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MEMORANDUM

HEAT TRANSFER IN A FISSIONING
URANIUM PLASMA REACTOR CAVITY

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16. Abstract

This report investigates two schemes by which a fission-heated uranium plasma located in the central cavity of a test reactor could be insulated to keep its temperature above condensation in a neutron flux of 10^{15} neutrons/(cm^2)(sec) or less. The first scheme was to use a mirrored cavity wall to reflect the thermal radiation back into the plasma. The second scheme was to seed the transpirational cavity wall coolant so as to make it opaque to thermal radiation, thus insulating the hot plasma from the cold wall. The analysis showed that a mirrored cavity wall must have a reflectivity of over 95 percent or that seeded argon must be used as the wall coolant to give an acceptable operating margin above fuel condensation conditions.

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HEAT TRANSFER IN A FISSIONING URANIUM PLASMA REACTOR CAVITY

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SUMMARY

The cavity heat-transfer processes in a fissioning uranium plasma test reactor were analyzed. The thermal neutron flux was limited to about 10^{15} neutrons/(cm^2)(sec) or less, which means that the heat-source strength was limited to 20 kW/g of fissionable material. The problem is not in cooling the cavity wall, but in insulating the uranium plasma to keep its temperature above its local condensation temperature. The problem is especially severe at the outer boundaries of the plasma region.

Two schemes were investigated. The first scheme was to use mirrored cavity walls to reflect the thermal radiation back into the uranium plasma. The second scheme was to seed the transpirational wall coolant so as to make it opaque to thermal radiation, thus insulating the hot plasma from the cold wall. The analytical approach taken was to approximate thermal radiation by a diffusion process with appropriate "jumped" boundary conditions on temperature at the edge of the plasma region

For a mirrored metallic wall, a realistic wall reflectivity is about 90 percent. For this case the operating pressure was taken to be a few hundreds of atmospheres. At a neutron flux of 10^{15} neutrons/(cm^2)(sec), the temperature at the edge of the plasma was calculated to be within 500 K of the condensation temperature. The corresponding cavity power was in the tens of megawatts. This operating region is, at best, marginal. If the mirrored cavity wall could be made with a reflectivity of over 95 percent, the required power could be reduced by at least a factor of 2 and the concept would become much more attractive.

In the second scheme when seeded hydrogen was used as the wall coolant gas the edge temperature of the plasma was very close to the condensation temperature. When seeded argon was used as the wall coolant gas, the edge temperature of the plasma was much higher than condensation temperature. This result was explained with a simple one-dimensional model which indicated that increasing either the gas molecular weight or the seed mass fraction increased the edge temperature of the uranium plasma. Heavily seeded argon used as the transpirational wall coolant appears to be the better scheme to keep the edge of the uranium plasma from condensing for a given reactor thermal neutron flux, pressure level, and test region size.

INTRODUCTION

The Fissioning Uranium Plasma Reactor Facility was a proposal to use a solid-core nuclear reactor to generate neutrons in a central cavity of the reactor (ref. 1). These neutrons produce fissions in a uranium plasma located in this cavity, shown in figure 1. The heat transfer from this plasma to a cavity coolant is the subject of this report.

Like all reactors the power density for this reactor is equal to the neutron flux times the density of the fissionable material. Since the density of the uranium plasma is much less than the density of the solid core, the power generated in the uranium plasma is much lower than the power generated in the solid core. The power level of the solid core is limited; thus, the power level of the uranium plasma is also limited - but at a much lower value. The problem is not in cooling the cavity wall, but in insulating the uranium plasma to keep its temperature above its local condensation temperature.

This can be done in several ways. First, the inside cavity wall can have a mirrored surface, which would reflect the radiation from the uranium plasma back into itself. Second, transpirationally cooling the walls with a gas seeded with small solid particles would insulate the hot plasma from the cold wall. (Solid particles are used to increase the gas opacity to thermal radiation.) The objective of this study is to determine the required wall reflectivity and the choice of wall coolant, the amount of solid seed, and/or the radial flow profile desired.

The approach is to approximate thermal radiation by a diffusion process with appropriate jump boundary conditions. The properties used for hydrogen and uranium are the same as those used in reference 2. The properties of argon are extrapolated from reference 3.

ANALYSIS

A heat-transfer model of the cavity of the Fission Uranium Plasma Reactor Facility is shown in figure 2. Flow (either hydrogen or argon) enters a slotted wall from a higher pressure plenum at a temperature T_p. It then picks up the amount of heat deposited on the wall, leaving the wall at a temperature T_w, and flowing into a lower pressure cavity. In terms of enthalpy h this heat balance is

$$q_w = -(\rho v)_w (h_w - h_p) \tag{1}$$

(The wall coolant is nonseeded in the mirrored wall case or seeded with depleted uranium in the other case.)

Inside the cavity, there is an energy balance between the radially inward convection toward the plasma and the radially outward heat flux toward the wall. In vector notation this can be written as

$$0 = (\vec{\rho v}) \cdot \nabla h + \nabla \cdot \vec{q} - Q'''\tag{2}$$

where Q''' is the internal heat-generation rate (or nuclear heat source). This heat source is proportional to neutron flux times the density of the fissionable material. If the neutron flux is not attenuated by the plasma, the internal heat generation from the nuclear fission is

$$Q''' = \eta \rho_f\tag{3}$$

where η is a constant with units of w/kg; and ρ_f is the density of fissionable material.

The flow $\vec{\rho v}$ and the density of fissionable material are functions of radial position. Inside the plasma the flow is zero, the properties are just a function of temperature, and the heat flux can be written as a diffusion process.

$$\vec{q} = -\left(\frac{16\sigma T^3}{3a} + k_{mol}\right)\nabla T\tag{4}$$

A variable g can be defined as

$$g \equiv \int_0^T \left(\frac{16\sigma T^3}{3a} + k\right)dT\tag{5}$$

and then the heat flux becomes

$$\vec{q} = -\nabla g\tag{6}$$

The energy equation (eq. (2)) becomes

$$\nabla^2 g = -\eta \rho_f\tag{7}$$

In Cartesian coordinates this equation can be integrated and becomes

$$\left(\frac{dg}{dx}\right)^2 = +2\eta(f_\ell - f) = (-q)^2\tag{8a}$$

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where f is defined by

$$f \equiv \int_0^g \rho_f \, dg \qquad (8b)$$

Taking the negative square root of equation (8a) and substituting into equation (6) yields

$$q = \sqrt{2\eta(f_\ell - f)} \qquad (9a)$$

Integrating equation (9a) yields

$$x = \frac{1}{\sqrt{2\eta}} \int_g^{g_\ell} \frac{dg}{\sqrt{f_\ell - f}} \qquad (9b)$$

Evaluating equations (9) at the edge of the plasma and eliminating η gives the following relation for the centerline conditions:

$$\frac{q_e x_e}{\sqrt{f_\ell - f_e}} = \int_{g_e}^{g_\ell} \frac{dg}{\sqrt{f_\ell - f}} \qquad (10a)$$

The power per unit mass of fissionable material is then

$$\eta = \frac{q_e^2}{2(f_\ell - f_e)} \qquad (10b)$$

If it is assumed that the nuclear heat source is a constant, the power per unit mass of fissionable material is

$$\eta_0 = \frac{q_e}{x_e \bar{\rho}_f} \qquad (11a)$$

where $\bar{\rho}_f$ is defined by

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$$\overline{\rho}_f \equiv \frac{1}{x_e} \int_0^{x_e} \rho_f \, dx \tag{11b}$$

and the profile used to evaluate equation (11b) is

$$g = g_e - \frac{q_e}{2x_e}\left(x^2 - x_e^2\right) \tag{11c}$$

A comparison of equations (10) and (11) gives an estimate of the error involved with the assumption of a constant nuclear heat source.

If we assume a constant nuclear heat source and spherical geometry, the heat flux becomes

$$q = q_e\left(\frac{R}{R_e}\right) = \frac{\eta \overline{\rho}_f R}{3} \tag{12a}$$

where $\overline{\rho}_f$ is defined by

$$\overline{\rho}_f = \frac{3}{R_e^3} \int_0^{R_e} \rho_f R^2 \, dR \tag{12b}$$

and the profile used to evaluate equation (12b) is

$$g = g_e - \frac{q_e}{2R_e}\left(R^2 - R_e^2\right) \tag{12c}$$

The edge condition can be calculated by using the technique of reference 4.

$$4a\sigma T_e^4 \, \Delta R = 2a\left(q_e^+ + q_e^-\right)\Delta R + Q''' \, \Delta R \tag{13a}$$

and

$$q_e = q_e^+ - q_e^- \tag{13b}$$

Equations (13) can be combined and result in

$$\sigma T_e^4 = \frac{1}{2}\left(q_e + 2q_e^-\right) + \frac{Q_e'''}{4a_p} \tag{14}$$

If the wall coolant is transparent and the walls are specularly reflecting, the technique of reference 5 gives

$$q_e^- = \left(\frac{A_e}{A_w}\right)q_w^- \tag{15a}$$

$$q_e = \left(\frac{A_e}{A_w}\right)q_w \tag{15b}$$

$$q_w^- = \epsilon_w \frac{A_e}{A_w}\sigma T_w^4 + (1 - \epsilon_w)q_w^+ \tag{15c}$$

and

$$q_w = q_w^+ - q_w^- \tag{15d}$$

where the radiation is partitioned between the inner uranium plasma and outer spherical wall, and between the outer spherical wall and itself. Equations (15) can be substituted into equation (14) and result in

$$\sigma T_e^4 = \sigma T_w^4 + \left(\frac{1}{\epsilon_w} - \frac{1}{2}\right)q_e + \frac{Q'''}{4a} \tag{16}$$

Equation (16) is also true for slab geometry.

If the wall coolant is not transparent but very opaque, the heat flux is a diffusion process. The edge condition can then be approximated by assuming

$$q_e^- \approx \sigma T_0^4 \tag{17a}$$

and

$$\sigma T_e^4 = \sigma T_0^4 + \frac{1}{2}q_e + \frac{Q_e'''}{4a} \tag{17b}$$

where T_0 is the coolant-side temperature of the interface. Equation (17a) is true if the gradient of the temperature, on the wall coolant side of the interface, is small.

The nuclear heat source in the region outside the fissioning plasma is zero. Thus, for spherical geometry; equations (2) and (6) can be written as

$$0 = \rho v \frac{dh}{dR} - \frac{1}{R^2} \frac{d}{dR} (R^2 q) \tag{18a}$$

and

$$q = - \frac{dg}{dr} \tag{18b}$$

where the properties are assumed to be functions of temperature but not position. Given the inside and outside wall temperature and with the use of equation (1), equations (18) can be solved as an initial-value problem from the wall inward. A jump boundary condition at the wall is not necessary since convection is dominant.

To gain insight into this problem, assume the region between the plasma and the wall can be subdivided into two regions (see fig. 2(b)). Near the plasma, conduction is dominant and convection can be neglected. Near the wall, convection is dominant. Assume the flow enters the cavity, flows inward at a constant rate through the first region, then turns at the interface of the two regions, and flows out the exhaust nozzle of the cavity.

Assume the transpirational wall coolant is a mixture of solid particles and a perfect transparent gas. The radius of the particles is R_s and the density is ρ_s. Assume the gas is monatomic with a molecular weight equal to M and at a pressure of P and a temperature of T. The mass fraction y is the mass of solid particles per unit mass of coolant. The specific heat is

$$C_p = \frac{5}{2} \left(\frac{\mathscr{R}}{M} \right) (1 - y) \tag{19a}$$

where the specific heat of the solid particles has been neglected and $\mathscr{R}$ is the gas constant. The absorption coefficient is

$$a = \left(\frac{3}{4R_s \rho_s} \right) \left(\frac{MP}{\mathscr{R}T} \right) \left(\frac{y}{1 - y} \right) \tag{19b}$$

If molecular conduction is neglected, the conductivity becomes the radiative conductivity

$$k = \frac{64R_s \rho_s \mathscr{R} \sigma T^4}{9MP} \left(\frac{1-y}{y}\right) \qquad (19c)$$

For a slab geometry, the heat flux in the conduction region is a constant.

$$q_e = -k_w \left(\frac{T}{T_w}\right)^4 \frac{dT}{dx} \qquad (20a)$$

This can be integrated to give

$$\frac{q_e(x_t - x_e)}{k_w T_w} = -\frac{1}{5}\left[\left(\frac{T_t}{T_w}\right)^5 - \left(\frac{T_e}{T_w}\right)^5\right] \qquad (20b)$$

where the jump boundary condition is neglected and the subscript t refers to the fluid turning point at the interface. If there is no transpirational coolant, the turning point is the wall.

$$\frac{q_e(x_w - x_e)}{k_w T_w} = -\frac{1}{5}\left[1 - \left(\frac{T_e}{T_w}\right)^5\right] \qquad (20c)$$

The maximum heat flux at the wall, considering only transpirational cooling, is

$$q_w = -\rho v C_p T_w \qquad (21a)$$

where the plenum temperature is assumed to be zero. When equation (21a) is used as a boundary condition, the heat flux in the convection region can be obtained by integrating equation (2).

$$q = -\rho v C_p T \qquad (21b)$$

Evaluating equation (21b) at the turning point yields

$$q_e = -\rho v C_p T_t \qquad (21c)$$

Using the conduction formulation of heat flux and equation (21b) yields

$$q = -\rho v C_p T = -kW \left(\frac{T}{T_w}\right)^4 \frac{dT}{dx} \qquad (21d)$$

This can be integrated from the wall to the turning point to give

$$\left(\frac{\rho v C_p}{k_w}\right)(x_w - x_t) = \frac{1}{4}\left[1 - \left(\frac{T_t}{T_w}\right)^4\right] \qquad (21e)$$

These equations can be nondimensionalized by the following set of parameters:

$$N_c = \rho v C_p \frac{x_w - x_e}{k_w} \qquad (22a)$$

$$\epsilon = \frac{T_e}{T_w} \qquad (22b)$$

$$r = \frac{x_w - x_t}{x_w - x_e} \qquad (22c)$$

$$\xi = q_e \frac{x_w - x_e}{k_w T_w} \qquad (22d)$$

Substituting equations (22) into equations (20b), (21c), and (21e) and rearranging yields

$$\frac{T_t}{T_w} = \left[\epsilon^5 - 5(1 - r)\xi\right]^{1/5} = -\frac{\xi}{N_c} = \left(1 - 4N_c r\right)^{1/4} \qquad (23)$$

Solving this set of equations in terms of $N_c r$ results in

$$\xi = -\frac{1}{5}\left(1 - 4N_c r\right)^{1/4}(1 + N_c r) + \frac{\epsilon^5}{5} \qquad (24a)$$

$$r = \frac{(-N_c r)\left(1 - 4N_c r\right)^{1/4}}{\xi} \qquad (24b)$$

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$$N_c = -\xi\left(1 - 4N_c r\right)^{-1/4} \tag{24c}$$

where

$$N_c = \frac{45\rho v P y (x_w - x_e)}{128 R_s \rho_s \sigma T_w^4} \tag{24d}$$

For the case of no transpirational cooling, equation (24a) becomes

$$\xi_c = \frac{1}{5}\left(\epsilon^5 - 1\right) \tag{25}$$

For the case of a large amount of transpirational cooling, equations (24) become

$$\xi = \xi_c + \frac{\sqrt{2}}{5}\left(-N_c r\right)^{5/4} \tag{26a}$$

$$r = \frac{\sqrt{2}\left(-N_c r\right)^{5/4}}{\xi} \tag{26b}$$

$$N_c = \frac{-\xi}{\sqrt{2}\left(-N_c r\right)^{1/4}} \tag{26c}$$

Solving equations (26a) and (26b) for ξ yields

$$\xi = \frac{5\xi_c}{5 - r} \tag{27}$$

The calculational procedure is summarized as follows: First, the assumption of constant heat generation in slab geometry was checked. The concept of a mirrored wall in spherical geometry was then investigated. The pros and cons of seeded argon versus seeded hydrogen were studied and explained with a simple one-dimensional model.

DISCUSSION

The Fissioning Uranium Plasma Reactor Facility was a proposal to use a solid-core nuclear reactor to "drive" a uranium plasma located in a central cavity (ref. 1 and

fig. 1). The operation of this fissioning uranium plasma was energy limited. The problem addressed is not in cooling the cavity wall, but in insulating the uranium plasma to keep its temperature above its local condensation temperature. A heat-transfer model, shown in figure 2, was analyzed by using a diffusion approximation of thermal radiation with appropriate jump boundary conditions. The properties used were similar to those used in references 2 and 3.

The calculational procedure was first to check the assumption of constant heat generation in slab geometry. (Heat generation should be proportional to the density or to one over the temperature.) This was done by comparing equations (10) (variable heat source) to equations (11) (constant heat source). The result of this calculation is shown in figure 3 with the solid lines being the variable-heat-source solution and the dashed lines being the constant-heat-source approximation. Over the pressures and the edge heat fluxes of interest, the heat-source-strength η can be approximated by the constant-heat-source method. The same thing was noticed for a few spot calculations in spherical geometry; and therefore, the rest of the calculations use the constant-heat-source approximation.

To investigate the concept of a mirrored cavity wall, equations (12) and (16) were used to generate figure 4. Metallic walls are generally about 90 percent reflective. The wall temperature was set at 500 K. (Wall temperatures as high as 2000 K resulted in only slight changes from the 500 K nominal wall case.) The uranium plasma was located in the central 25 percent of the cavity volume. The region between the plasma and the cavity wall was transparent. Conduction and convection off the plasma were neglected.

Figure 4(a) shows the necessary heat-source strength to keep the edge of the uranium plasma 2000, 1000, 500, or 0 K above the condensation temperature. Reference 1 indicates that about 10^{15} neutrons/(cm^2)(sec) is the upper limit on the thermal neutron flux. This corresponds to about 2×10^7 W/kg, (20 kW/g), as the upper limit of the heat-source strength. The only region in figure 4(a) which is less than 2×10^7 W/kg is in the hundreds of atmospheres pressure, and the edge temperature of the uranium plasma must be within 500 K of the condensation temperature. From figures 4(b) and (c), for this region, the cavity power is between 5 to 20 MW and the wall heat flux is less than 2 kW/cm^2. This operational region is, at best, marginal.

The performance of the mirrored cavity wall concept is a strong function of the wall reflectivity (or one minus the wall emissivity). Figure 5 shows the effect on the necessary heat-source strength of varying the wall emissivity. The calculation was done at 100 atmospheres and with the edge temperature of the plasma at the condensation temperature. If the mirrored cavity wall could be made with a reflectivity of over 95 percent, the concept would become much more attractive.

The alternative to using mirrored cavity walls is to use an opaque gas flowing radially inward to convect the heat back toward the uranium plasma. Solid seed particles are used to increase the gas opacity to thermal radiation. There is a minimum gas flow

necessary for hydrodynamic stability of the uranium plasma or for wall cooling. The choice of wall coolant gas, the amount of solid seed, and the desired radial flow profile are investigated herein.

Figure 6 shows some typical cavity temperature profiles for hydrogen and argon wall cooling gases. The gases were seeded to the same mass fraction, 0.25, and had the same nondimensional flow profile (i.e., a linear decrease to zero at the edge of the plasma). The flow through the wall was adjusted so that the hot gas stood off the wall about the same distance. For the hydrogen case, the edge temperature of the plasma was very close to the condensation temperature. For the argon case, the edge temperature of the plasma was much higher than the condensation temperature.

Figure 7 shows the maximum uranium plasma edge temperature as a function of thermal neutron flux for hydrogen and argon for pressures of 133 and 200 atmospheres. (Thermal neutron flux is proportional to heat-source strength, where the constant of proportionality is higher for argon, since hydrogen absorbs some neutrons.) For hydrogen as the wall coolant, the edge temperature of the uranium plasma is very close to the condensation temperature. Argon is obviously the best choice of wall coolant from this viewpoint.

To explain this result, the simple one-dimensional model (eqs. (24)) was used to generate figure 8. To minimize the reactor power for a given plasma edge temperature, wall temperature, seed fraction, wall coolant, and geometry, the product, $-N_c r$, must be a minimum. Therefore, it is desired to use the least possible amount of flow through the wall and to have this flow turn as soon as possible. Obviously, N_c and r are not independent variables, as shown in figure 8. The minimum value of ξ is ξ_c. If the condensation temperature is about 5000 K and the maximum wall temperature is about 1000 K, the value of ϵ is greater than 5. Using equation (25) gives the value of ξ_c as greater than about 625. From figure 8, $N_c r$ must be greater than 100 before ξ differs appreciably from ξ_c. The maximum value of ξ is given from equation (27) when r is equal to 1 and becomes $\xi = 1.25 \, \xi_c$. Therefore, ξ can only vary by 25 percent.

Since ξ is relatively constant, the minimum reactor power results from a minimum k_w in equation (22). From equation (19c), k_w can be reduced by increasing either the seed mass fraction or the gas molecular weight. Changing the molecular weight from that of hydrogen to argon results in a drop in reactor power of a factor of 15. Doubling the seed mass fraction from 0.25 to 0.50 results in a drop in reactor power of a factor of 3.

CONCLUSIONS

The cavity heat transfer in a fissioning uranium plasma reactor is analyzed in this report. Two schemes were investigated to keep the plasma edge temperature above

condensation. First was the mirrored-cavity-wall scheme, which would reflect the thermal radiation back into the uranium plasma. Second was the seeded transpirational wall coolant, which would convect the heat back towards the plasma.

The analysis resulted in the following conclusions for the mirrored-cavity-wall scheme:

1. For a realistic wall reflectivity of 90 percent, the operating pressure was in the hundreds of atmospheres, the edge temperature of the plasma was within 500 K of the condensation temperature, the cavity power was in the tens of megawatts, and the wall heat flux was less than 2 kW/cm^2.

2. If the mirrored cavity wall could be made with a reflectivity of over 95 percent, the required power could be reduced by at least a factor of 2 and the concept would become much more attractive.

The analysis resulted in the following conclusions for the seeded-transpirational-wall-coolant scheme:

1. For seeded hydrogen as the wall coolant gas, the edge temperature of the plasma was very close to the condensation temperature.

2. For seeded argon as the wall coolant gas, the edge temperature of the uranium plasma was much higher than the condensation temperature.

3. Increasing either the gas molecular weight or the seed mass fraction increased the edge temperature of the uranium plasma.

Seeded argon used as the transpirational wall coolant was the best scheme to keep the edge of the uranium plasma from condensing for a given reactor flux.

Lewis Research Center,
    National Aeronautics and Space Administration,
        Cleveland, Ohio, June 26, 1973,
            503-04.

APPENDIX - SYMBOLS

A area, m^2

a absorption coefficient, m^{-1}

C_p specific heat, J/(kg)(K)

f auxiliary function

g auxiliary function

h enthalpy, J/kg

k thermal conductivity, J/(m)(sec)(K)

m molecular weight

N_c nondimensional flow parameter, a measure of convection to conduction

P pressure, N/m^2

Q''' internal heat-generation rate, W/m^3

q heat flux, W/m^2

R radius, m

$\mathscr{R}$ gas constant, 8.3143 J/(K)(mol)

r nondimensional depth of penetration of wall coolant flow

T temperature, K

v velocity, m/sec

x distance, m

y mass fraction of seed in wall coolant

ϵ ratio of plasma edge temperature to wall temperature

ϵ_w emissivity of cavity wall

η heat-source strength per unit mass of fissionable material, W/kg

ξ nondimensional heat flux

ξ_c nondimensional heat flux with no flow

ρ density, kg/m^3

$\bar{\rho}$ average density, kg/m^3

σ Stefan-Boltzmann constant, 5.6697×10^{-8}, $w/(m^2)(K^4)$

Subscripts:

$\mathfrak{c}$	center of plasma
e	edge of plasma
f	fissionable material
mol	molecular
p	plenum
s	seed
t	turning point of wall coolant
w	cavity wall
0	wall coolant adjacent to plasma

Superscript:

±	component in plus or minus direction

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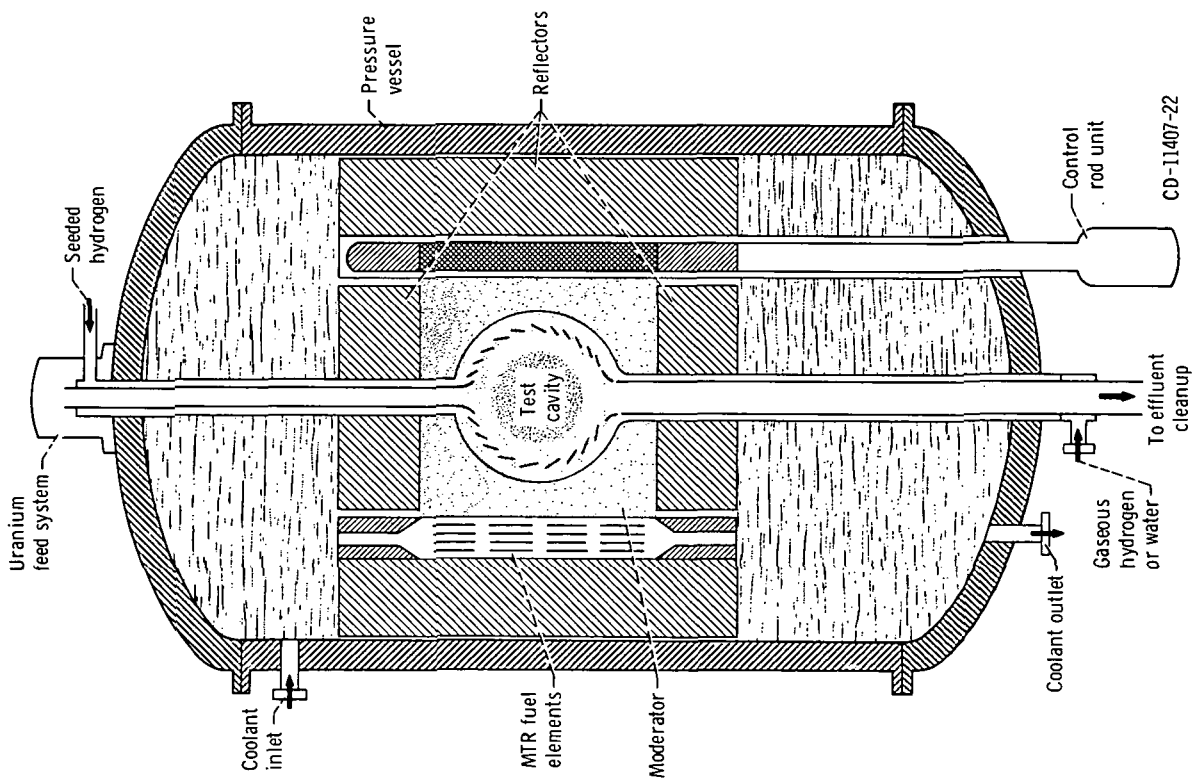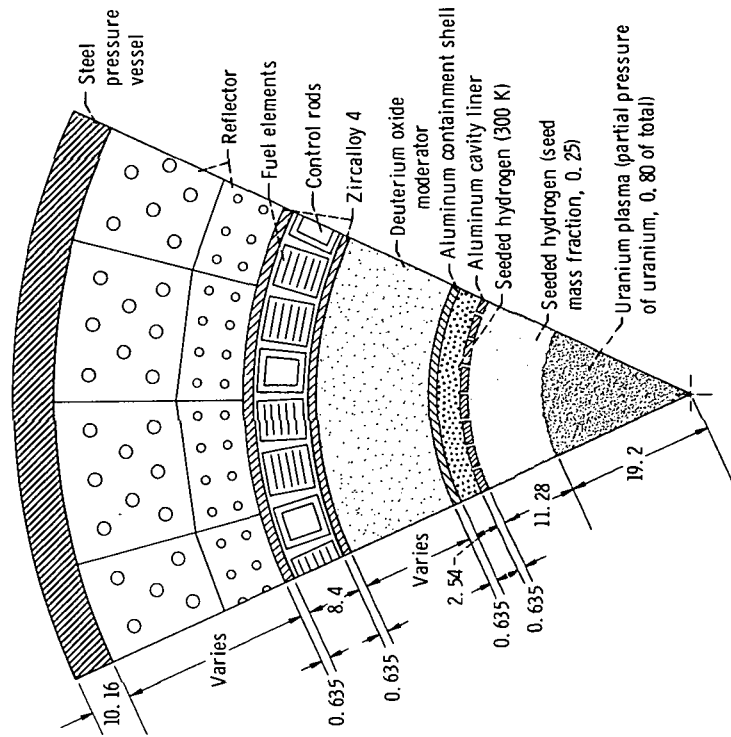
(b) Plan view of reactor center. (All dimensions are in cm.)

Figure 1. – Cavity test reactor.

(a) Reactor schematic.

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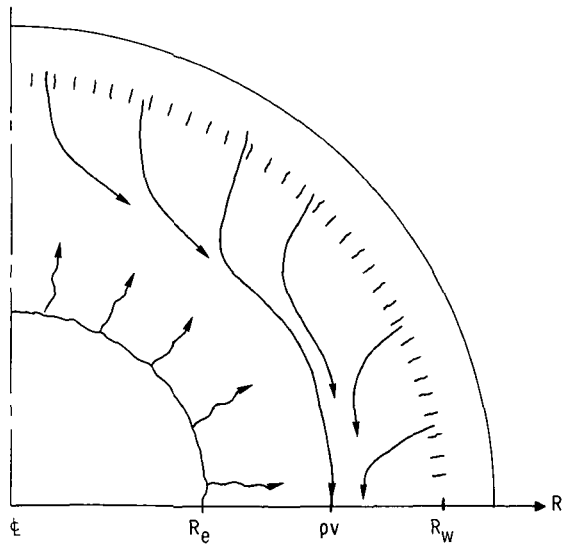
(a) Spherical geometry.
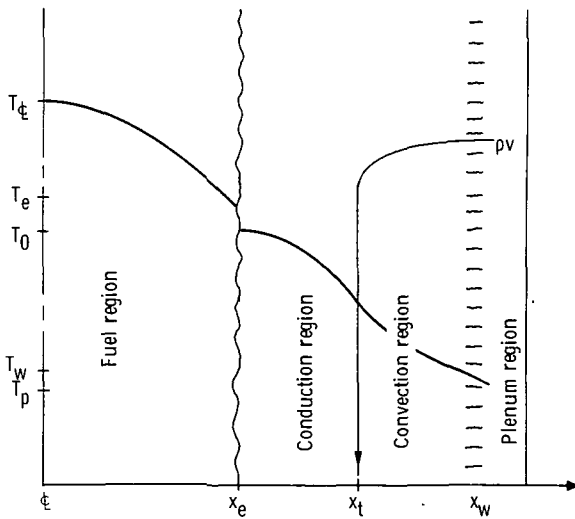
(b) Slab geometry.

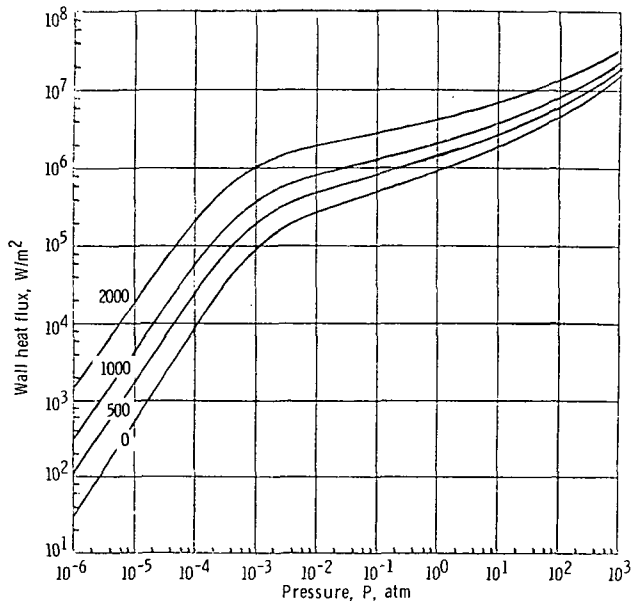Figure 2. - Heat-transfer model.
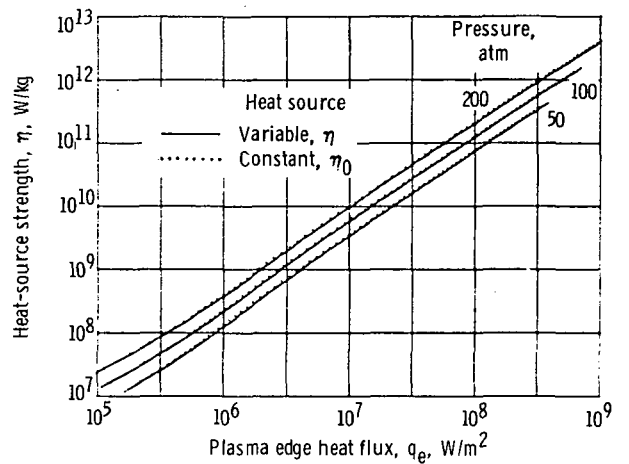
Figure 3. - Comparison of variable heat source (proportional to density of fissionable material) to constant heat source as function of plasma edge heat flux for various pressures, for the reactor shown in figure 1.
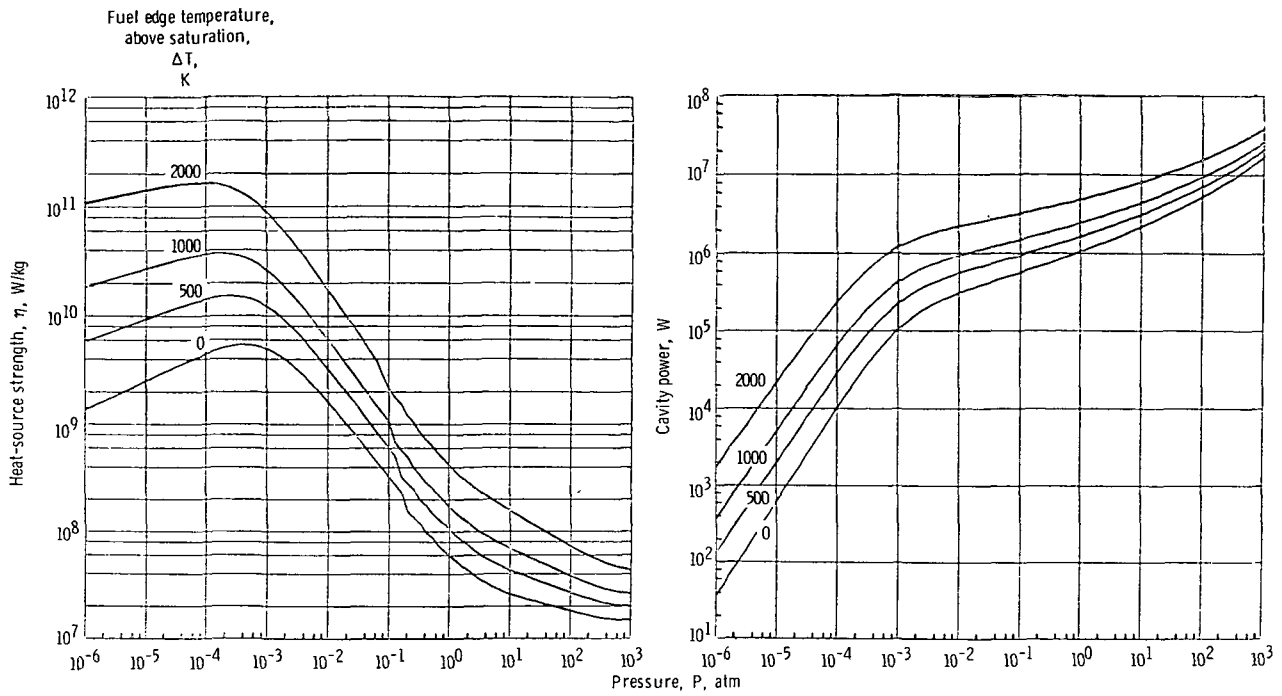
(a) Heat-source strength as function of pressure.

(b) Cavity power as function of pressure.

(c) Cavity wall heat flux as function of pressure.

Figure 4. - Necessary heat-source strength, cavity power, or cavity wall heat flux for uranium plasma inside a 0. 61-meter (2-ft) diameter cavity with 90-percent reflecting walls and a transparent wall coolant gas to keep plasma edge temperature 2000, 1000, 500, or 0 K above the condensation temperature.

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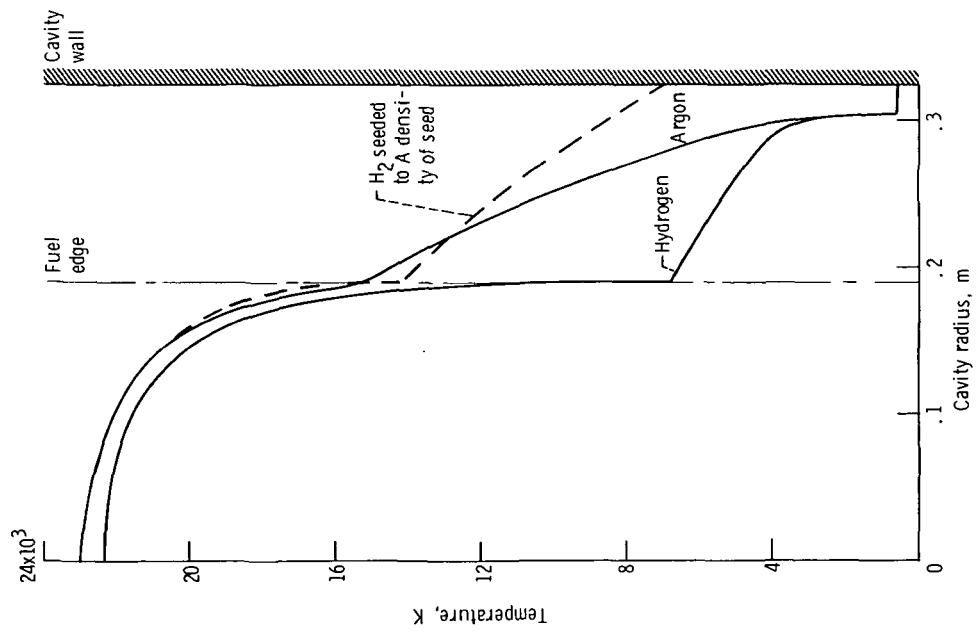
Figure 6. - Typical cavity temperature profiles of seeded hydrogen and seeded argon wall-cooling gas. Seeded mass fraction 0.25; flow adjusted so hot gas is some distance from wall; pressure, 133 atm; neutron flux, 10^{15} neutrons/(cm^2)(sec); power, 5.57 MW.
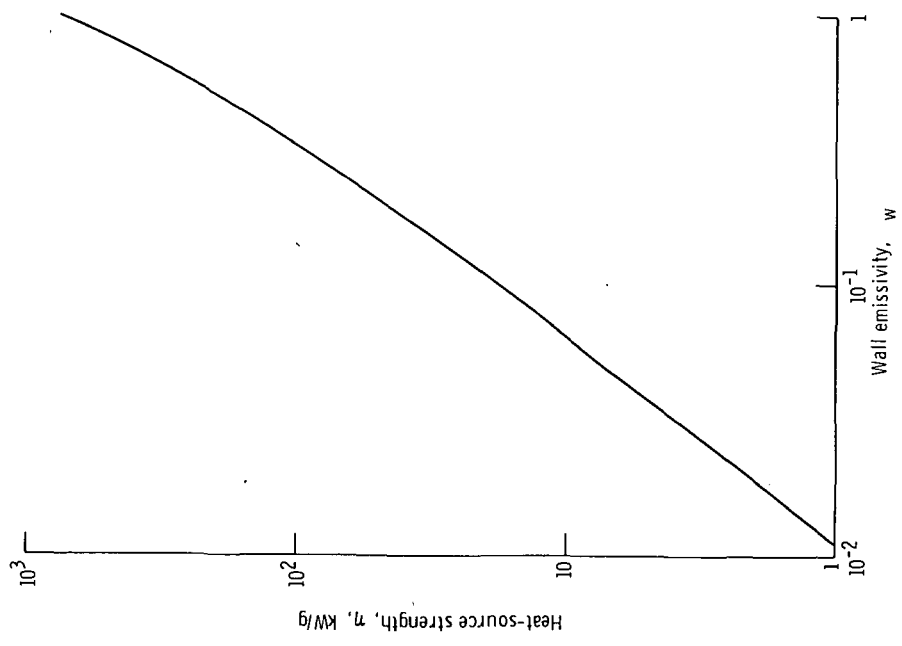

Figure 5. - Heat-source strength as function of wall emissivity for pressure of 100 atmospheres and plasma edge temperature condensation temperature.
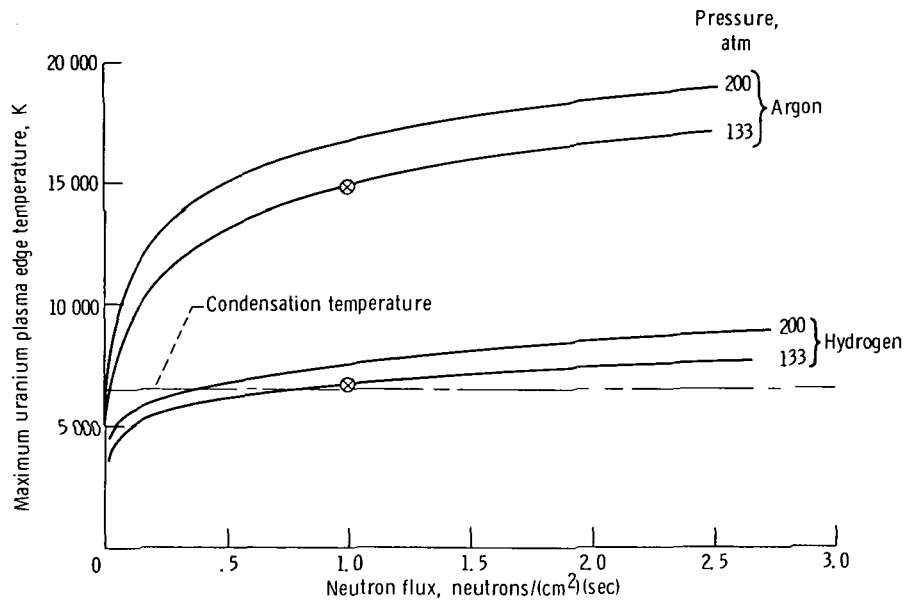
Figure 7. – Maximum uranium plasma edge temperature as function of thermal neutron flux for seeded hydrogen and seeded argon for pressures of 133 and 200 atmospheres.
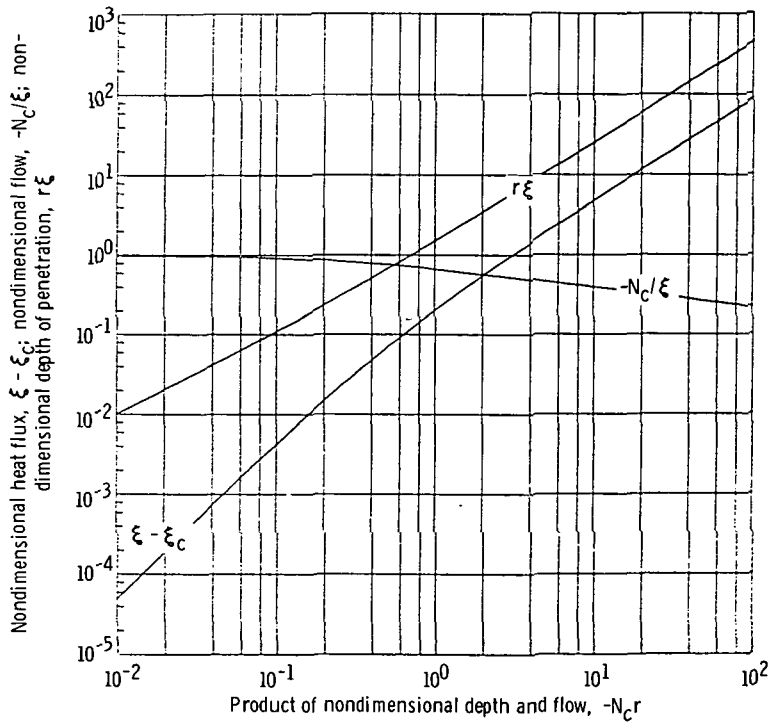

Figure 8. – One-dimensional radiant-heat-transfer analysis of mixture of a solid seeded gas and a perfect transparent gas.

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