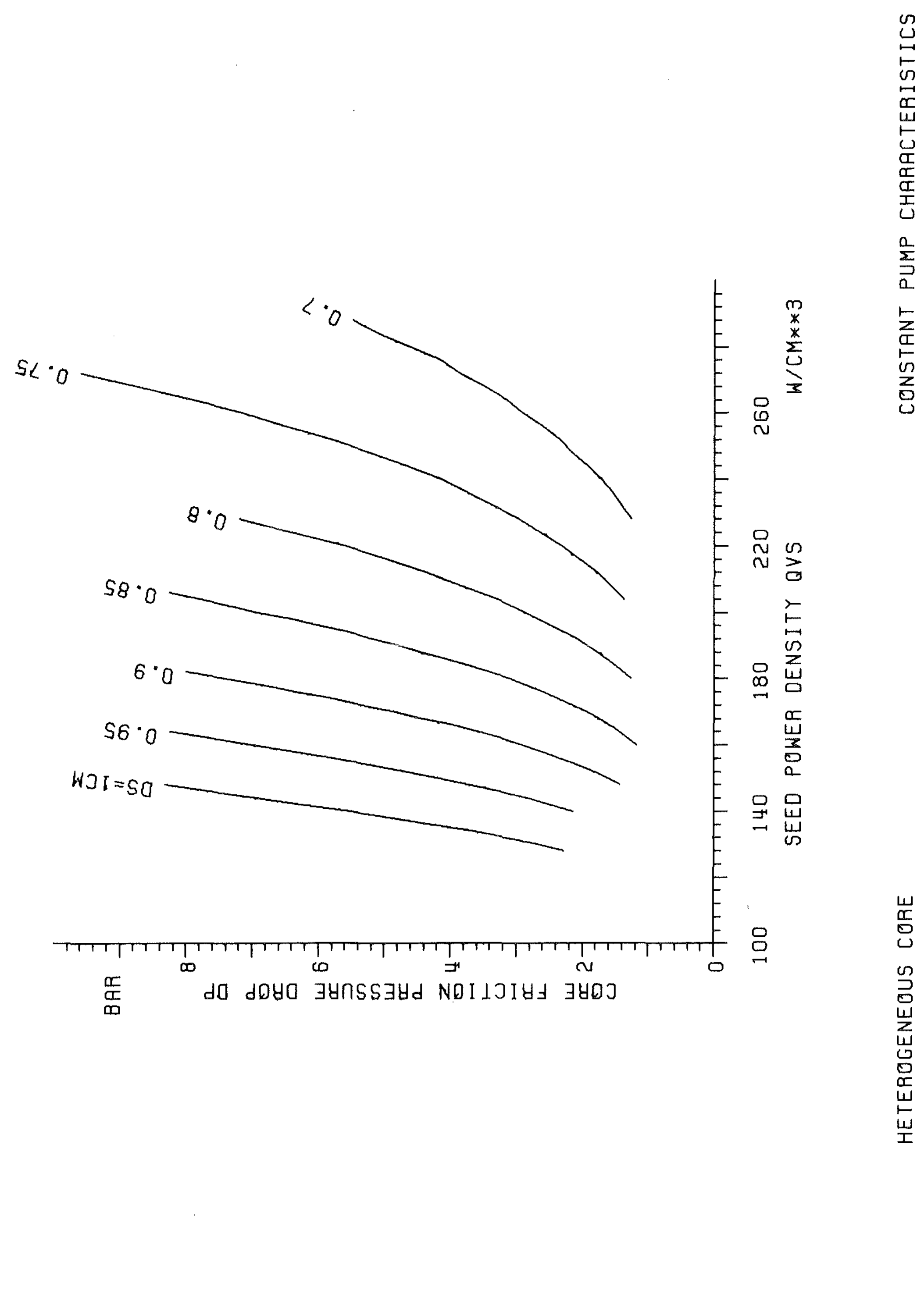
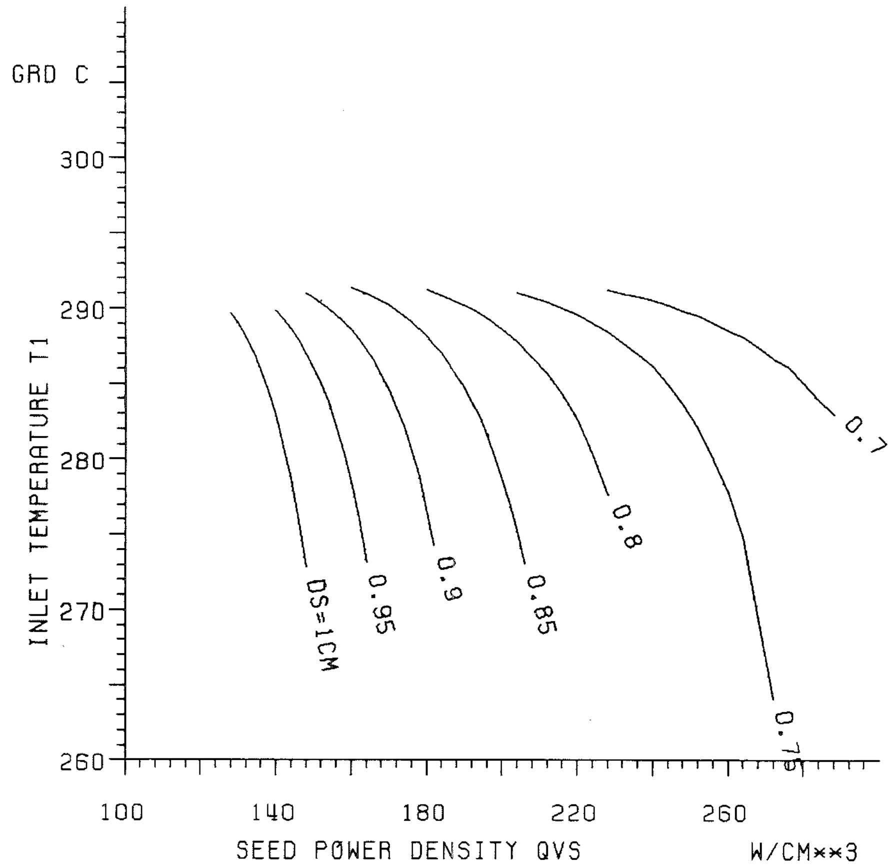

CONSTANT PUMP CHARACTERISTICS
HETEROGENEOUS CORE
CORE FRICTION PRESSURE DROP DP
BAR
0
2
4
6
8
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7

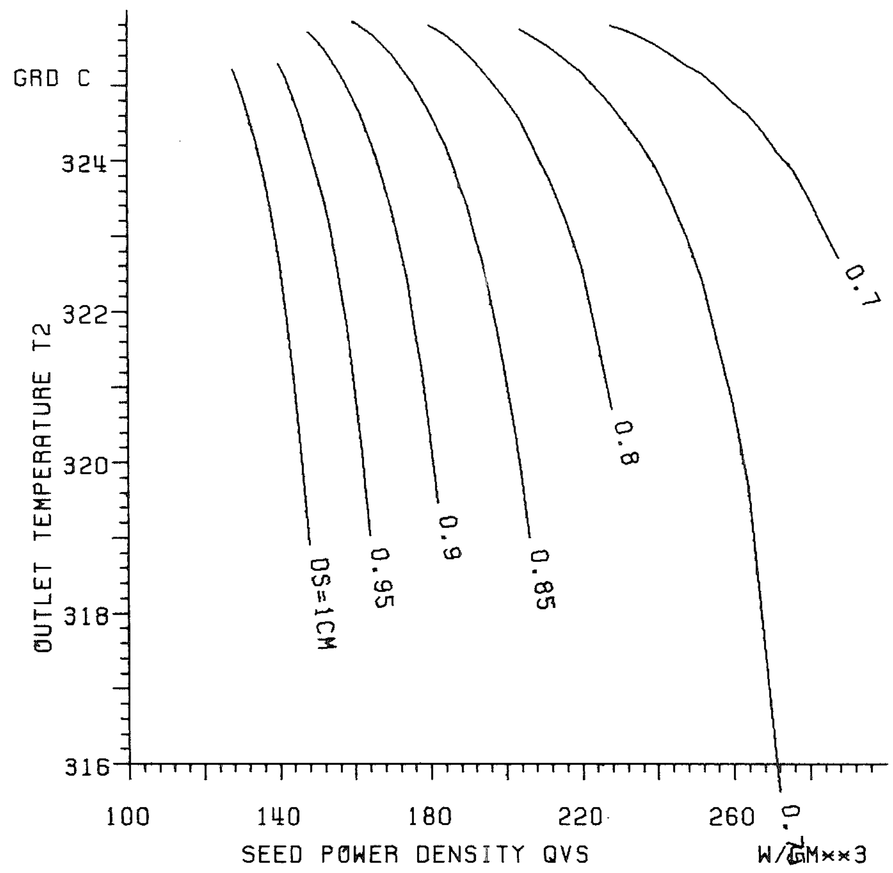
Fig. 29



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

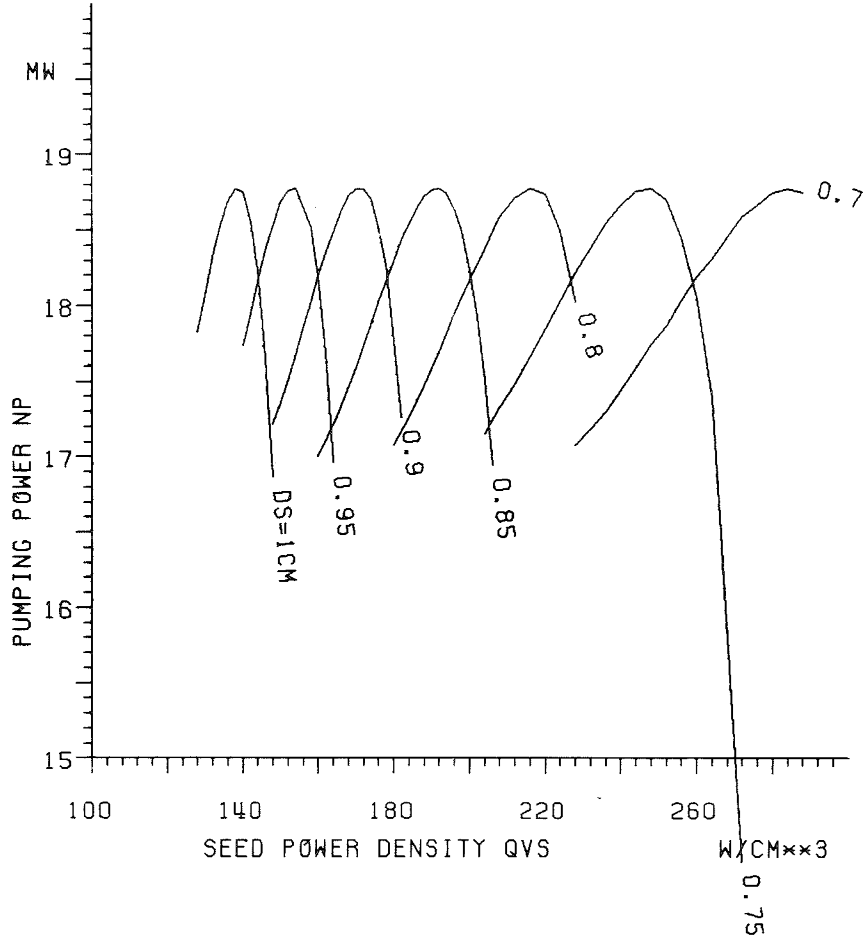
Fig. 30



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

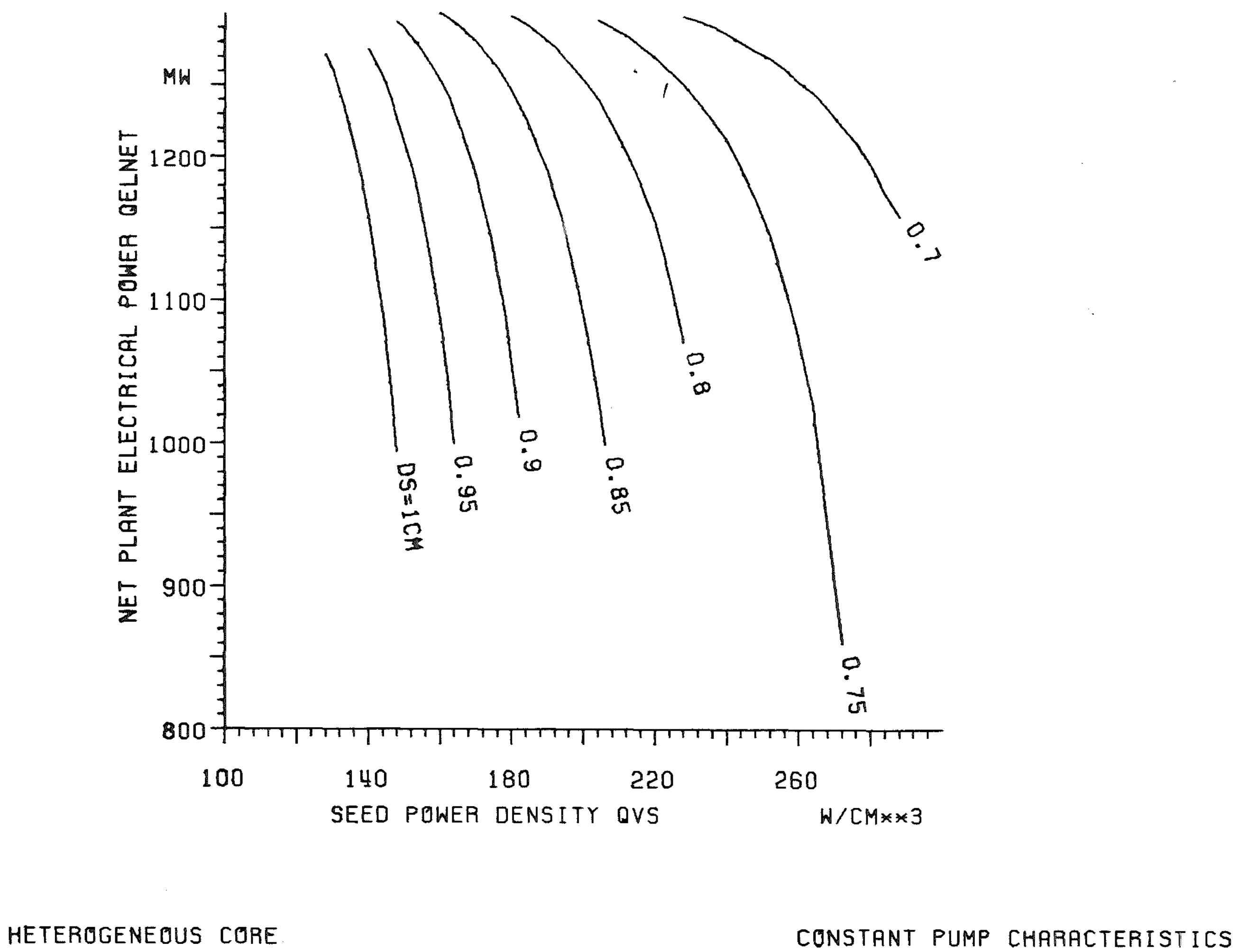
Fig. 31



HETEROGENEOUS CORE

CONSTANT PUMP CHARACTERISTICS

Fig. 32



NET PLANT ELECTRICAL POWER QELNET
MW
1200
1100
1000
900
800
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

Fig. 33

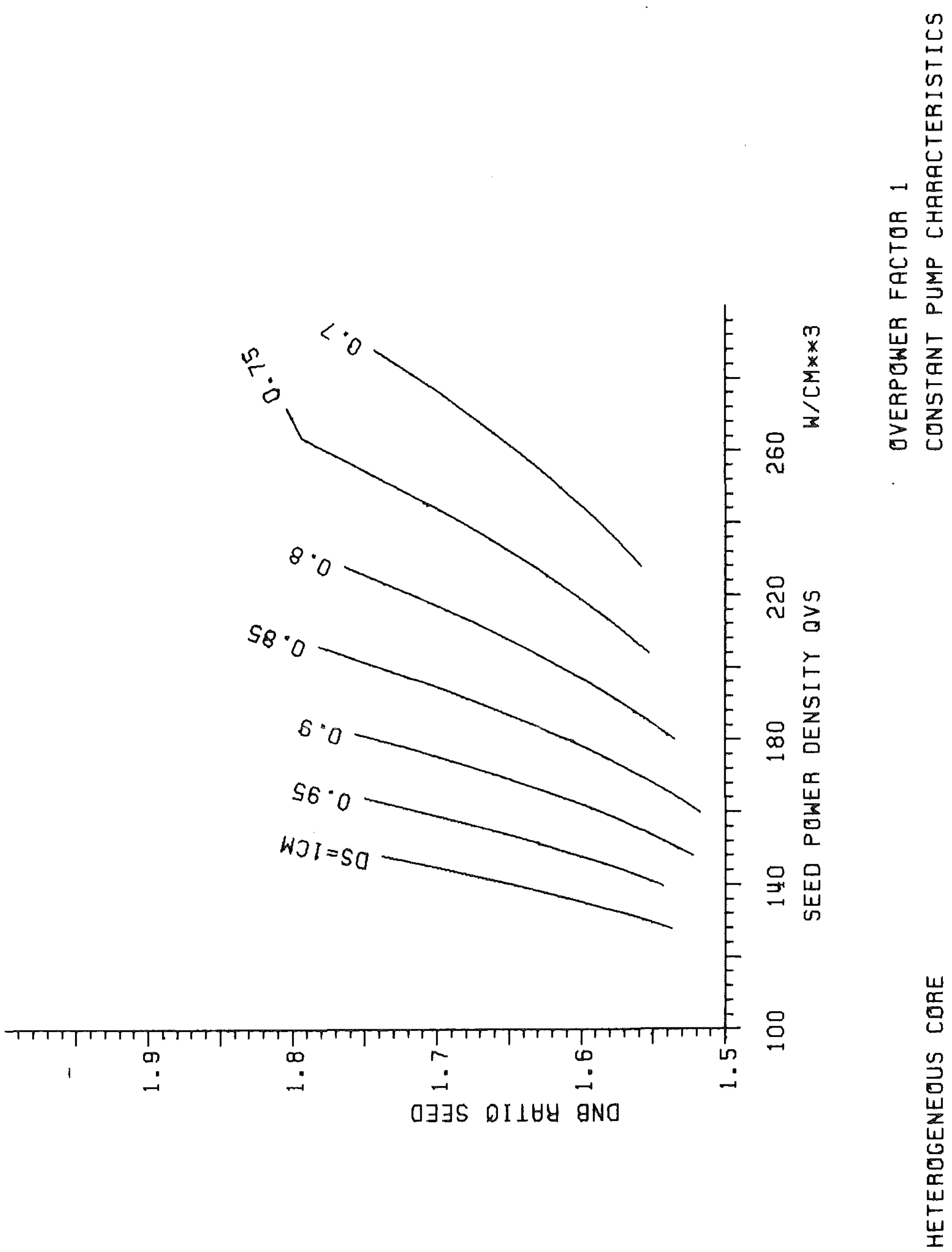
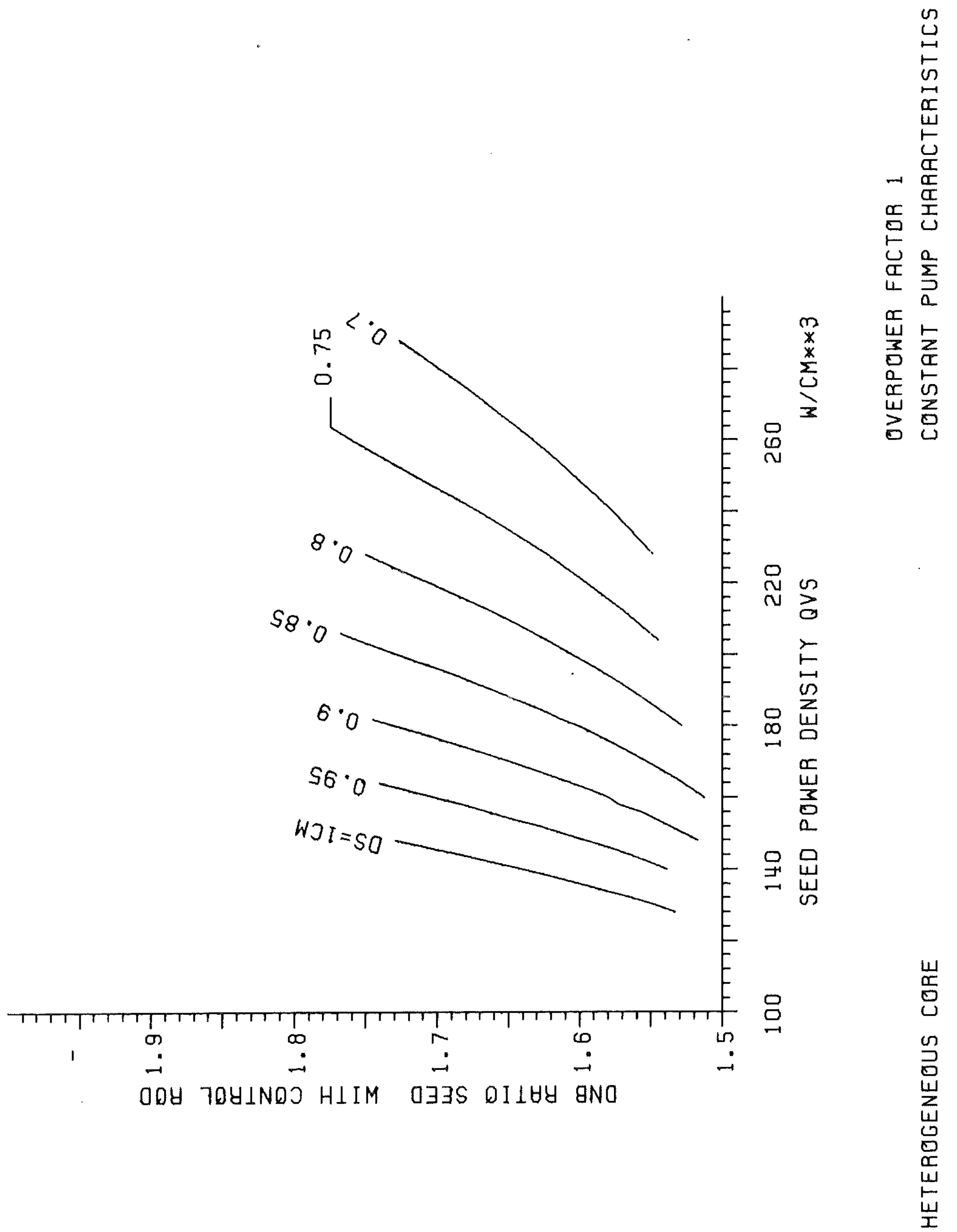
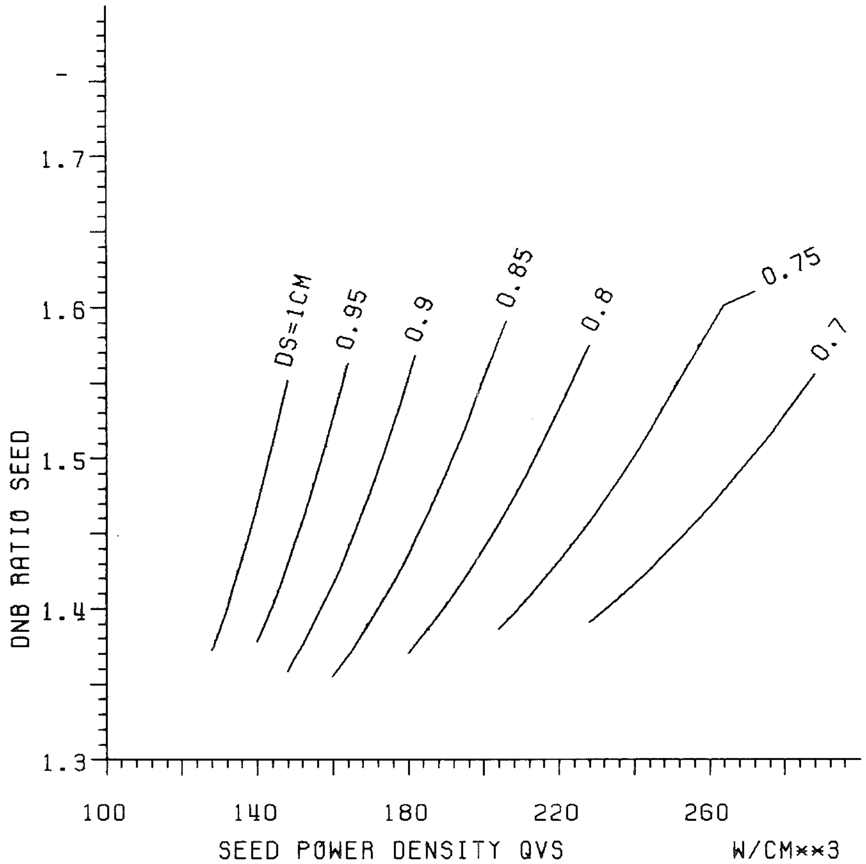

DNB RATIO SEED
1.9
1.8
1.7
1.6
1.5
100
140
180
220
260
SEED POWER DENSITY QVS W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS
HETEROGENEOUS CORE

Fig. 34



DNB RATIO SEED WITH CONTROL ROD
1.5
1.6
1.7
1.8
1.9
SEED POWER DENSITY QVS W/CM**3
100
140
180
220
260
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

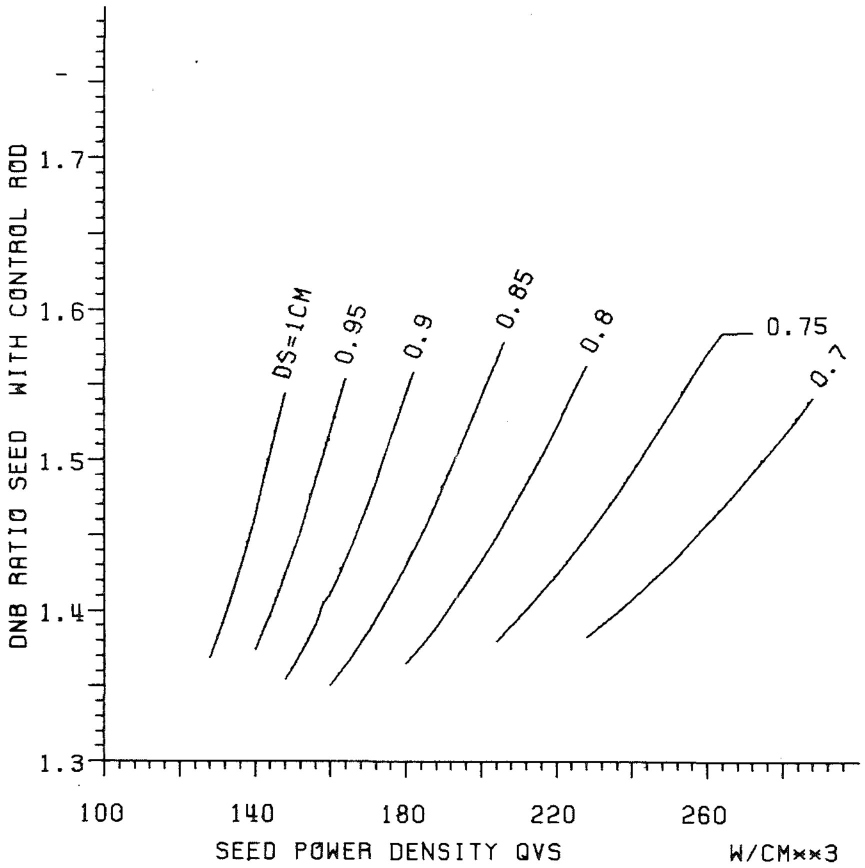
Fig. 35



HETEROGENEOUS CORE

OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

Fig. 36



HETEROGENEOUS CORE

OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

Fig. 37

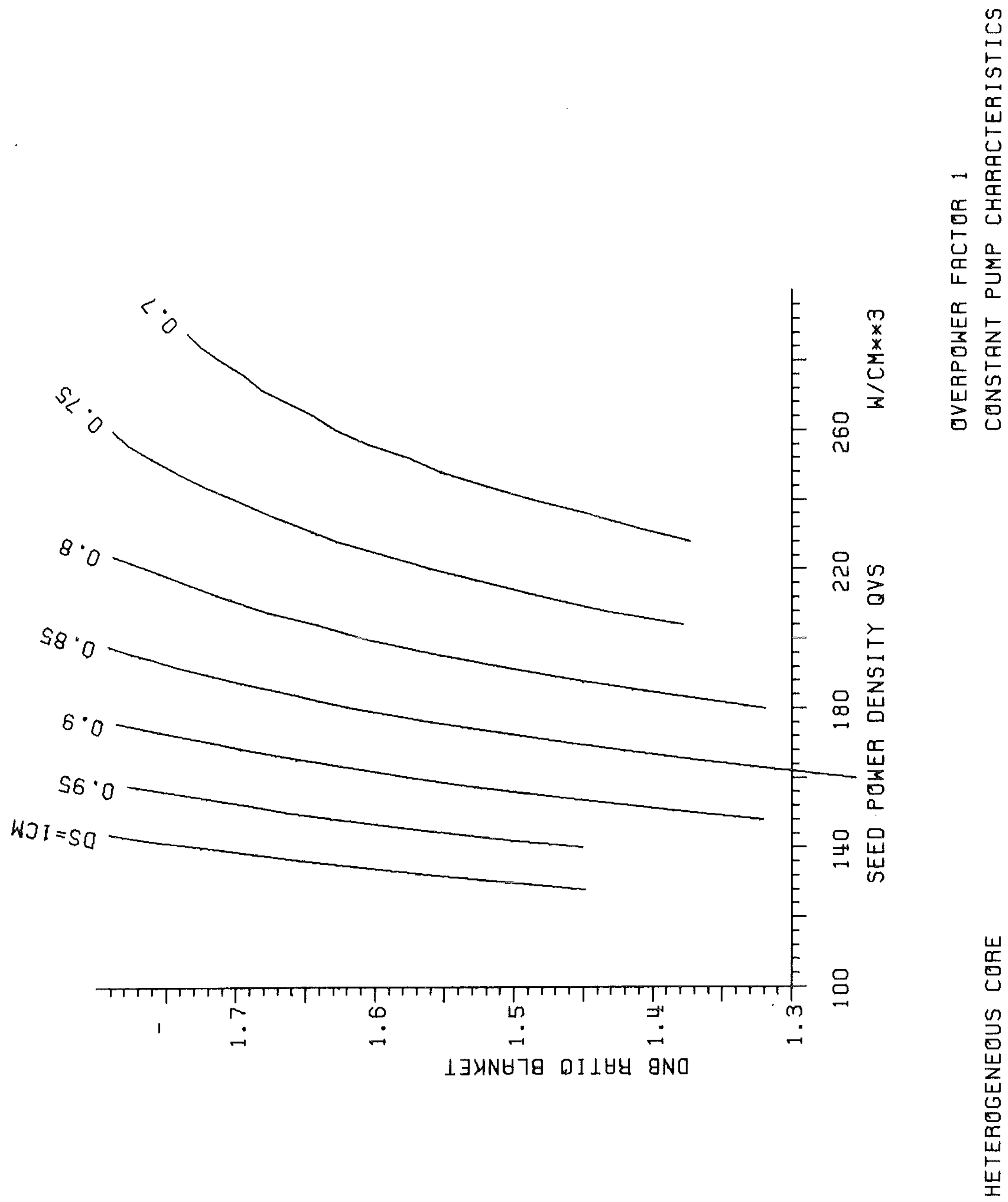

DNB RATIO BLANKET
1.3
1.4
1.5
1.6
1.7
100
140
180
220
260
SEED POWER DENSITY QVS W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

Fig. 38

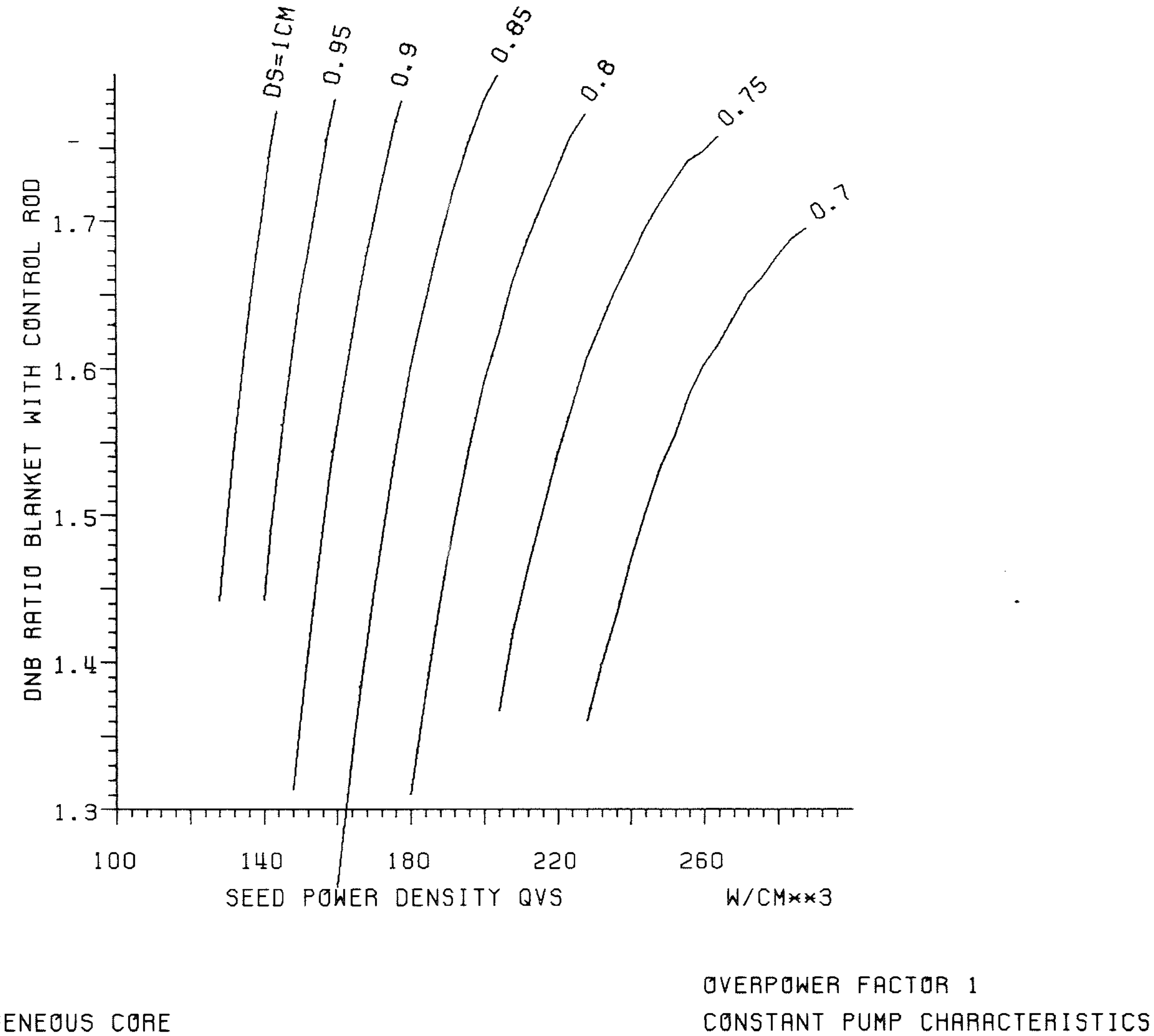
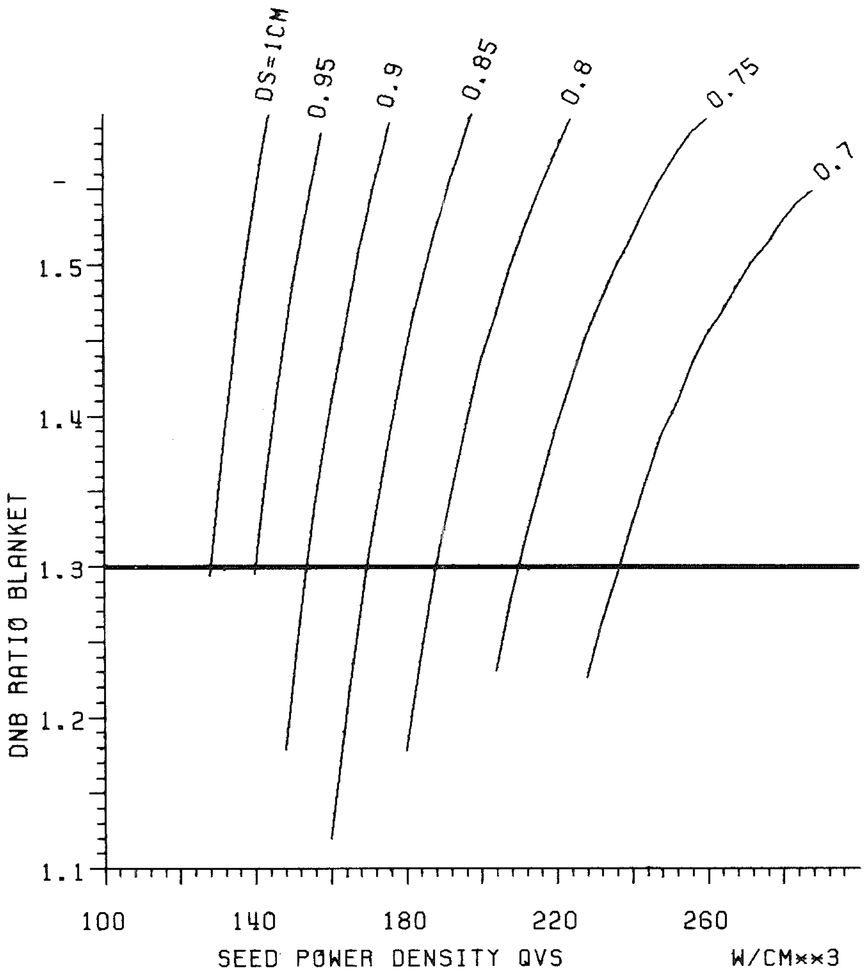

DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
DNB RATIO BLANKET WITH CONTROL ROD
1.3
1.4
1.5
1.6
1.7
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS
HETEROGENEOUS CORE

Fig. 39



OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

HETEROGENEOUS CORE

Fig. 40

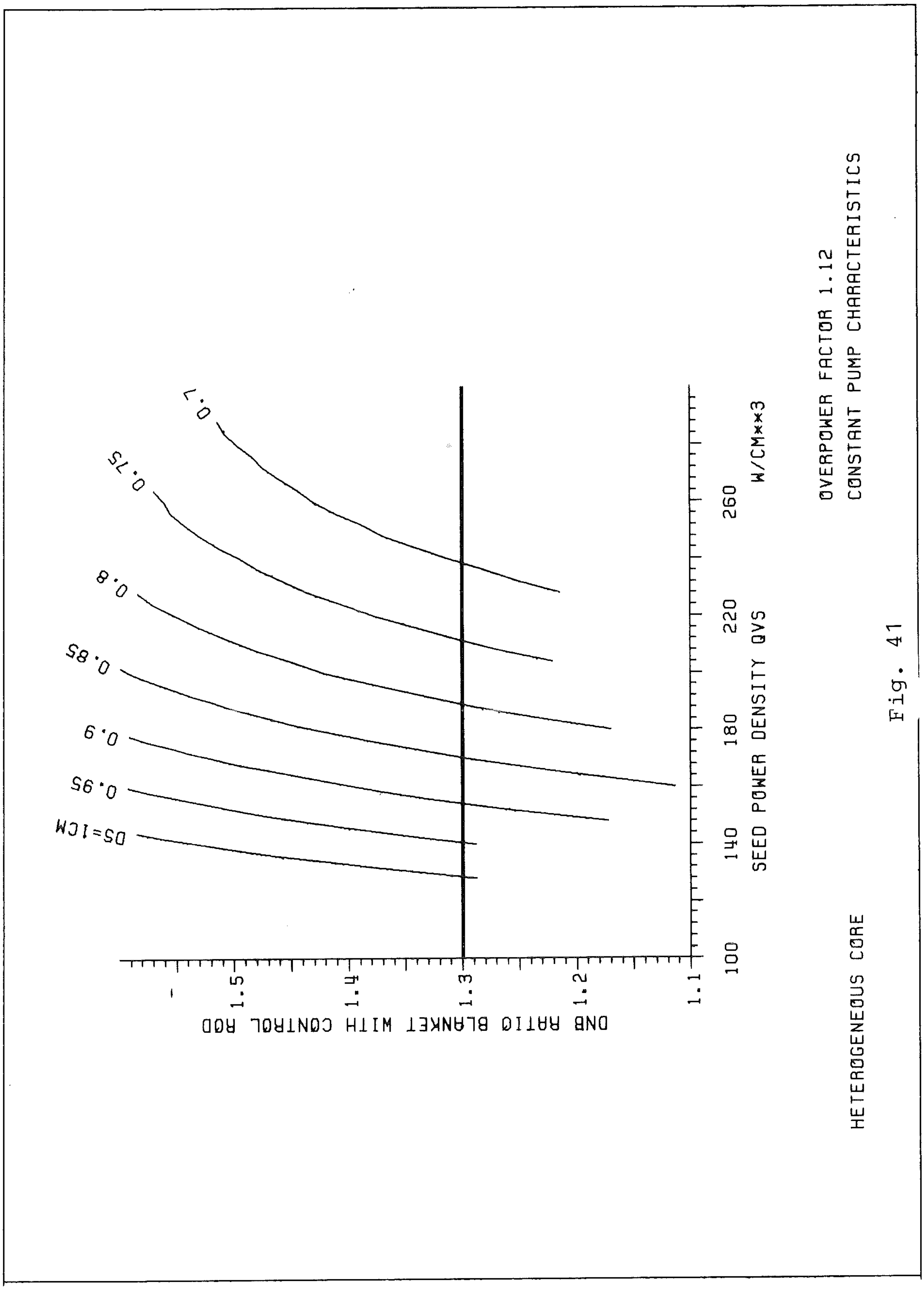

OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS
HETEROGENEOUS CORE
DNB RATIO BLANKET WITH CONTROL ROD
SEED POWER DENSITY QVS W/CM**3
100
140
180
220
260
1.1
1.2
1.3
1.4
1.5
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7

Fig. 41

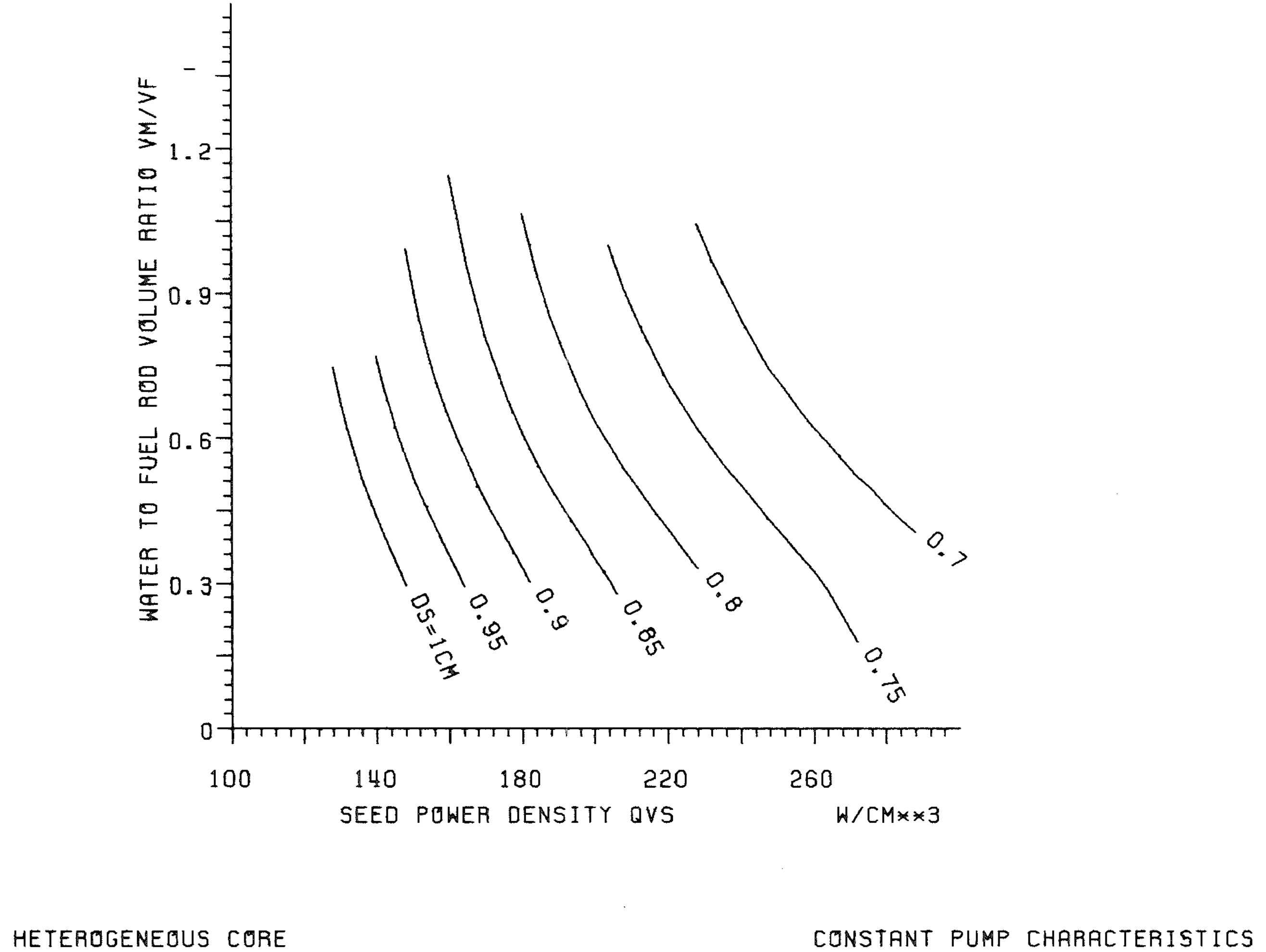
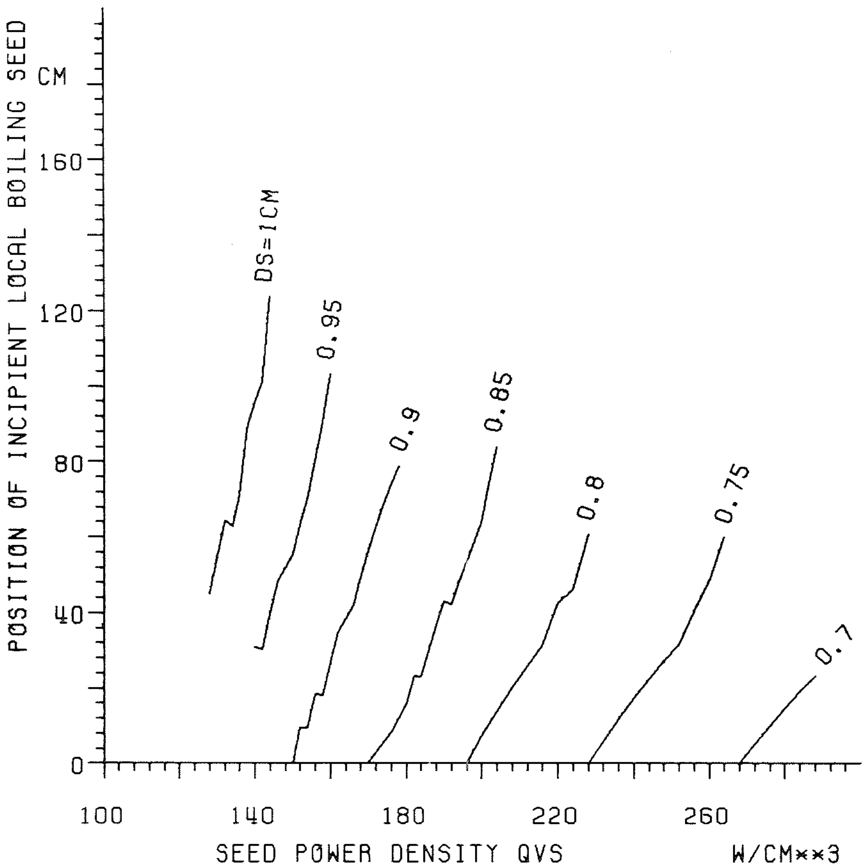

WATER TO FUEL ROD VOLUME RATIO VM/VF
1.2
0.9
0.6
0.3
0
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
CONSTANT PUMP CHARACTERISTICS

Fig. 42



HETEROGENEOUS CORE

OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

Fig. 43

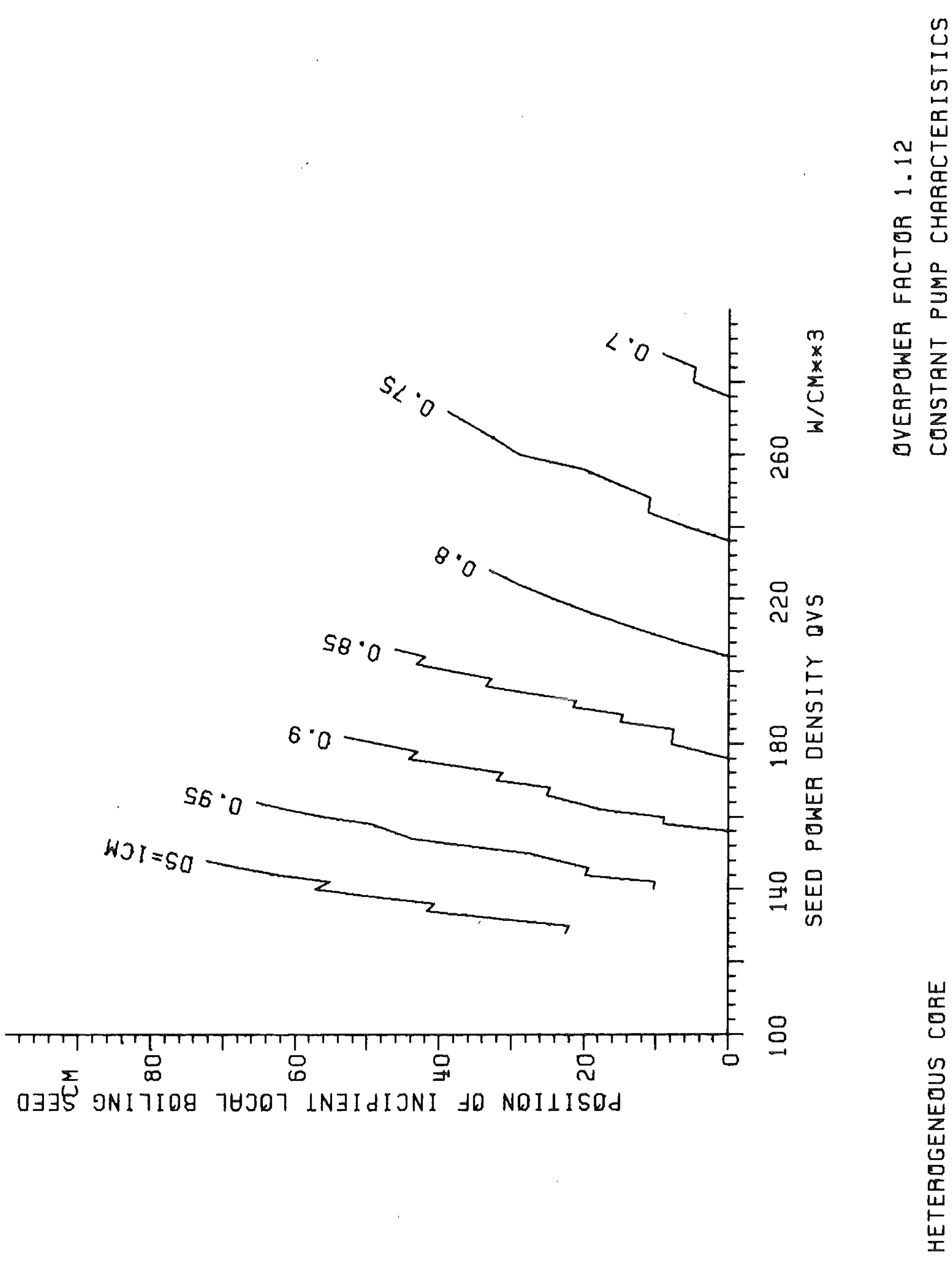

POSITION OF INCIPIENT LOCAL BOILING SEED
CM
0
20
40
60
80
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
DS=1CM
0.95
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
OVERPOWER FACTOR 1.12
CONSTANT PUMP CHARACTERISTICS

Fig. 44

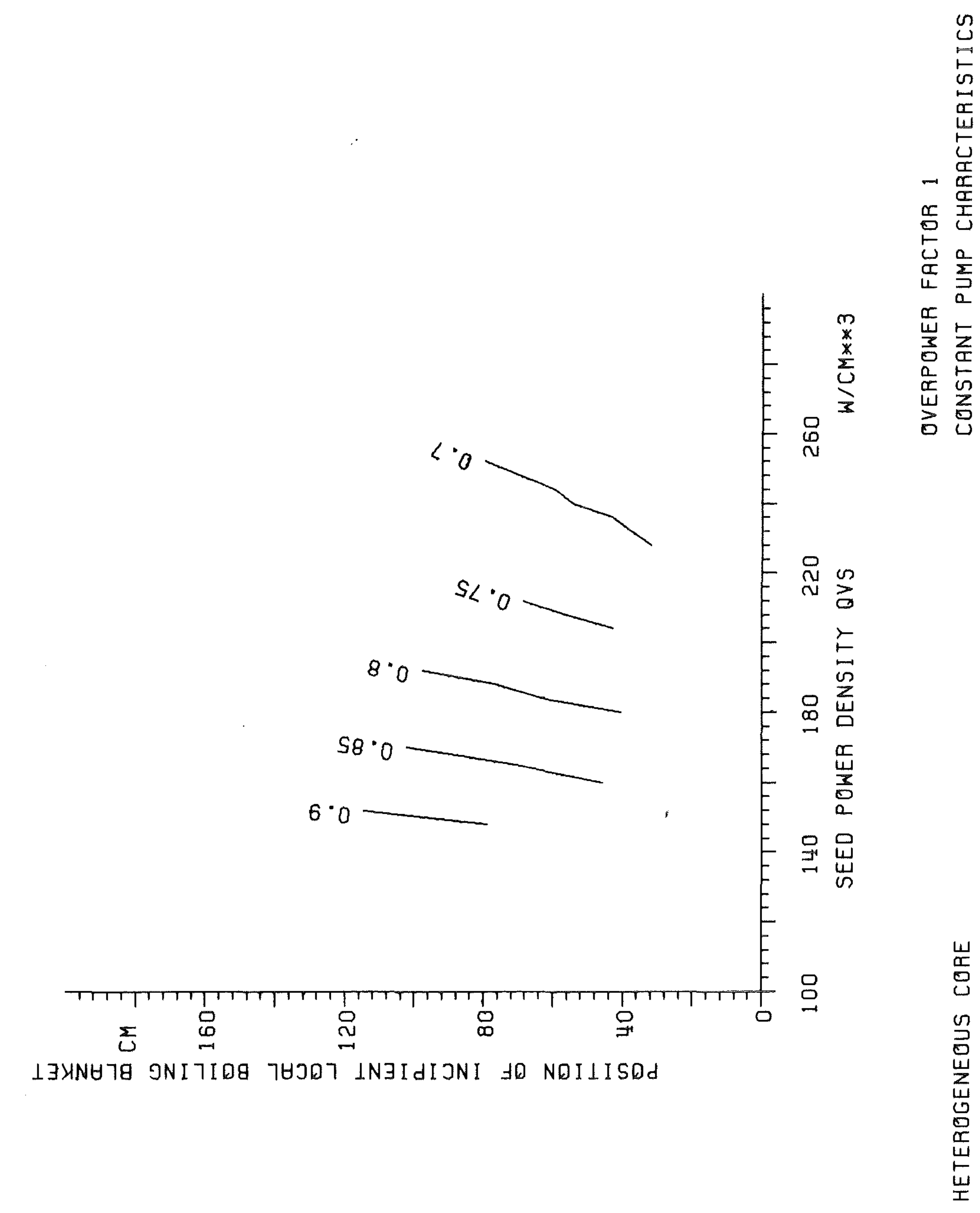
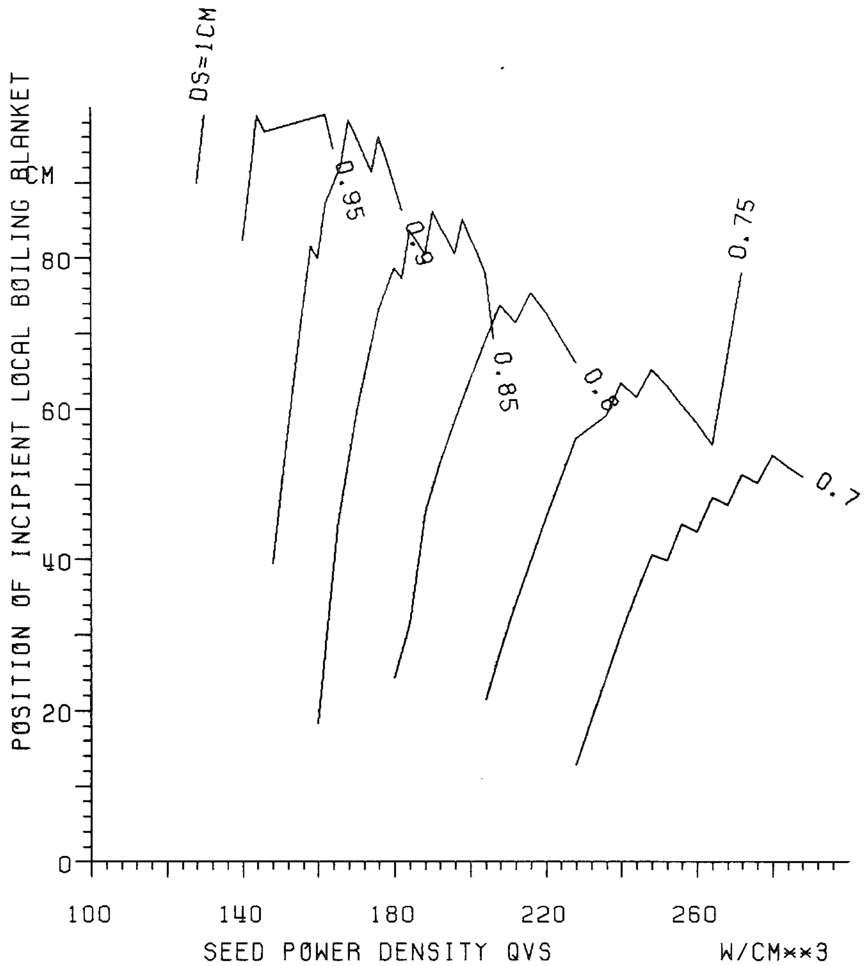

POSITION OF INCIPIENT LOCAL BOILING BLANKET
CM
160
120
80
40
0
100
140
180
220
260
SEED POWER DENSITY QVS
W/CM**3
0.9
0.85
0.8
0.75
0.7
HETEROGENEOUS CORE
OVERPOWER FACTOR 1
CONSTANT PUMP CHARACTERISTICS

Fig. 45



OVERPOWER FACTOR 1.12

CONSTANT PUMP CHARACTERISTICS

HETEROGENEOUS CORE

Fig. 46

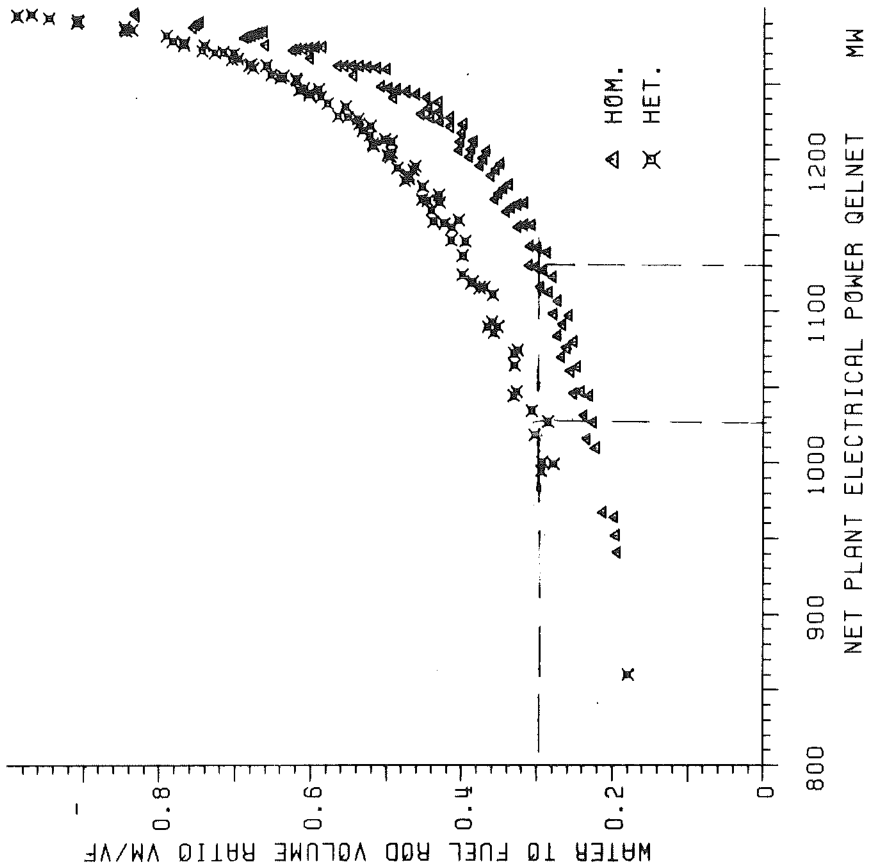

WATER TO FUEL ROD VOLUME RATIO VM/VF
0
0.2
0.4
0.6
0.8
1
800
900
1000
1100
1200
NET PLANT ELECTRICAL POWER QELNET MW
HØM.
HET.

Fig. 47