NATURAL CONVECTION ANALYSIS OF THE MITR-II

DURING LOSS OF FLOW ACCIDENT

by

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S.B. Pahlavi University 1974

Submitted in partial fulfillment of

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Signature of Author _____ Signature redacted _____

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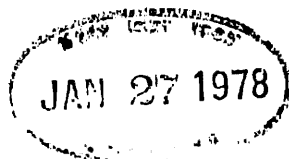Certified by _____ Signature redacted _____

Thesis Advisor

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Chairman, Department Committee on Graduate Students

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Submitted to the Department of Nuclear Engineering,
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ABSTRACT

The natural convective cooling of the MITR-II, in a
transitory period due to loss of electrical power to the
main panel is studied in this work.

The transient behavior of the Reactor after scram
due to loss of flow is examined for an infinite operation
at the steady state power of 5 MWth. The shutdown energy
due to fission of the delayed neutrons, decay of fission
products and the activated core materials is transferred
by the pump coast down and natural convection flow.

A series of incore temperature measurements were
made as part of the reactor startup procedure to full
licensed power. A computer program was written to compare
the nominal calculation of the average core temperature
distribution with the experimental values. The calculated
and measured temperatures are in general agreement except
that the calculations predict the peak temperature at an
earlier time than observed experimentally. The analysis is
expanded to the hot channel temperature evaluation during
loss of primary forced flow.

A single channel model is used to simulate the hot
channel for calculation of temperature distribution in
five possible cases that the accident might occur.

It is calculated that the hottest point in the core,
due to loss of flow accident for steady state power of
5 MWth will be below the saturation temperature, even if
one of the natural convection valves remains in the closed
position.

In the case that two of the incore check valves do not
open after the accident, boiling will occur about 10 seconds
following the accident. Although the fuel surface temperature

exceeds saturation at a height of approximately 12 inches from the bottom of the fuel plate, it is still far below the softening point of aluminum, (450°C).

Increasing the core inlet temperature encourages the onset of nucleation boiling. The fuel surface temperature increases to 104.5°C. Boiling will occur for a few seconds on the uppermost part of the fuel plate if the primary heat exchanger outlet temperature is increased to 52°C.

Thesis Supervisor: David D. Lanning

Title: Professor of Nuclear Engineering

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ACKNOWLEDGEMENTS

CHAPTER I

INTRODUCTION

1.1 General

The modified Massachusetts Institute of Technology

Research Reactor, MITR-II, is cooled with H_2O that is

circulated by two primary pumps. Sufficient cooling is

provided in order to operate at five thermal megawatts

steady state power within the acceptance criteria. The heat

generated is transferred to the secondary water system

and is rejected into the atmosphere by force draft cooling

towers.

The MITR-II is designed to function within a safety

limit in all possible ways with regard to loss of coolant

flow. The reactor will scram whenever there is a reduction

in primary coolant flow or pressure below a set point.

There is a backup low level scram protection in the con-

tainment tank to keep the water not any lower than three

inches below overflow. Two antisiphon valves which are

maintained in the closed position by the primary pumps

pressure, open automatically to prevent siphoning of the

main tank water in the unlikely event of pipe break. Four

incore check valves are designed and installed to remove

the after scram heat generation due to loss of flow accident.

These valves open to produce a loop for natural convection heat removal as soon as the pressure on both sides of them balances.

As part of the Safety Analysis Report of the MITR-II, loss of flow accident was studied by Choi (Ref. 1.1 and 1.2) and it was shown that "cooling by natural convection flow after a shutdown is sufficient to prevent the wall temperature from reaching the boiling point during the first 50 minutes".

To demonstrate that the decay heat resulting from long term operation at 5 MWth can be removed by natural convection, a series of temperature measurements were made as part of the startup procedure. A thermocouple fuel element was inserted into a central position (A-2) to measure fuel wall temperatures at 0.1 and 4.0 inches from the bottom of the fuel plates. Spider hole inlet and fuel element average outlet temperatures were also measured. The transient experiments above 2 MWth were done based on the assumption of loss of electrical power to the main panel. Therefore both primary pump switches as well as the reactor minor scram button were pushed at the same time. The temperature measurements were made for loss of flow accident up to 2 MWth. In this

case the primary pumps were stopped and the reactor was scrammed automatically due to flow coast down. The MITR-II, Core-4, transient behavior is studied in this work analytically and compared with the experimental results. A computer code is written to analyze the reactor function after a scram due to loss of flow accident. It is capable of solving transient problems involving loss of primary flow such as loss of electrical power, pump trip or breakdown, and pipe break in the reactor inlet system. To compare with the startup experiments, the first case is considered here and it is assumed that before the accident the reactor was operating at steady state conditions. A single channel model is used to analyze the average core power distribution or hot channel separately. It is also shown how the computer program could be modified for multi-channel calculations.

1.2 Description of the MITR-II

The MITR-II is a light water cooled and moderated and heavy water reflected nuclear reactor which uses flat plate-type, finned aluminum clad highly enriched uranium fuel elements. It is designed to operate at a steady state power of five thermal megawatts. Figure 1.1

FIG . 1.1 Vertical Cross Section of the
MITR-II

shows a vertical cross sectional layout of the MITR-II.

The reactor is located at the center of a gastight cylindrical steel building equipped with a controlled pressure relief system. The reactor is located inside of two concentric tanks and a core shroud. The outermost tank is a four foot diameter D_2O reflector tank and is used to maintain a D_2O level for neutron reflection. Heat generated in the core is removed by primary light water forced convection system. Primary coolant enters the reactor through the inlet plenum and into the annular area between the core tank and the core shroud. It then flows downward through the upper plenum to the bottom of the hexagonal core support housing assembly where it is directed upward through the fuel elements. It then moves slowly within the chimney and core shroud to the three exit ports which form the outlet plenum, just above the level of the inlet plenum.

The fuel is arranged in a compact core configuration to minimize the thermal neutron flux in the reflector region where the experimental beam ports are located. Because of rather high heat generation in the core, the fuel plates are finned to augment heat transfer. The fuel element consists of fifteen fuel plates assembled

between two grooved side plates. The fuel plates are slightly over 2.5 inches wide with 110 longitudinally-milled square fins on either side; 0.01 inches high and 0.01 inches wide grooves. More detail about fuel elements can be found in Reference 1.3. The fissionable material consists of uranium enriched to approximately 93% U-235. Each fuel element contains about 445 grams of U-235.

The control blades come down around the outside of the core and are effective by cutting off thermal neutron transport between the reflector and the core. The control blades are made of Cadmium in an aluminum sandwich.

On August 14,1975, MITR-II reactor went critical for the first time with 20 fuel elements loaded which was considerably less than the 27 positions available in the core. Because of the small control bank worth, only one additional element could be added to the core without exceeding the shutdown margin required by Technical Specifications. However, a twenty-one element core would not have sufficient heat transfer area for 5 MWth operation and also the empty fuel position would allow too much bypass flow and unacceptable power peaking.

In order to be able to load more fuel into the
reactor, the fixed absorber was lowered and the reac-
tor went critical for the second time, with a loading
of 22 active fuel elements,3 solid dummy elements, and
one sample assembly containing a neutron source. Two
additional active elements were loaded and one dummy
was removed. The Core-I loading at the beginning of
power distribution measuring is shown in Figure1.2.

In February,1976, when an attempt was made to
remove a fuel element from the core, it was discovered
that about 2/3 of the reactor fuel elements were stuck
in the core because the cadmium fixed absorber sandwiches
were swollen beyond the acceptable tolerances for the
compact core arrangement. Water had leaked into the
sandwich from the seal weld and corroded the cadmium.
Hydrogen from the corrosion process had built up a gas
pressure inside the sandwich and caused swelling,(Ref.1.4).

In order to prevent damage to the fuel elements,
the fixed absorbers were removed. Core-II was designed to
contain fewer fuel elements and more solid dummies in
order to counter balance the positive reactivity effect
of removal of the fixed cadmium absorbers. To minimize
the power peaking effect of the water gap produced by
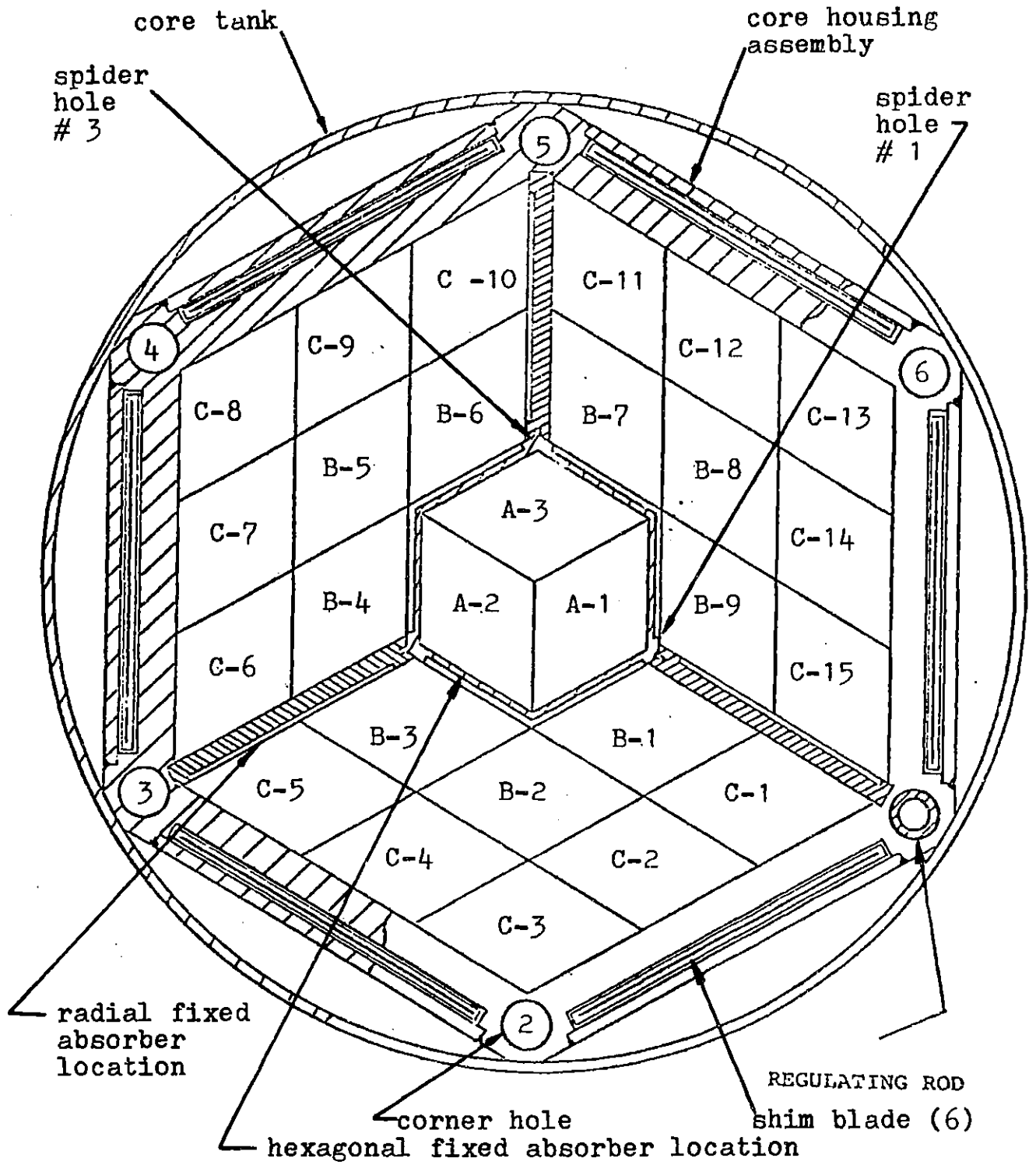
FIG. 1.2 (a) Core Section of MITR- II

REGULATING ROD
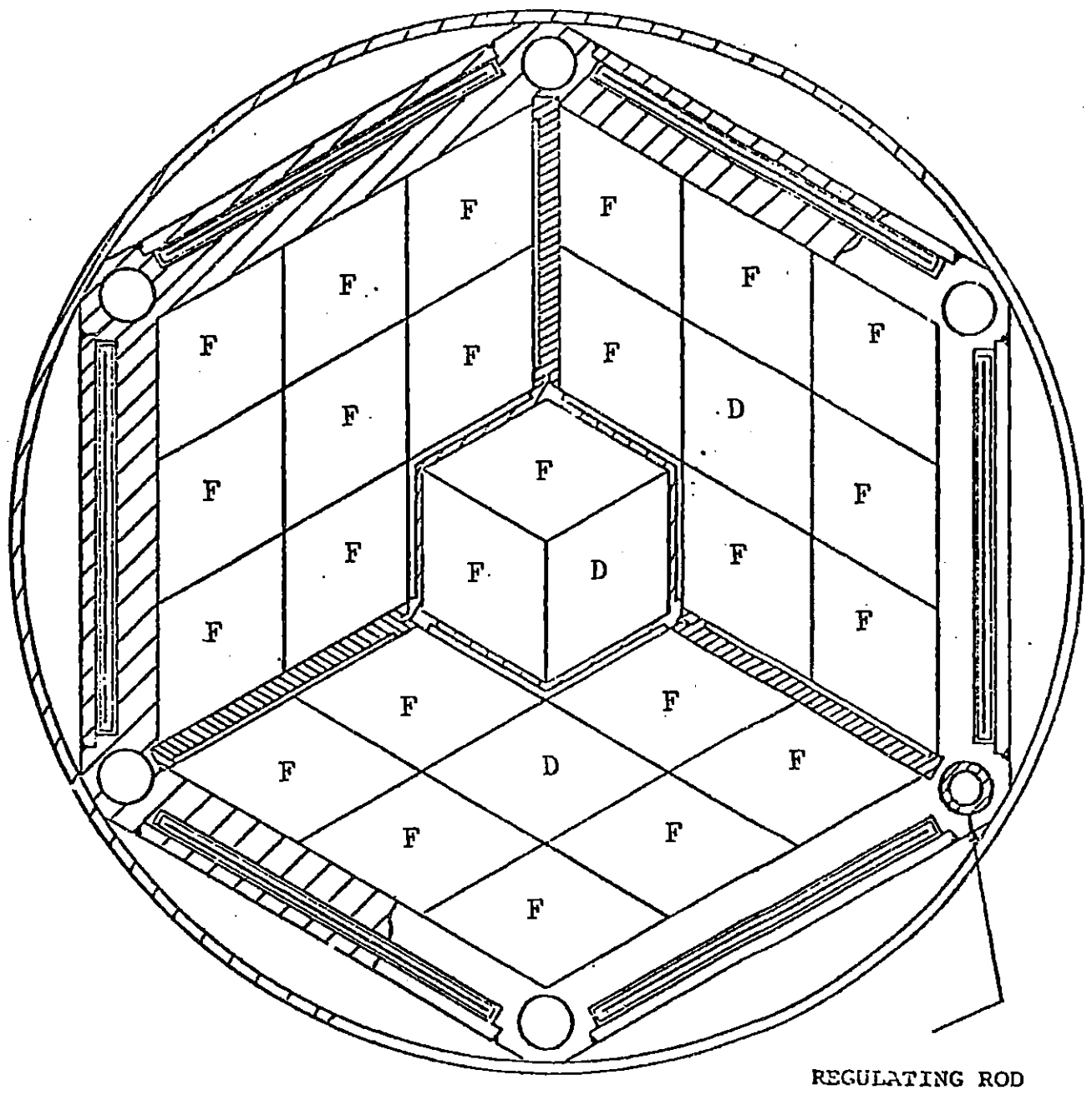
F - Fuel Element
D - Dummy Element

FIG . 1.2 (b)   Core I with Cd as fixed absorber

removing the fixed absorbers, and to decrease the worth
of solid dummies in the B ring they were loaded into
positions B-3, B-6 and B-9 , as is shown in Figure 1.3.
By placing solid dummies in these positions and because
of "notch up" plate arrangement, no single plate was
directly against the water gap caused by removal of the
fixed absorbers.

To prevent swelling, Hafnium was selected as the
absorber material for the fixed absorber. In November,1976,
Core III went critical with the same loading as Core I.
Calculations showed that for long term operations, only
2 dummies could be placed in the core. Therefore the final
Core III loading had 25 fuel elements and 2 dummies as is
shown in Figure 1.4.

Core III had all the requirements of Technical
Specifications, except that due to high negative reac-
tivity of hafnium, too many fuel elements were loaded
into the core. Since the MITR-II is a research reactor,
it was decided to provide more space in the core for ex-
perimental facilities. Therefore the hafnium fixed absor-
bers were removed to be able to put more dummy elements in
the core.

Core IV was designed with 4 dummies and 23 fuel
elements with no fixed absorber, to be the final core
configuration for long term operation at full licensed
power of 5 MWth. Figure 1.5 shows Core IV loading at the
time of startup natural convection measurements.
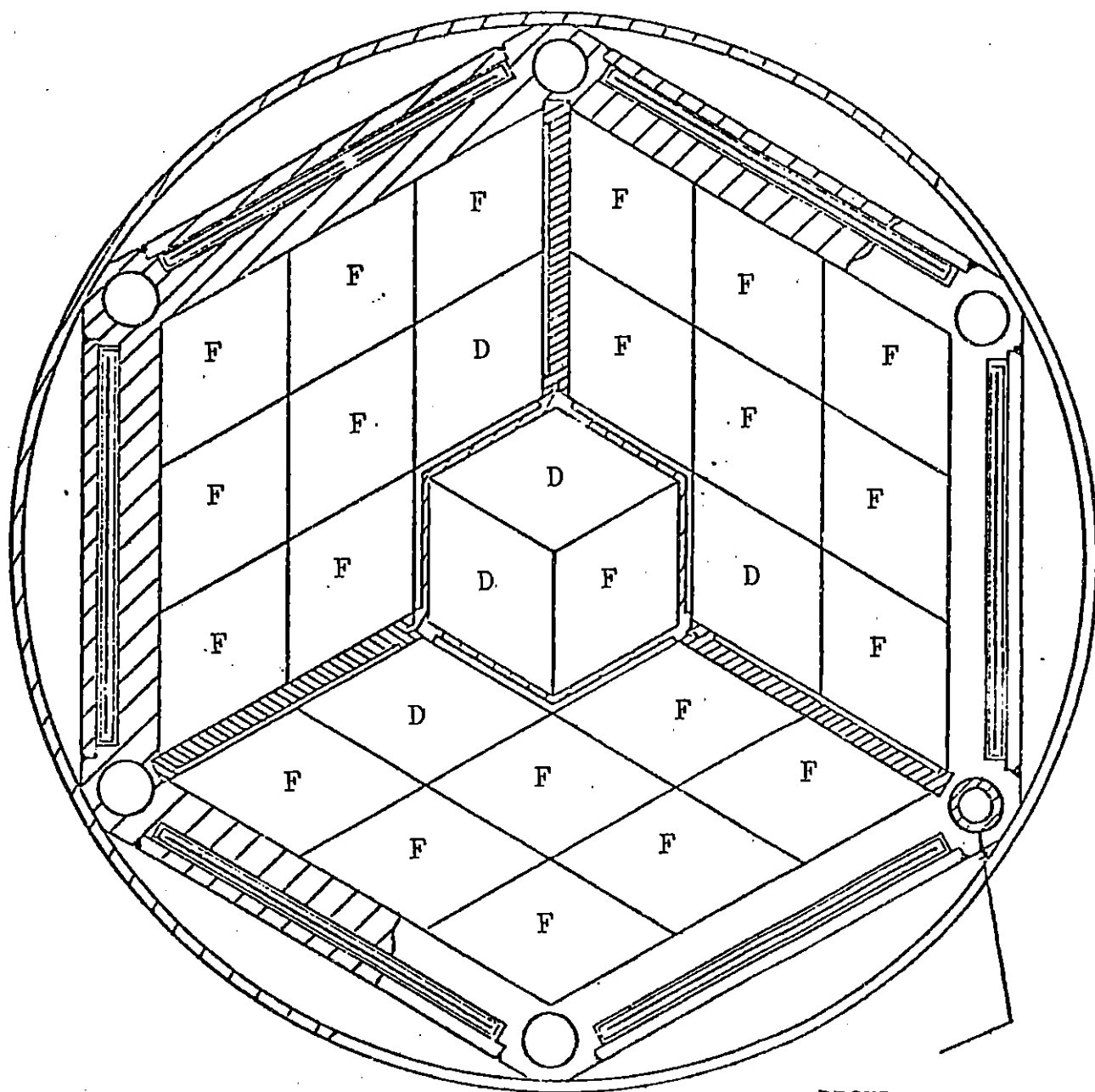
REGULATING ROD

F - Fuel Element

D - Dummy Element

FIG. 1.3 Core II with no fixed absorber
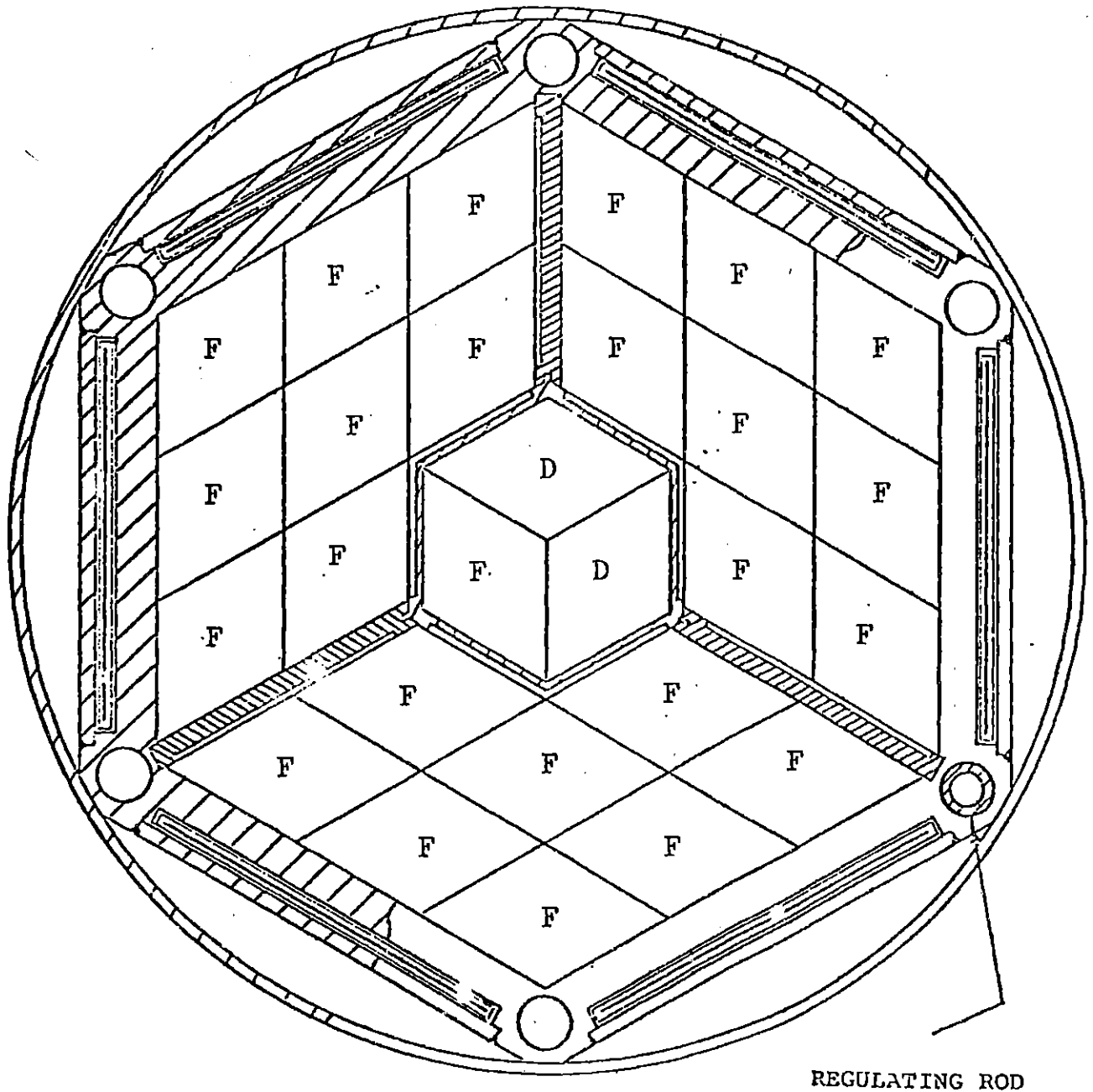
REGULATING ROD

F – Fuel Element

D – Dummy Element

FIG. 1.4 Core III with H_f as fixed absorber
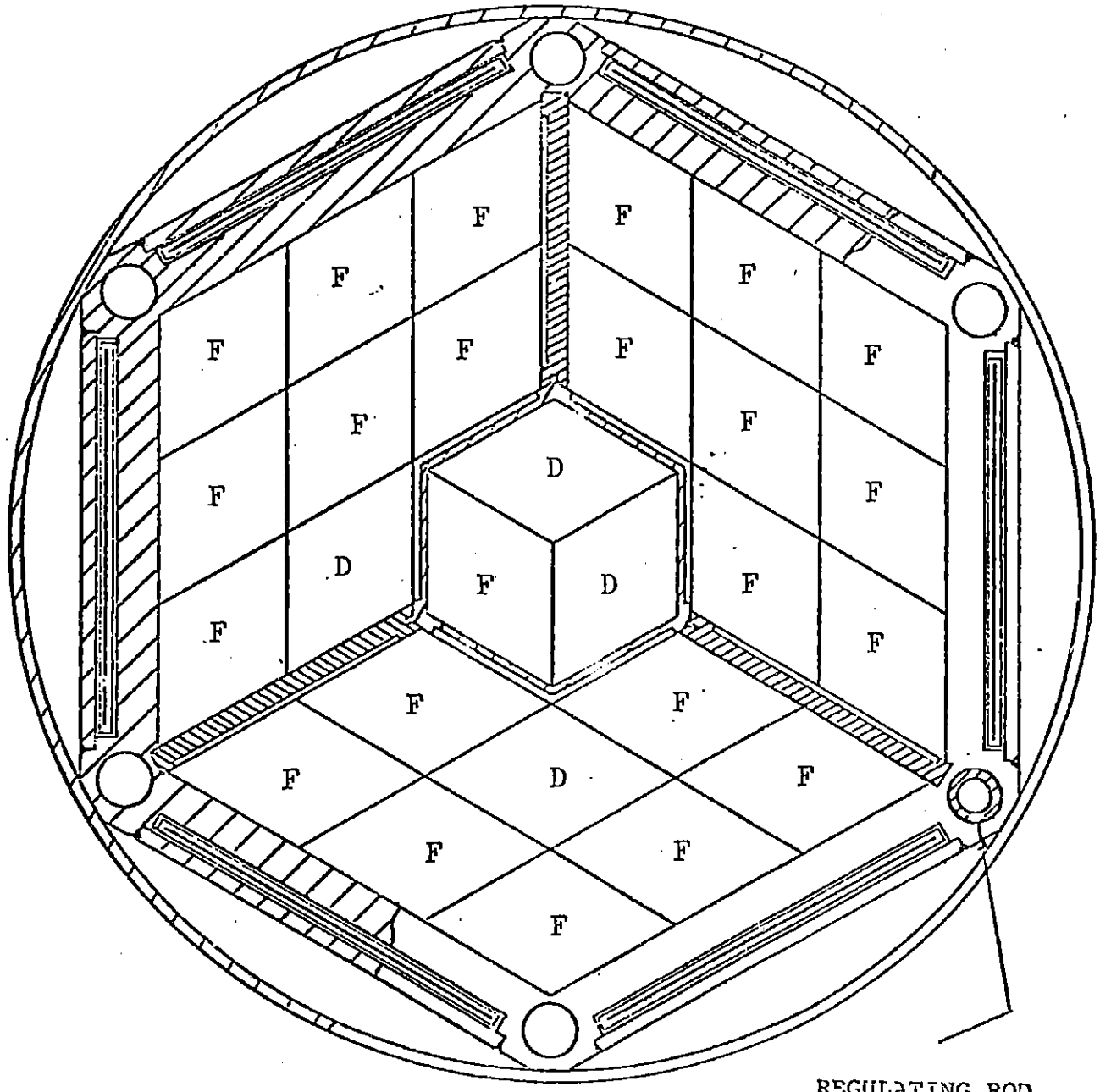
REGULATING ROD

F — Fuel Element

D — Dummy Element

FIG. 1.5 Core IV with no fixed absorber

1.3 Natural Convection Loop

A natural convective cooling loop is predicted in the
Safety Analysis Report to be produced in the case of primary
pump failure, to remove the decay heat from the core. This loop
as is shown in Figure 1.6, is maintained closed by natural
convection valves due to primary coolant pressure and opens
automatically when the flow decreases. In the case that the
pump forced flow is not considerable and natural convection
valves are opened, the decay heat released into the channels
produces a density difference between the core and the down-
commer which transfers the cold water in the lower plenum
up into the core cooling channels. As this proceeds, the heat
exchanger outlet water from the annular space between the core
tank and the core shroud mixes with the containment tank water
coming through the chimney in the upper plenum and enters the core

The chimney was installed at the top of the core to pro-
tect the shim blades from turbulency of the core outlet. It
also helps to increase the driving pressure in the natural
convection. The hot water outlet of the core goes up through
the chimney and mixes with the containment tank water before enter
ing the natural convection loop.
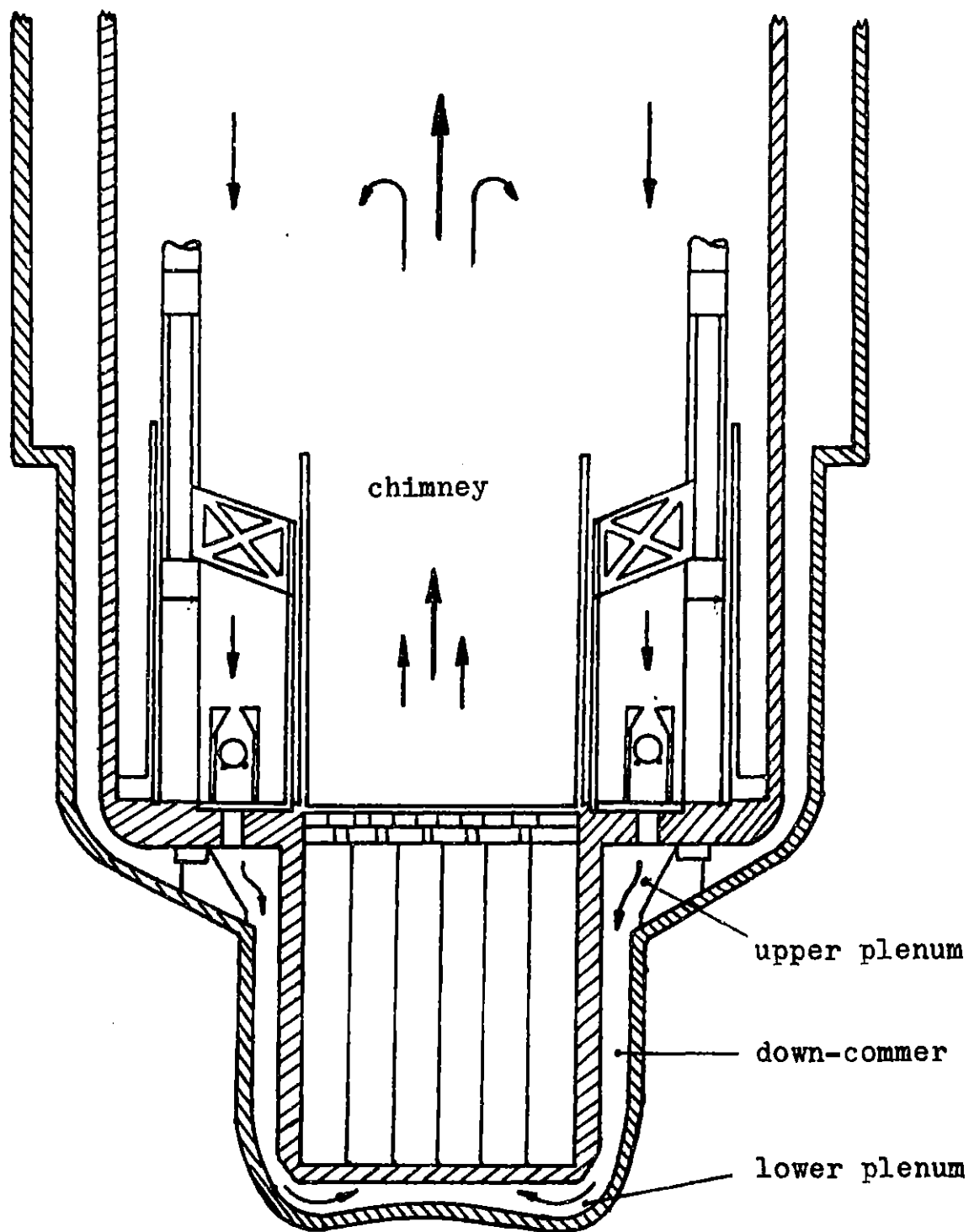
FIG. 1.6 Natural Convection Loop

CHAPTER II

REACTOR BEHAVIOR AFTER LOSS OF FLOW ACCIDENT

2.1 General

Startup Natural Convection Tests, at power level above 2 MWth, were done based on the assumption of loss of electrical power to the main panel. This loss of power would trip both primary pumps at the same time that the magnets holding the shim blades are disabled and therefore scram the reactor.

Choi (Ref.1.2) estimated the maximum release time of the magnetic clutches in the control rods to be 0.06 seconds. Weekly startup procedure sheet shows that it takes about 0.45 seconds for the shim bank to reach 80% of full insertion.

In startup natural convection tests above 2 MWth, both the minor scram and primary pump switches were pushed at the same time. Assuming a scram delay time of 0.41 seconds (Ref.1.2) it takes about 0.86 seconds from the time of scram to 80% of full insertion of the shim bank. To be more conservative a value of 0.9 seconds is assumed where in reality it takes about 0.51 seconds.

Shim bank integral reavtivity measurements shows a reactivity worth of 4.8 β for 80% full insertion of the shim bank for a critical height of 7.9 inches. This value is smaller than the individual blade worth measurements due to perturbation of shim bank on them.

Although it takes about one second to insert all the
control blades, the power does not die rapidly. After a sudden
shutdown, about 90% of the neutron population dies off in about
0.01 seconds (Ref.2.2), but only a few percent of the precursors
decay in that time. Then the rest of the neutron and precursor
population dies away with a decay period of more than 10 seconds.
This decay period depends on the half life of the longest
delayed neutron group.

Energy released from fission products in the form of
beta and gamma radiation, contributes to the energy sources after
the scram.

Decay heat from activated core materials can be considered
as one of the other shutdown energy sources.

2.2 Pump Coast-Down and Loss of Flow

The coolant flow rate during a coast-down transient was measured for MITR-I (Ref.1.1) and it was found that after about 3.25 seconds the pump flow rate was almost zero. In MITR-II the transient flow rate is larger due to the differences in core and piping design. The flow rate and pressure drop have been measured in the MITR-II by using differential pressure transmitters and a voltage recorder. These values are normalized according to the calibration curve of flow v.s. voltage, (Ref.2.3). The results are calculated at the flow meter MF-1, for reference.

It is found that in MITR-II the pump flow goes to zero after about 7.5 seconds, as shown in Fig.2.1, and pressure at MF-1 reaches infinite value after 7.0 seconds.

In order to be able to use flow rate and pressure coast-down values in calculations related to the initiation of natural convection, the following equations are used where the constants are values chosen to fit the experimental values.

$$G(t)/G(t_0) = 2.283 \exp(-0.1t) + 0.0283t - 1.283 \tag{2.1}$$

$$P(t)/P(t_0) = [0.48t + 1]/[2t + 1] \tag{2.2}$$

FIG. 2.1 Flow and Pressure at MF-1 after Pump Coast-down in MITR-II

$$\frac{G(t)}{G(0)} = 2.283\ e^{-0.1t} + 0.0283t - 1.283$$

$$\frac{P(t)}{P(0)} = \frac{0.48t+1}{2t+1}$$

Time after Loss of Power (sec.)
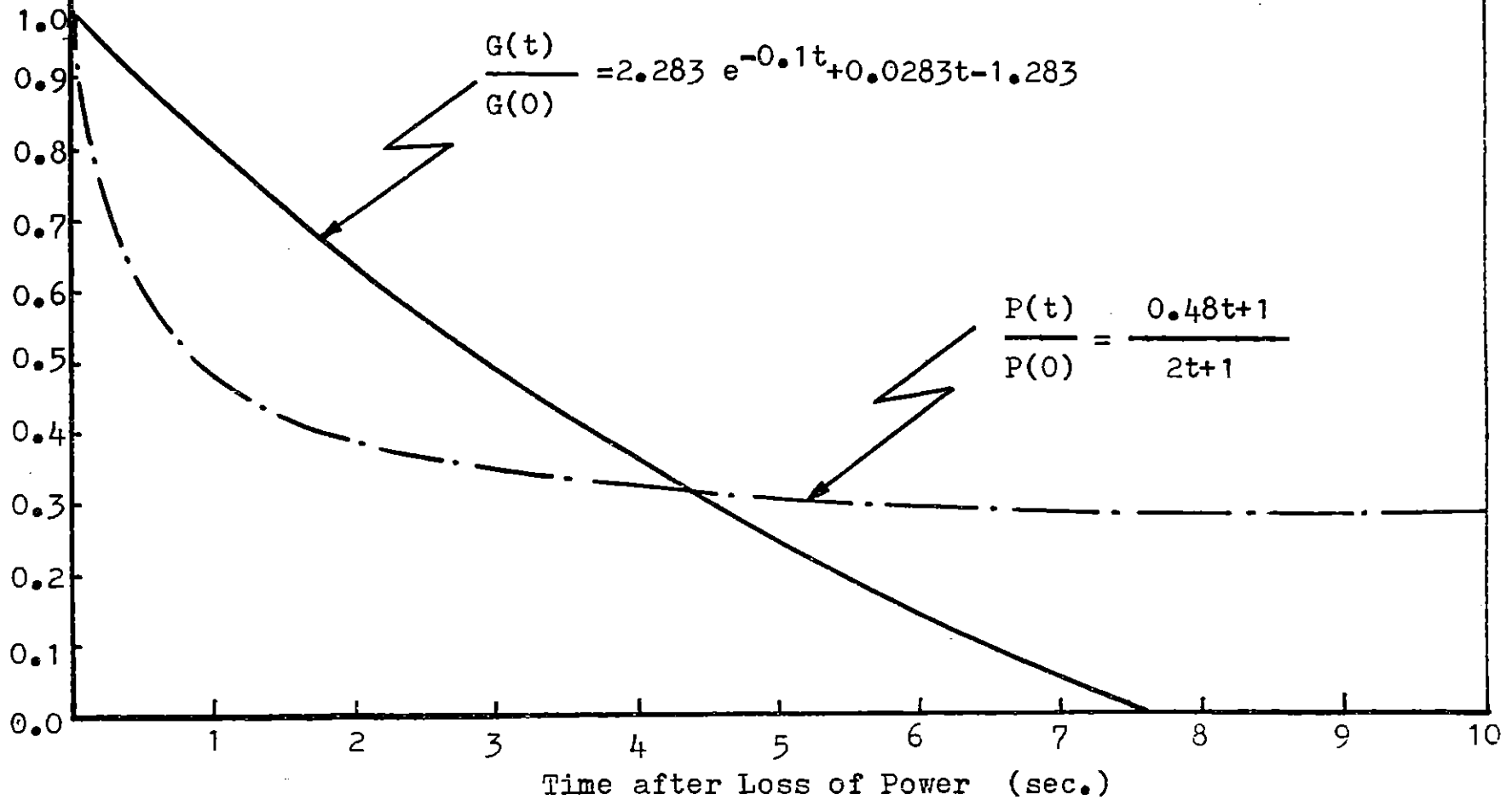
where,

        t is the time after loss of power in seconds,

        $G(t)$ and $P(t)$ are flow rate and pressure at time t
at MF-1 respectively, and

        $G(t_o)$ and $P(t_o)$ are those values at steady state condition.

It is noted that the maximum deviation from true value
is 8.5% for flow rate and 4.0% for pressure.

As the flow coasts down in the primary loop, pressure
in the upper plenum decreases to a value that balances the
pressure at the top of the natural convection valves. This valve
balancing pressure is the sum of atmospheric pressure, static
head of water in the containment tank, and pressure due to
weight of the natural convection ball. At this time the ball
drops and the pressure at the bottom of the valve exceeds the
static pressure at the top by some amount equal to the weighted
value of the ball. This causes some flow forced up through the
natural convection valves which decreases with the pressure
in the upper plenum, and stops as soon as the transient pressure
balances the static head above the natural convection valves.

The total time that this reverse flow takes is found to
be less than 0.1 seconds due to; fast pressure drop in the
upper plenum, small contribution of the balls to the static
pressure, and large pressure drop in the natural convection
valves. As will be shown by the calculations, the contribution

of the natural convection to heat transfer from the core

is not significant before the valves are opened. Even then,

the coast-down flow still remains dominant until it decreases

to a value of about 10 lbs./ft**2/seconds. Thereafter

natural convection takes over and transfers the decay   heat

from the core.

2.3 Energy Release by Delayed Neutrons

Energy released by delayed neutrons can be found by
solving the non-stationary neutron diffusion equation. If the
neutron flux in the reactor is ϕ_0 up to the moment of shutdown,
equation 2.3 will give the thermal neutron flux as a function
of time, t, after shutdown:

(Ref.2.6):

$$\phi(t)/\phi_0 = \sum_{j=0}^{m} A_j \exp(\omega_j t)$$

$$\sum_{j=0}^{m} A_j = 1 \tag{2.3}$$

$$\sum_{j=0}^{m} \lambda_i A_j / (\omega_j + \lambda_i) = 1 \qquad\qquad i = 1, 2, \ldots, m.$$

where m is the number of neutron precursors,

β_i is the fraction of the total number of neutrons
emitted from the precursor ,

$$\beta = \sum_{i}^{m} \beta_i \quad ,$$

λ_i is the decay constant for fission products of ith group,

and ω_i is the eigen value of the inhour formula.

Equation 2.3 is simplified for the cases that:

$$\rho/K_{eff} \simeq \rho \qquad \text{and} \qquad \lambda_i \ll 1/T$$

and the following equation is found:

$$\phi(t)/\phi_0 = \sum_{i=1}^{m} (\beta_i/(\rho + \beta))\exp[(-\rho/(\rho + \beta)\lambda_i t) \qquad (2.4)$$

where K_{eff} is the effective neutron multiplication factor,

     T   is the neutron lifetime in the reactor, and

     ρ is the instantaneous reactivity reduction at the moment of shutdown.

Equation 2.5 is therefore suggested (Ref. 2.7) for decay energy due to delayed nuetrons:

$$\frac{P(t)}{P_0} = \frac{\beta_{eff}}{\beta} \sum_{i=1}^{m} \left[\frac{\beta_i}{\rho + \beta_{eff}} \exp \left(\frac{-\lambda_i \rho t}{\rho + \beta_{eff}} \right) \right] \qquad (2.5)$$

Where the value for effective total delayed neutron fraction, β eff, is taken to be 0.00786 (Ref.2.1), and six delayed neutron precursors are chosen with β_i and λ_i for U-235 as shown in Table 2.1 (Ref.2.8).

The effect of delayed photoneutrons produced in the D_2O reflector, due to fission of U-235, is not considered in equation 2.5.

The half-lives and yields of photoneutrons from fission products of an atom of U-235, in an infinite medium of D_2O, is shown in Table 2.2, (Ref.2.14). Summation of the numbers presented in the last column shows that a total number of

Group	Decay constant λ_i (sec.$^{-1}$)	Yield, β_i, (nt/fiss.)
1	0.0124	0.000215
2	0.0305	0.001424
3	0.1110	0.001274
4	0.3010	0.002568
5	1.1400	0.000748
6	3.0100	0.000273

Table 2.1

Decay Constant and Yield Of the Delayed Neutrons

Table 2.2

j	Half-life	Decay con. λ_j	$\dfrac{\text{Photoneutron yield}}{22 \text{ s.delayed nt.yield}}$	$Y_j = \dfrac{\text{Photoneut.} 10^{-5}}{\text{Fission}}$
1	2.5 s	2.77×10^{-1}	0.469	158.00
2	41.0 s	1.69×10^{-2}	0.147	49.50
3	2.4 m	4.81×10^{-3}	0.0504	17.00
4	7.7 m	1.50×10^{-3}	0.0242	8.14
5	27.0 m	4.28×10^{-4}	0.0149	5.01
6	1.65 h	1.17×10^{-4}	0.0168	5.65
7	4.37 h	4.37×10^{-5}	0.00232	0.78
8	53.00 h	3.63×10^{-6}	0.00074	0.25

Sum $= 244.33 \times 10^{-5}$

Half Lives and Yields of Photoneutrons from U^{235} Fission Products in D_2O

2.44×10^{-3} photoneutrons are produced per fission of U-235. This is even less for finite system as in the case of MITR-II because of the leakage of a considerable number of photons out

Yarmen (Ref.2.14) showed that about 0.093×10^{-3} photoneutrons are generated by photons having had one and only one collision, in the time interval of 2-1000 seconds after fission, and the rest $(2.44 \times 10^{-3} - 0.093 \times 10^{-3})$ is due to those photoneutrons produced by the uncollided photons, (with an approximation of about 12%).

The threshold energy for photoneutron reaction is 2.23 Mev and the maximum photon energy in MITR-II can be assumed to be six Mev (Ref.2.13). For a uniform photon energy, the number of photoneutrons produced per second, per fission of U-235, at time t after fission, can be found in the Equation 2.6 :

$$N(t)= \sum_{j=1}^{J} Y_j \lambda_j e^{-\lambda_j \tau} \qquad (2.6)$$

where λ_j is the decay constant of the time-wise group j
  ($j=1,2,\ldots,j$), and
  Y_j is the total number of photoneutrons of group produced per fission of U-235.

Note that the total number of 2.44×10^{-3} photoneutrons per fission can be obtained by intergrating N(t) over the infinite time after fission.

The energy released by photoneutrons at time t after shutdown is therefore found from the following equation :

$$\frac{P_{ph}(t)}{P(0)} = \int_0^{t'} \left[\sum_{j=1}^{J} Y_j \lambda_j e^{-\lambda_j t} \right] dt \qquad (2.7)$$

where $P(o)$ is the steady state power, and

P_{ph} (t) is the power released by photoneutrons at time t after shutdown.

2.4 Heat Generation From Decay of Fission Products

The power emitted by fission products is evaluated in the form of a curve as a function of time after shutdown, (Ref. 2.7).

For infinite reactor operation Dudziak (Ref.2.8) fits the following equation to experimental curves :

$$\frac{P(t)}{P_o} = 5 \times 10^{-3} A t^{-a} \qquad (2.8)$$

Where t is the time after shutdown in seconds,

P (t) and P_o are the power at time t and the steady state power respectively.

The values of A and a are given as a function of time for U-235 as following :

Applicable Time Interval (Sec.)	A	a
$10^{-1} \leqslant t < 10^{1}$	12.05	0.0639
$10^{1} \leqslant t < 1.5 \times 10^{2}$	15.31	0.1807
$1.5 \times 10^{2} \leqslant t < 4 \times 10^{6}$	26.02	0.2834

The following equation is suggested when $t_o \ll t_s$:

$$\frac{P\ (t_s)}{P\ (t_o)}\ \ 5 \times 10^{-3}\ t_o\ a\ A\ t_s^{-(a+1)} \tag{2.9}$$

where t_o is steady state operational time before shutdown (sec.),

and t_s is the time after shutdown (sec.).

2.5 Heat Stored in Activated Core Materials

Aluminum is the major metal used in the core structure. It becomes radioactive and decays with emitting β and γ rays.

Choi, (Ref.1.1) derived the following equation for the decay power of activated aluminum in the core for an average thermal flux of $= 1 \times 10^{14}$ (n/cm^2 sec.).

$$P\ (t) = 1.94 \times 10^4\ e^{-0.0052t}\quad (Btu/hr)$$

Three-dimensional CITATION calculation for no fixed absorber in the core and shim bank at 7.9 inches from the bottom shows an average flux of 2.0×10^{13} (n/cm^2. sec.), in the core. This value does not change significantly for a critical shim bank height of 10 inches. The average thermal neutron flux is assumed reasonably to be 3×10^{13} n/cm^2. sec.

Therefore :

$$\frac{P(t)}{P_o} = 3.41 \times 10^{-4} e^{-0.0052t} \qquad (2.10)$$

where t is time after shutdown in seconds,

P (f)&P_o are decay power due to activated core material
and the steady state reactor power respectively.

2.6. Heat Distribution in the Core

By comparing the energy sources during reactor steady
state operation and shutdown transient condition, one will
find out that ɣ rays contribute to a larger extent in after
scram decay sources, whereas in fission 80% of the energy
comes from fission products. In other words 80% of the energy
is produced within a very short range of the source in
reactor at power. But in a shutdown reactor, due to long range
of ɣ radiation, energy production appears far from the source
and therefore has a smoothing effect on the heat flux
distribution in the core.

Since the spatial heat distribution in the core has a
relatively smooth shape, the power distribution after the
scram can be assumed to have the same shape as in the steady
state operation.

Core power distribution was first evaluated by a
finite difference diffusion code, Exterminator II (Ref.2.11),
and then by using Computer Code CITATION, (Ref.2.12). Radial
peaking factor, for the shim bank at a height of 10 inches from

the bottom was found to be 1.30 for center plate, and 1.22 for a plate at the edge of the core next to the D_2O reflector.

Removing the fixed absorbers from the core has changed the power distribution in the core.

Axial flux distribution was measured by copper wire activation analysis. Copper wires of 0.0252 inches diameter were covered with 0.01 inches clear polyolefin, (unsaturated ethylene) and placed in coolant channels between fuel plates. They were irradiated at 200 nominal watts for one hour and then left for at least one more hour for Cu^{66} to decay. The wires were scanned and activities due to Cu^{64} isotopes at various axial positions were recorded. The activities were corrected for decay and background countrate, and different irradiations were correlated to one power.

The following equation is suggested by Allen(Ref.1.4) for initial countrate calculation :

$$C_o = \frac{C_t - B}{e^{-\lambda t}} \quad \frac{SMCOB}{COB(K)} \tag{2.11}$$

where t is the time from the end of irradiation to the beginn-

ing of the count,

C_t is the raw countrate at time t,

B is the background countrate,

λ is the decay constant for Cu^{64},

SMCOB is the reference cobalt countrate from plate
scanning,

COB(K) is the cobalt foil countrate for the Kth
irradiation, and

C_o is the normalized initial countrate.

The activity induced in the copper wire was caused by
both thermal and resonance neutrons. To find the fission
rate in U^{235}, Equation 2.11 should be multiplied by a factor
f defined as :

$$f = \frac{\text{fission rate in } U^{235}}{\text{activity due to } Cu^{64}}$$

$$f = \frac{\Sigma_{f3}\,\phi_3 + \Sigma_{f2}\,\phi_2 + \Sigma_{f1}\,\phi_1}{\Sigma_{Cu_3}\phi_3 + \Sigma_{Cu_2}\phi_2 + \Sigma_{Cu_1}\phi_1} \qquad (2.12)$$

where ϕ is the neutron flux,

Σ_f is the macroscopic fission cross section for U^{235}

Σ_{cu} is the macroscopic absortion cross section for Cu, and

subscripts 3,2, and 1 refer to thermal (0.0025 ev-0.4 ev),
epithermal (0.4 ev -3 kev) and fast neutron energy group
in CITATION,respectively.

Using the folowing approximations;

$$\frac{\sigma_{Cu_1}}{\sigma_{Cu_3}} \ll \frac{\sigma_{Cu_2}}{\sigma_{Cu_3}}$$

$$\frac{\sigma_{Cu_1}}{\sigma_{Cu_3}} \simeq \frac{\sigma_{f1}}{\sigma_{f3}}$$

and since $\quad \dfrac{\sigma_{Cu}}{\sigma_{Cu_3}} > \dfrac{\sigma_{f2}}{\sigma_{f3}}\quad$,Equation 2.10 can be simplified

as follows:

$$f = 1 - \frac{\dfrac{\phi_2}{\phi_3}\dfrac{\sigma_{Cu2}}{\sigma_{Cu3}} - \dfrac{\sigma_{f2}}{\sigma_{f3}}}{1 + \dfrac{\phi_2}{\phi_3}\dfrac{\sigma_{Cu2}}{\sigma_{Cu3}}}$$

where $\quad\sigma\quad$ is the microscopic cross section, and

$$\frac{\sigma_{Cu2}}{\sigma_{Cu3}} = [\frac{[\sigma_{Cu3}]_{1/\nu \text{ resonance}} + [\sigma_{Cu3}]_{non \, 1/\nu \text{ resonance}}}{\sigma_{0 \, Cu3}}]\frac{\sigma_0 \, H_2O}{\Sigma_3^- \, H_2O}$$

and a subscript $_0$ (zero) refers to 2200 m/sec. neutron

energy group.

Substituting the values for cross sections, Equation 2.13

is found :

$$f = 1 - \frac{\dfrac{\phi_2}{\phi_3}(0.1729 - \dfrac{\sigma_{f2}}{\sigma_{f3}})}{1 + 0.1729 \dfrac{\phi_2}{\phi_3}}\qquad (2.13)$$

Table 2.3

Region	Fuel Element	σ_{f2}/σ_{f3}
1	C	0.07733
3	A	0.07711
4	A	0.09153
5	C	0.09080
6	C	0.07690
13	A	0.09130
14	C	0.09210

Ratio of Epithermal to Thermal Fission Cross section
for Different Fuel Specifications

FIG . 2.2 Core Power Distribution with Shim bank at 7.9"

Hot channel in fuel element C-13

Core average over A and C rings

Percent Power

Bottom
Top

Inches Along the Fuel Plate
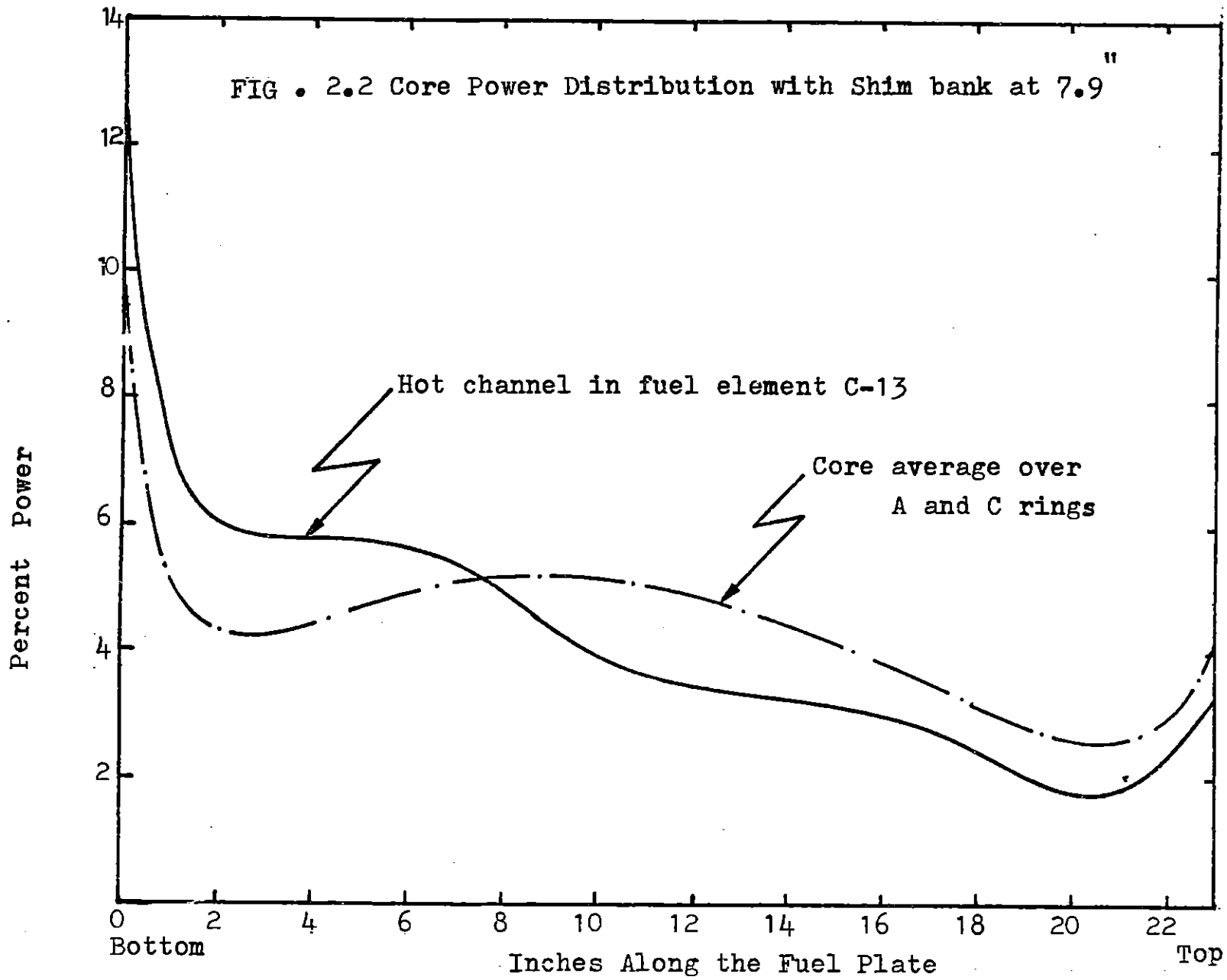
The neutron flux ratio ϕ_2 / ϕ_3 is obtained by taking
the ratio of epithermal to thermal flux at each wire position
from the three-dimensional CITATION computer calculation.
The value of $\sigma_{f2} / \sigma_{f3}$ is found from Table 2.3, where the
Region number is the one used in CITATION for fuel specification.

Figure 2.2 shows axial heat flux distribution measured
by copper wire for different heights of shim bank and different
positions in the core with no fixed absorber in the core.

2.7 Dissipation of Decay Energy in the Reactor

The three different kinds of decay energy produced
in the core after shutdown are transferred to the containment
tank by pump coastdown and natural convection flow. One
can assume that the steady state power is removed by primary
heat exchangers,i.e. the temperature in the containment
tank is the same as steady state core outlet temperature.
Therefore due to decay heat addition to the tank, the temperature
of the water increases. Although part of the energy is trans-
mitted to the outside through the reactor shielding and the
off-gas monitoring system, and since the rate of enthalpy
increase in the containment tank is slow (about 0.02 Btu/lbm
per minute) heat transfer from the tank can be neglected.
Energy dissipated in the reflector and the shielding is estim-
ated by Choi (Ref.1.1), and it is found that about 5.31% of the
fission energy is deposited in the D_2O reflector, and only

0.91% in the shielding. This value is not considerable in
the shutdown reactor. On the other hand due to high thermal
resistance of the helium gap it can be assumed that no heat
is transmitted through the gap from the relatively hot
graphite into the reflector.

Therefore after the natural convection begins and the
hot water in the tank starts flowing down into the lower
plenum, there might be some heat convection between the
down-commer and the D_2O reflector. Due to high conductivity
of the aluminum walls (188 Btu/hr/ft°F), free heat convection
can be considered between the hot water flowing down into
the down-commer and relatively stagnant flow in the D_2O
reflector tank.

In the steady state operation a pump and heat exchanger
remove the heat deposited in the reflector with a flow rate
of about 140 gpm. Heavy water enters the reflector tank
at a temperature of 36°C and leaves at about 38°C. Therefore
after scram, due to loss of electrical power, D_2O is left
enclosed between the core and the reflector tank at the
exit temperature.

Natural convection flow in the down-commer will lose
some heat by free convection to the reflector through the
core tank wall. Eckert (Ref.2.10) suggests Equation 2.1 4
for natural convection to a fluid enclosed between two
vertical walls:

$$\dot{q}'' = \frac{k_e}{b} (T_h - T_c) \qquad\qquad (2.14)$$

where $\dot{q}''$ is the average heat flow per unit time and area,

    b is the normal distance between the two walls,

    T_h and T_c are the temperatures on the hot and cold

        sides of the system, and

    k_e is equivalent heat conductivity.

The values of k_e are found experimentally and plotted versus a dimensionless factor $Gr_b Pr$, Grashof's number times Prandlt's number. For the special case of interest with :

    containment tank mixed temperature, $T_h = 125^{\circ}F$

    D_2O reflector tank outlet temperature, $T_c = 100^{\circ}F$

    reflector thickness next to the down-commer, $b=1.114$ ft.,

the ratio ke/k for heavy water reflector is found to be 1.38. Therefore the rate of heat flux transmitted to the reflector is about 10.836 Btu/ft^2/hr, or the total leakage power from the down-commer after scram is only about 33.77 watts.

CHAPTER III

THERMAL HYDRAULIC ANALYSIS IN STEADY STATE AND TRANSIENT

3.1 General

Although natural convection valves are closed in
steady state operation, the buoyancy of relatively hot water
in the core will also help to remove the heat insignificantly.

Average core outlet temperature is about 50°C at 5 MWth
steady state power and 2050 gpm flow rate. This energy is
removed from the water in two primary heat exchanges and water
enters the core at 40°C. When natural convection valves
open, a loop is produced ; cold water coming from the heat
exchangers is in one leg, and decay heat is being added
to the core coolant channels in the other leg. The density
difference between the two legs initiates a small flow
which is directly proportional to the driving force. Decay heat
addition to the core flow increases the driving force and
therefore the natural convection flow. Since shutdown energy
generation decays exponentially, a time is reached that natural
convection flow is just enough to remove the decay heat
without increasing the enthalpy. Thereafter the flow rate
decreases with decay power.

During the normal reactor operation, a flow disparity
is observed at the core inlet (Ref.1.4). This flow disparity
is more uniform during natural convection because the
down-coming flow is laminar, so each of the n, channels

should take $1/n^{th}$ of the total flow. But the flow rate in

natural convection depends on the heat flux, or in other

words , on the amount of energy released into the channel.

Eselgroth and Grifith (Ref.3.1) show that "for an array

of channels, the pressure drop across any individual channel

is independent of the flow through it" and is common to all

channels, for the case flow passing from one header to another

through n identical channels with low flow rate.

In natural convection both flow rate and pressure drop

are governed by heat flux in different channels. Therefore

if there is a uniform pressure distribution in the lower

plenum at the core inlet, right above at the core outlet,

there should be both pressure and flow distribution due to

density variation. These different temperature and flow

streams will mix due to turbulency, and a height will be reached

where there is a mixed temperature, density, and pressure.

This point can be well considered to be at the top level

of the chimney.

3.2 Conservation Equations and Their Application to Natural Convection

The natural convection loop described in the last

section, can be analyzed as a single channel. Momentum

Integral Model is applied to one dimensional transient fluid flow.

In this model, variation of mass flow rate with position

in the channel due to axial changes in density and vapor content with time is considered. Also because of small pressure difference along the core (less than 1 psia), single pressure can be used for evaluating all fluid properties (Ref.3.2).

The following equations express the conservation of mass, momentum and energy in the constant area channel with z being the axial direction from bottom to top of the core (Ref.3.2) :

$$\frac{\partial \rho}{\partial t} + \frac{\partial G}{\partial z} = 0 \tag{3.1}$$

$$\frac{\partial G}{\partial t} + \frac{\partial}{\partial z}(\upsilon G^2) = -\frac{\partial P}{\partial z} - \frac{f\upsilon G^2}{2D_h} - \rho g \tag{3.2}$$

$$\rho \frac{\partial H}{\partial t} + G \frac{\partial H}{\partial z} = (\phi+rq")/\ell_1 \tag{3.3}$$

where ϕ is fuel surface heat flux per unit time

   q"   heat generation rate per unit fuel surface area,

   r   is fraction of q" directly produced in the collant,

   ℓ_1 is the half channel thickness,

   G   is the mass flow rate per unit area,

D_h is hydraulic diameter (4 flow area/ wetted perimeter),

g is component of accelleration of gravity in the negative z direction,

P is absolute pressure and

ρ, ν, and H are thermal properties; density, specific volume and enthalpy respectively with $\rho = \rho(H)$ and $\nu = \nu(H)$.

Substituting Equation 3.3 into Equation3.1 will give a more convenient form of mass conservation :

$$\frac{\partial G}{\partial z} = -\frac{1}{\rho} \left(\frac{\partial P}{\partial H}\right) \left[\frac{\phi + rq''}{\ell_1} - G\frac{\partial H}{\partial z} \right] \tag{3.4}$$

where it is assumed that: $\partial P/\partial t = (d\rho/dH)(dH/dt)$

Momentum Equation 3.2 should be integrated over the entire loop, L, to be consistant with the assumption of single reference pressure. This yields Equation 3.5 for average mass velocity, $\bar{G}$:

$$\frac{d\bar{G}}{dt} = \frac{1}{L}(\Delta P - F) \tag{3.5}$$

where $\bar{G} = \frac{1}{L} \int_0^L Gds$

Δp is pressure difference between core inlet and outlet

F   is the total resistance to fluid flow, composed of friction, shock,elevation, and spacial accelleration portions of channel pressure drop.

Axial and radial heat conduction in the fuel plates are neglected. All the energy is assumed to be deposited in the coolant because of small thickness and high conductivity.

Steady State Solution - Conservation equations for steady state condition can be obtained from Equations 3.1 to 3.3:

$$\partial G/\partial z = 0 \tag{3.1a}$$

$$\frac{\partial}{\partial z}(\nu G^2) = -\frac{\partial P}{\partial z} - \frac{f\nu G^2}{2D} - \rho g \tag{3.2a}$$

$$G\frac{\partial H}{\partial z} = \frac{\phi + rq''}{\ell_1} \tag{3.3a}$$

where all the parameters were defined before.

Mass conservation will give constant flow rate through the channels which are forced by primary pumps at G_o lbm/ft^2/sec.

Application of first order forward difference method
to energy equation gives enthalpy at every mesh point, j,
knowing the steady state core inlet enthalpy, H_1:

$$H_{j+1} = H_j + \frac{Q_{j+1/2}}{\ell_1 G_0} \Delta Z_j$$

where ΔZ_j is the selected mesh distance, and

$$Q_{j+1/2} = 1/2 \, (\phi_{j+1} + \phi_j) + 1/2[(rq'')_{j+1} + (rq'')_j]$$

then the fuel wall temperature can be found directly from
enthalpy as following :

$$T_{w_j} = H_j/Cp_j + \phi/h_j$$

where h_j and C_{p_j} are heat convection coefficient and specific
heat at constant pressure, and they are evaluated as functions of
enthalpy at mesh point j. In appendix A the values for C_p are
normalized to the constant pressure specific heat at the
enthalpy corresponding to 100 $^\circ F$. Therefore wall temperature
is found in $^\circ F$ from Equation 3.6, where H; (Btu/lbm), C_p; (Btu/lbm $^\circ F$)
and ϕ and h are evaluated in corresponding dimensions:

$$T_{w_j} = \frac{1}{Cp_j} \, (H_j - 68.05) + \phi_j/h_j + 100^\circ F \qquad (3.6)$$

Determination of Time-Step Size - To proceed the calculations
in transient from known values
at time t^i to unknowns at t^{i+1}, a correct evaluation of time
step $t^i = t^{i+1} - t^i$ should be made.

Minimum fluid transport time is determined by :

$$\Delta t_{tr}^i = \min_{j=1 \text{ to } N} \left[\frac{\Delta Z_j (\rho_j^i + \rho_{j-1}^i)}{(G_j^i + G_{j-1}^i)} \right] \tag{3.7}$$

where this quantity differs from time-step to time-step in transient calculations.

The time-step size will finally be chosen the smaller value of Equation 3.7 and the specified time interval t_o.

Transient Enthalpy Calculation - Having the time-step size, the enthalpy at the advanced time may be determined by applying any finite difference method to Equation 3.3. Integration of this equation, using the Cuachy polygon formula (3.4), will give the following three-point equation :

$$H_j^{i+1} = H_j^i - \alpha_{j-1/2}^i (H_j^i - H_{j-1}^i) + 2\Delta t^i Q_{j-1/2}^i / \rho_{j-1/2}^i \tag{3.8}$$

where
$$
\left.
\begin{aligned}
G_{j-1/2}^i &= \tfrac{1}{2} (G_j^i + G_{j-1}^i) \\
\rho_{j-1/2}^i &= \tfrac{1}{2} (\rho_j^i + \rho_{j-1}^i) \\
Q_{j-1}^i &= \frac{1}{2\ell_1} (\phi_j^i + \phi_{j-1}^i) + \frac{1}{2\ell_1} [(rq'')_j^i + (rq'')_{j-1}^i] \\
\alpha_{j-1/2}^i &= G_{j-1/2}^i \Delta t^i / \rho_{j-1/2}^i \Delta Z_j^i
\end{aligned}
\right\} \tag{3.9}
$$

For the first node, H_1 is determined from down-commer enthalpy in pump coastdown or mixed containment tank enthalpy calculation in natural convection as is described in appendix A. This method, known as characteristic explicit method, is stable for positive and negative flow rates, and values of α such that $|\alpha| \leq 1$. The characteristic values of α for natural convection are less than 0.2.

The wall temperature can be found from energy balance between the fuel plate and fluid enthalpy. This allows the fuel plate to be an energy sink in some region, usually in the top of fuel, where the heat flux is small. Normalizing the constant pressure specific heat to enthalpy at $100°F$, the fuel wall temperature may be found from Equation 3.10 :

$$T_{wj}^i = [H_j^i - 68.05]/Cp_j^i + \phi_j^i/h_j^i + 100°F \qquad (3.10)$$

where $\phi_j^i = q_j^i/\gamma_{ej}^i = \dfrac{\text{heat generation rate per unit length}}{\text{effective fuel plate parameter}}$, and

γ_{ej}^i = (base channel perimeter covered by fins) x
(fin effectiveness)

Evaluation of Transient Flow- The total fluid resistance in
the natural convection loop, shown
as F in Equation 3.5, may be decomposed in terms as following;

$$F = \sum_{loop} K\,\bar{G}^2/2\rho \;+\; \sum_{loop}(1-\sigma^2)\bar{G}^2/2\rho \;+\; \oint \frac{f\bar{G}^2}{2D\rho}\,ds \;+\; \oint \rho g ds \qquad (3.11)$$

where the terms on the right hand side are recognized as shock,
spacial acceleration, friction and elevation pressure drop in the
loop. K is loss coefficient, σ is the area ratio (σ < 1) at cross-
sectional area changes, and f is Darcy friction factor.

In steady state and pump coast-down, ΔP in Equation 3.5 is
the pressure drop forced in the loop by primary pumps. In natural
convection there is no hydraulic force applied to the loop, therefore
$\Delta P=0$. The main driving force to natural convection flow is the
density difference between the two legs, namely down-commer and
core coolant channels. This is included in the last term shown in
Equation 3.11. Expansion of elevation pressure drop over the loop
gives:

$$\oint \rho g ds = \int_{core} \rho g dz + \int_{tank} \rho g dz + \int_{chim} \rho g dz + \int_{d.c.} \rho g dz$$

$$= -\int_0^\ell (\rho_{d.c.} - \rho_{core})g dz + \int_0^h (\rho_{chim} - \rho_{tank})g dz$$

Where l is the height of the core and h is the one of the chimney. Average flow rate in the loop can now be evaluated in terms of four different components of the loop. Assuming that no heat is transferred to or from the water in the containment tank and chimney, average flow rate in this part of the loop remains constant. For the core and down-commer it can be evaluated as follows:

$$\bar{G} = \frac{1}{2\ell}[\int_0^\ell Gdz + \int_\ell^0 G(-dz)]= \frac{1}{\ell} \int_0^\ell Gdz$$

Substitution into Equation 3.5 gives the following:

$$d\bar{G}/dt = (1/L) [\int_0^\ell (\rho_{D.C.} - \rho_{core})gdz + \int_0^h (\rho_{ch} - \rho_{tank}) gdz]$$

(3.12)

$$- [(\int K(G^2/2\rho)ds + \int(1-\sigma^2)(G^2/2\rho)ds + \int(fG^2/2D\rho)ds)_{core}$$

$$+ (\Sigma K\bar{G}^2/2\rho + \Sigma(1-\sigma^2)\bar{G}^2/2 + \Sigma(f\bar{G}^2/2D\rho)_{d.c.}]$$

Equation 3.12 simply states that the rate of change of average flow in the natural convection loop is equal to the difference between driving force; density difference between down-flow and up-flow,and the total pressure loss in the loop. In finite difference form Equation 3.12 may be written as follows:

$$\bar{G}^{i+1} = \bar{G}^i + \Delta t^i \psi^i$$

(3.13)

where ψ^i is the function on the right hand side of Equation 3.12 evaluated at the conditions at time i.

The finite difference solution of Equation 3.4 can be shown as:

$$G_j^{i+1} = \lambda_j^{i+1} \, G_{j-1}^{i+1} + \beta_j^{i+1} \qquad\qquad (3.14)$$

where it is assumed that

$$
\left.\begin{aligned}
(d\bar{\rho}/dH)_{j-\frac{1}{2}}^{i+1} &= [(\bar{\rho}_j - \bar{\rho}_{j-1})/(H_j - H_{j-1})]^{i+1}\\[2ex]
A_{j-\frac{1}{2}}^{i+1} &= (d\bar{\rho}/dH)_{j-\frac{1}{2}}^{i+1} \; [(H_j - H_{j-1})/\rho_{j-\frac{1}{2}}]^{i+1}\\[2ex]
\lambda_j^{i+1} &= (2 + A_{j-\frac{1}{2}}^{i+1})/(2 - A_{j-\frac{1}{2}}^{i+1})\\[2ex]
\beta_j^{i+1} &= 2(d\rho/dH)_{j-\frac{1}{2}}^{i+1} \; Q_{j-\frac{1}{2}}^{i+1} \; \Delta z \; /\rho_{j-\frac{1}{2}}^{i+1} \; (2 - A_{j-\frac{1}{2}}^{i+1})
\end{aligned}\right\} \qquad (3.15)
$$

and the other notations are defined in Equation 3.9.

For determination of individual mass velocity values at the advanced time interval, (i + 1), from the channel average flow rate given by Equation 3.13, Equation 3.14 may be rewritten as :

$$G_j^{i+1} = \gamma_j^{i+1} \, G_0^{i+1} + \delta_j^{i+1} \qquad\qquad (3.16)$$

where $\qquad \gamma_0^{i+1} = 0 \qquad , \qquad \delta_0^{i+1} = 0$

and $\quad \gamma_j^{i+1} = \lambda_j^{i+1} \gamma_{j-1}^{i+1} , \; \delta_j^{i+1} = \lambda_j^{i+1} \delta_{j-1}^{i+1} + \beta_j^{i+1}$

In addition let:

$$\bar{\gamma}^{i+1} = \frac{1}{2\ell} \sum_{j=1}^{n} \Delta z_j \; (\gamma_j^{i+1} + \delta_{u-1}^{i+1})$$

$$\bar{\delta}^{i+1} = \frac{1}{2\ell} \sum_{j=1}^{n} \Delta z_j \; (\delta_j^{i+1} + \delta_{j-1}^{i+1})$$

Then

$$G_0^{i+1} = (1/\bar{\gamma}^{i+1})(\bar{G}^{i+1} - \bar{\delta}^{i+1})$$

$$(3.17)$$

and $\;G_j^{i=1}\;$ may be found by substitution of Equation 3.17 into Equation 3.16, or resubstitution into Equation 3.14.

Stepwise procedure for transient calculation can be summerized in a flow chart as shown in Fig. 3.1.

3.3 Containment Tank Mixed Temperature Evaluation

It was shown before that it takes about 0.41 seconds from the initiation of scram signal until the control rods start dropping. During this time interval the reactor is operating at full power, but the pump coast-down has already started and flow is decreasing. Therefore the core outlet temperature increases to a maximum

FIG. 3.1 Summary of Transient Calculation

```
┌─────────────────────────┐
│ Steady State Calculat    │
│ -ion :given flow rate    │
│ , G_j^i , find enthalpy  │
│ and wall temperature     │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Pump coast-down ;        │
│   given G and   P        │
│   Eq.(3.8) ⟹ H           │
│   Eq.(3.10) ⟹ T_w        │
└─────────────────────────┘
            │
            ▼
      ( Natural Conv. )  ◄──────────────┐
            │                           │
            ▼                           │
┌─────────────────────────┐            │
│ Eq.(3.8) ⟹ H_j^{i+1}     │            │
└─────────────────────────┘   ┌──────────────────────┐
            │                 │ Knowing values at     │
            ▼                 │ (i+1),driving force   │
┌─────────────────────────┐  │ and pressure drop     │
│ Eq.(3.10) ⟹ T_wj^{i+1}   │  │ in the loop is        │
└─────────────────────────┘  │ found  for time       │
            │                 │ step (i+1).           │
            ▼                 └──────────────────────┘
┌─────────────────────────┐            │
│ Eq.(3.13) ⟹ G^{i+1}      │            │
└─────────────────────────┘            │
            │                           │
            ▼                           │
┌─────────────────────────┐            │
│ Eq.(3.17) ⟹ G^{i+1}      │            │
└─────────────────────────┘            │
            │                           │
            ▼                           │
┌─────────────────────────┐            │
│ Eq.(3.16) ⟹ G_j^{i+1}    │            │
└─────────────────────────┘            │
            │                           │
            ○───────────────────────────┘
            │
         ( OUT )
```
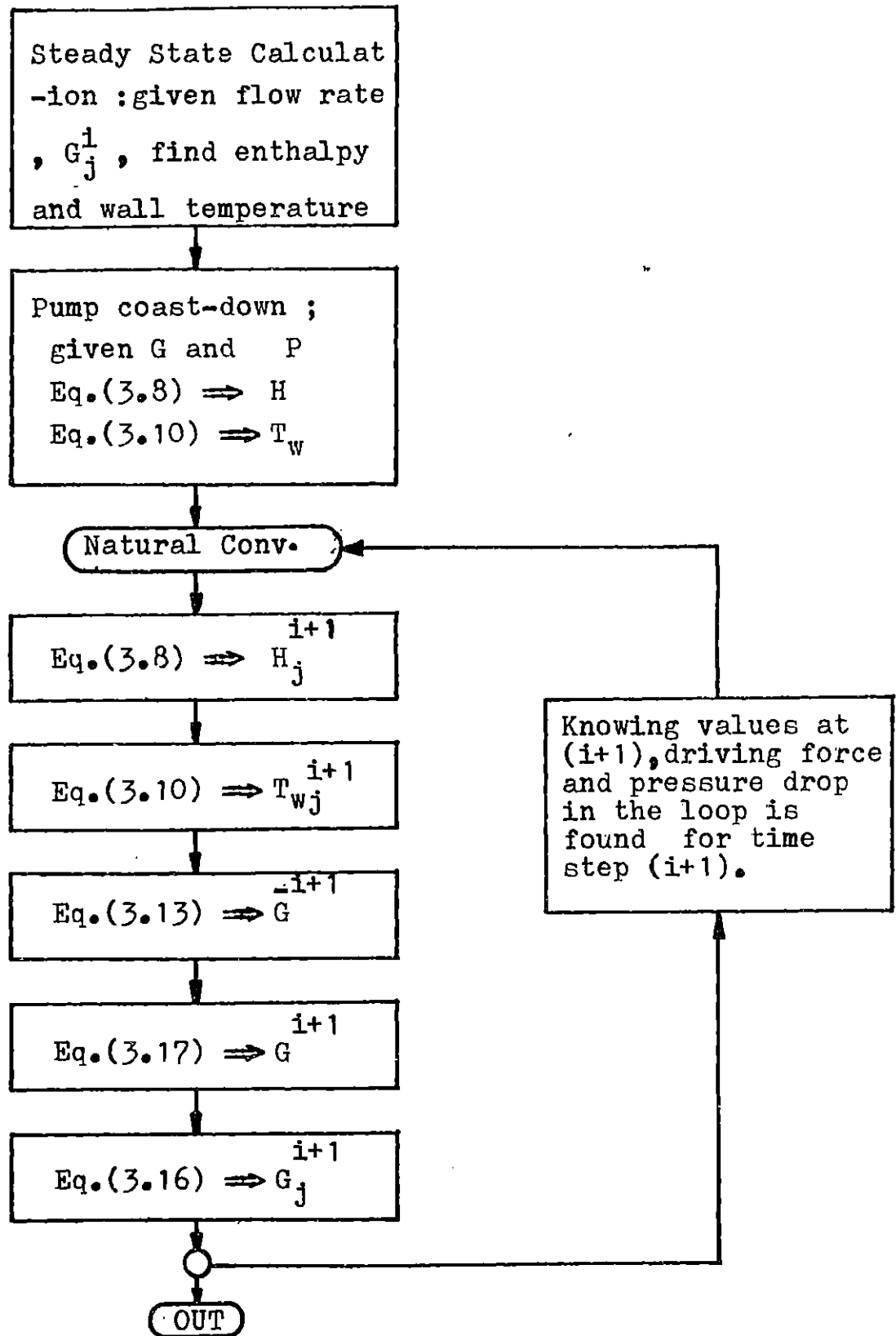
FIG. 3.1 Summary of Transient Calculation

and then decreases rapidly due to scram. As the decay heat is built
up in the core, the coolant temperature increases to a point that
natural convection flow can remove all the energy deposited in the
core. The outlet temperature decreases then with decay of shutdown
energy.

The reactor containment tank can be divided into two portions;
the shroud, and chimney plus the upper part tank. In steady state
operation both parts can be considered to be at the core average
outlet temperature. At this time the down-commer has the same temper-
ature as the heat exchangers outlet, namely 40°C. With the start
of transient, an average tank mixed temperature, or enthalpy, can be
found at any time. It may be assumed that the core outlet is mixed with
the latter part of the containment tank all at once, This is of course
conservative, but in reality, hot water moves up gradually in the
shape of a mushroom. If the water level in the tank remains constant,
from mass conservation, the amount of hot water entering the tank
is equal to the amount leaving the down-commer to the lower
plenum and into the core. From energy conservation the following
equation can be written:

$$H_{mix}^{i+1}\bar{\rho}^i\,V_t = H_{NM}^{i+1}\dot{m}^{i+1}\Delta t^i + H_{mix}^i\bar{\rho}^i\,V_t - H_{mix}^i\dot{m}^{i+1}\,\Delta t \qquad (3.18)$$

where $\quad \bar{\rho}^i = \rho(H_{mix}^i)\quad$ is the density of water at tank mixed enthalpy;

H_{mix}^i

H_{NM}^{i+1} is core average outlet enthalpy at time t ,

V_t is volume of the chimney plus upper tank, and

$\dot{m}^{i+1}$ is the mass flow rate at the core outlet

                at time .

Equation 3.18 can be written in a more convenient form:

$$H_{mix}^{i+1} = H_{mix}^i + [\dot{m}^{i+1}\Delta t/\bar{\rho}^i V_t](H_{NM}^{i+1} - H_{mix}^i) \qquad (3.19)$$

At the time that natural convection begins the down-commer,
from upper plenum to lower one,has the same temperature as the heat
exchangers outlet, and the water in the shroud may be assumed to
have the same temperature as the containment tank at steady state
operation. As soon as natural convection begins, some of the cold
water in the lower plenum moves up into the core, and some relatively
hot water from the tank enters the shroud. This goes on continuously
with time until some time, t_1, all the cold water is removed from
the down-commer and the first wave of hot water enters the core.
At some later time, t_2 , the first containment tank transient
mixed enthalpy will arrive at the bottom of the core. Therefore
the core inlet enthalpy is constant and has the same value as
heat exchangers outlet for t_1 seconds after natural convection
begins, and from time t_1 until t_2 it is constant and equal to
the steady state core outlet temperature. Thereafter, depending
upon the natural convection flow rate,containment tank mixed enthalpy

calculated at any time, may enter the core at some later time t_2. This depends upon the relative mass velocity leaving the core, G_{NM}^{i} and the one which left the core some time ago whose mixed tank enthalpy is now entering the lower plenum, G_{NM}^{i-m}.

3.4 Onset of Nucleation Boiling and Two Phase Flow

Water coming from the heat exchangers in steady state operation is very much subcooled and its temperature is still far below saturation when it leaves the core. Therefore the only time that boiling may occur is when pump flow is lost and water temperature might exceed saturation condition. Because of relatively larger heat flux at the lower part of the fuel plates, nucleation boiling might start on the channel wall if the fuel wall temperature reaches saturation. Even then, fully developed subcooled boiling does not begin immediately. A region of "partial boiling" exists between the subsaturation condition and fully developed subcooled boiling. Fig. 3.2 shows qualitative relationship between surface heat flux and wall temperature in different zones, (Ref. 3.5). For constant inlet subcooling, the relationship between wall temperature T_w and surface heat flux , q", will follow the line AB in single phase liquid and then BC' until the first bubbles nucleate at C'. Then the surface temperature drops immediately to C and then further increase in q" follows the line CDE. A higher degree of superheat is neccessary to initiate the first bubble
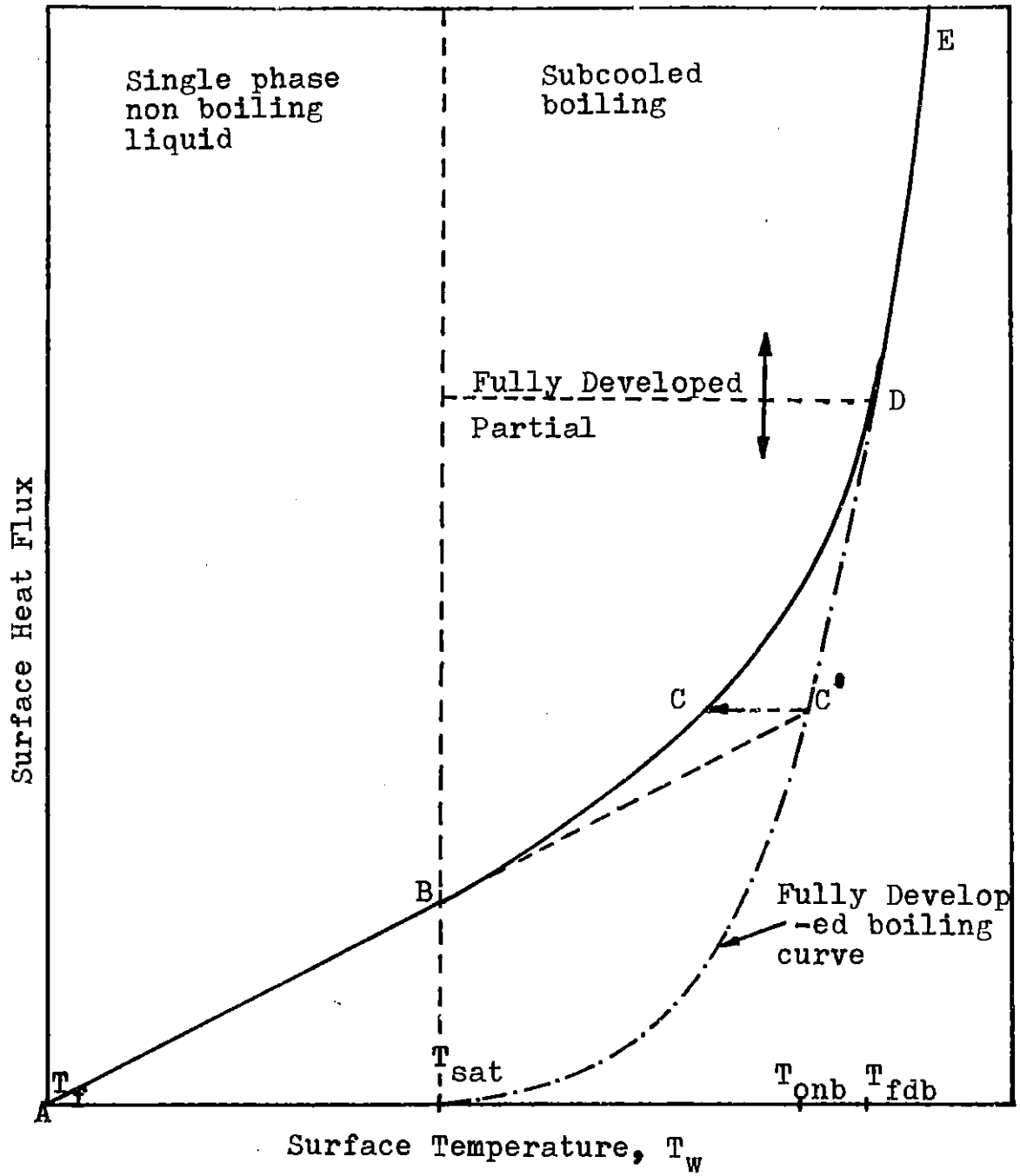
FIG 3.2 Boiling Phenomena in Convective Heat Transfer

nucleation at a given heat flux, than indicated by the curve BCD.

Bergles and Rohsenow (Ref.3.6) suggested the following equation for experimental data for water over the pressure range 15-2000 psia:

$$\phi_{ONB} = a(\Delta T_{sat})^b_{ONB} \qquad\qquad (3.20)$$

where ϕ_{ONB} is the surface heat flux for onset of nucleation boiling, $Btu/ft^2/sec$.

$(\Delta t_{sat})_{ONB}$ is the degree of superheat for wall temperature at the initiation of boiling, $^\circ F$, and

a and b are given as functions of pressure, in psia:

$$a = 4.33 \times 10^{-3} \, p^{1.156}$$
$$b = 2.30 \, / \, p^{0.0234}$$

Natural convection tests showed that in pump coast-down even at the peak value the fuel surface,or channel bulk temperature, does not reach the saturation point if all the natural convection valves are open to flow. It will be seen in Chapter V of this work, that the first peak temperature,which occurs at about 30 seconds after the accident, all the temperatures are still subcooled and no boiling is predicted. Analytical calculations show that for 5 MWth steady state power and $40\,^\circ C$ core inlet, the maximum bulk temperature in the hot channel will not reach saturation point even if one of the natural convection valves remains closed.

Two phase flow is analyzed in more detail in Appendix D for long term transients after loss of flow accidents due to pump trip.

3.5 Heat Transfer Coefficient in Laminar and Turbulent Flow

The best known and most widely used correlation for heat convection coefficient in turbulent regeme is Dittus-Boelter equation (Ref.3.7):

$$Nu = 0.023Re^{0.8}Pr^{0.4}, \quad \text{for} \quad Re \geq 4000 \tag{3.21}$$

where all the physical properties in dimensionless numbers are evaluated at the bulk temperature, and

$Nu = hD/k$

$Re = GD/\mu$

$Pr = \mu Cp/k$

h is heat transfer coefficient
D is hydraulic diameter of the coolant channel
k is thermal conductivity of the coolant,
G is mass velocity,
μ is absolute viscosity, and
C_p is constant pressure specific heat.

For laminar flow a variety of theoretical relationships are available. Rohsenow and Choi (Ref.3.8) recommend a constant value of 7.0 for Nusselt number, for laminar flow in rectangular channel with aspect ratio of 25. Aspect ratio is the ratio of the larger to the smaller side of the channel.

$$Nu = 7.0 \quad \text{for} \quad Re \leq 2300 \tag{3.22}$$

The other empirical equation based on experimental data (Ref.3.5) takes into account the effect of varying physical properties across the flow stream and the influence of free convection.

$$hD/k_f = 0.17 \ [GD/\mu_f]^{0.33}[Cp\mu/k]_f^{0.43}[Pr_f/Pr_w]^{0.25}[D^2\rho_f^2 g\beta\Delta T_f/\mu_f^2]^{0.1}$$

$$(3.23)$$

$$Re \ < \ 2000$$

where β is coefficient of expansion, and subscripts f and w
refer to evaluation of physival properties at film or wall
temperature respectively. Film temperature is defined to be the
average of wall and bulk temperature. To be more conservative,
the smaller values of Equations 3.22 and 3.23 can be used in
calculations.

In the intermediate transition area, $2300 < R_e < 4000$,
a linear interpolation on R_e is made between the turbulent and
laminar values of heat transfer coefficient.

To be more conservative the entrance effect on the heat
coefficient is ignored.

3.6 System Geometry

Primary coolant coming from heat exchangers join into
an 8" diameter pipe and after passing through a flow meter (MF-1)
enters the reactor tank at the top of the core shroud Fig .3.3 .
Flow cross-sectional area at core shroud is 3.648 sq.ft.,
and it becomes smaller to 1.193 sq.ft.. Primary water then
enters the upper plenum, whose average area and volume is estimated
to be about 2.206 ft^2 and 0.2637 ft^3 respectively. The down-
commer has an average flow area of 0.31 ft^2 for a height of
about 2.026 ft. The equivalent diameter of the down-commer
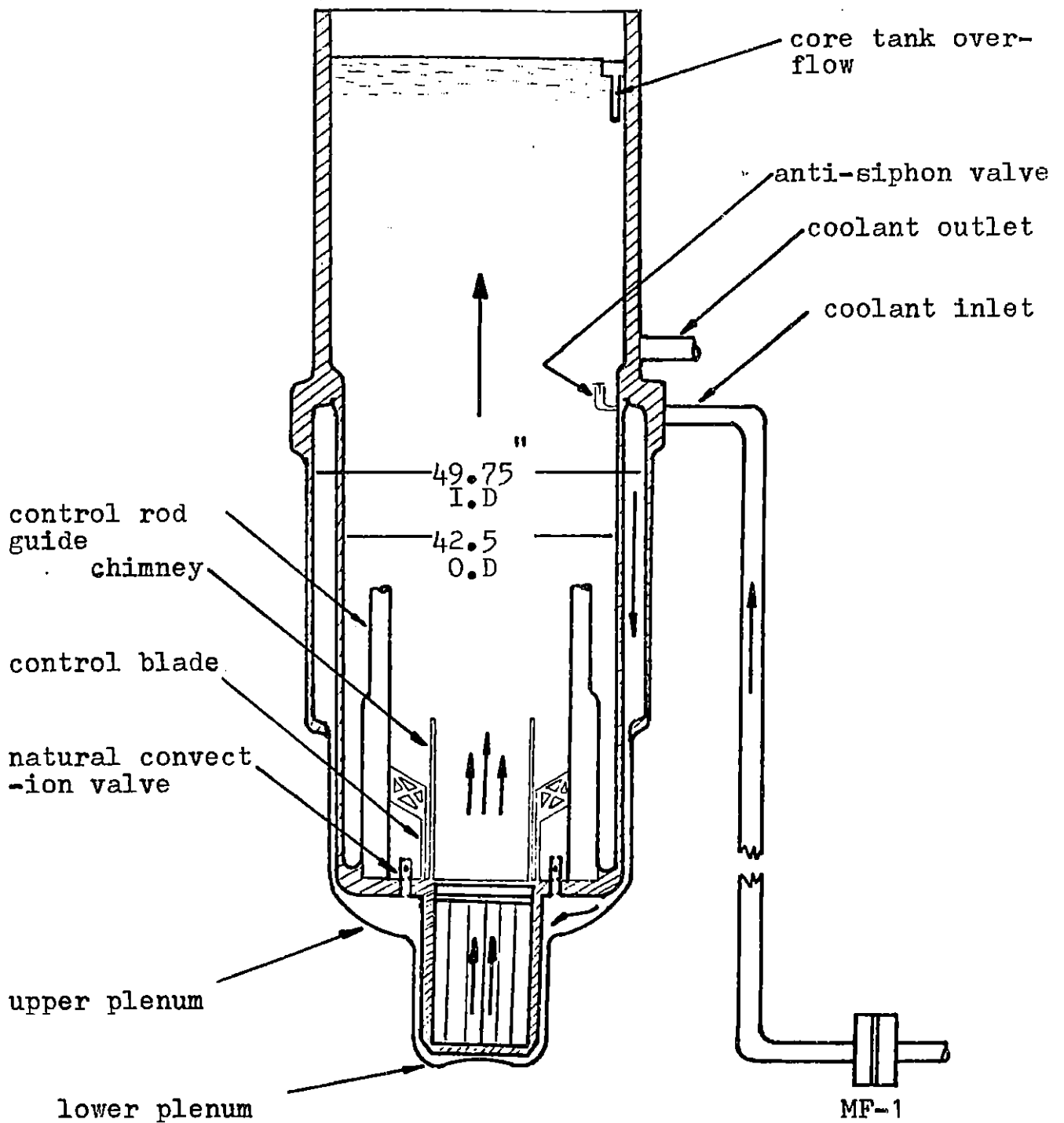
FIG. 3.3 Core Cooling in Steady State Operation

based on the definition of:

$$D_e = 4 \times \text{flow area/wetted perimeter}$$

is 0.13 ft.

Core housing has 27 spaces for orthorhombic fuel assemblies
with perpendicular distance between the flats of 2.405 inches.
Each fuel element has 15 cooling channels with aspect ratio of 25,
flow area per channel of 0.00141 ft^2, and hydraulic diameter of
0.00734 ft. The core channel length is 23 inches, of which only
22.375" is heated. The distance from channel exit to hold down
plate exit is 3.125 inches.

The core outlet is guided through a rectangular shaped
chimney of 2.5 ft. height to prevent the shim blades from turbulency
at the top of the core. The volume of the water between the fuel
storage rack and chimney is estimated to be about 5.145 cu.ft.

Total volume of the containment tank, with water level
at the over flow-height is 106.9 ft^3 which includes the volume
behind the chimney. In steady state operation, the water level
in the tank is controlled by the over-flow pipe which keeps
it at 3" below the top of the tank, or 10.04 ft. above the hold-
down plate. The heat transfer area of fuel plates in MITR-II
is increased by building longitudinally-milled square fins on
both sides of them. These fins are 10 mills height with a repeat-
ing cycle of 0.02 in.. To introduce the increase in area to heat
transfer, a "surface effectiveness" factor is defined as the ratiio

of heat dissipated by the finned surface to heat transferred by
an unfinned surface at the same wall temperature, convection coef-
ficient and back area. Taborda (Ref.3.9) gives the following
equation for heat effectiveness:

$$\eta_0 = (A_{fb}/A_B) + (A_{ft}/A_B)[\tanh m(t + w/2)/m(t + w/2)] \tag{3.24}$$

where

t is the height of the fin (0.01 in.)

w is the fin width (0.01 in.),

A_B is the repeating base area,

A_{ft} is the total fin surface area,

A_{fb} is the fin base area, and

$m = \dfrac{2h}{kw}$ for long fins, with h and k convection

and conduction heat transfer coefficient, respectively. The averag
value found for surface effectiveness using Equation 3.24 is
about 1.95, which is larger than the conservative constant value
of 1.486 used in SAR (Ref.2.1).

3.7 Friction Coefficients and Form Factors

Final design of the natural convection valve is composed
of an aluminum housing and a stainless steel ball to reduce the
chance of remaining closed after pump coast-down, Fig.3.4. The
resistance made to natural convection flow is a function of
mass velocity. Based on this the total height of the valve is
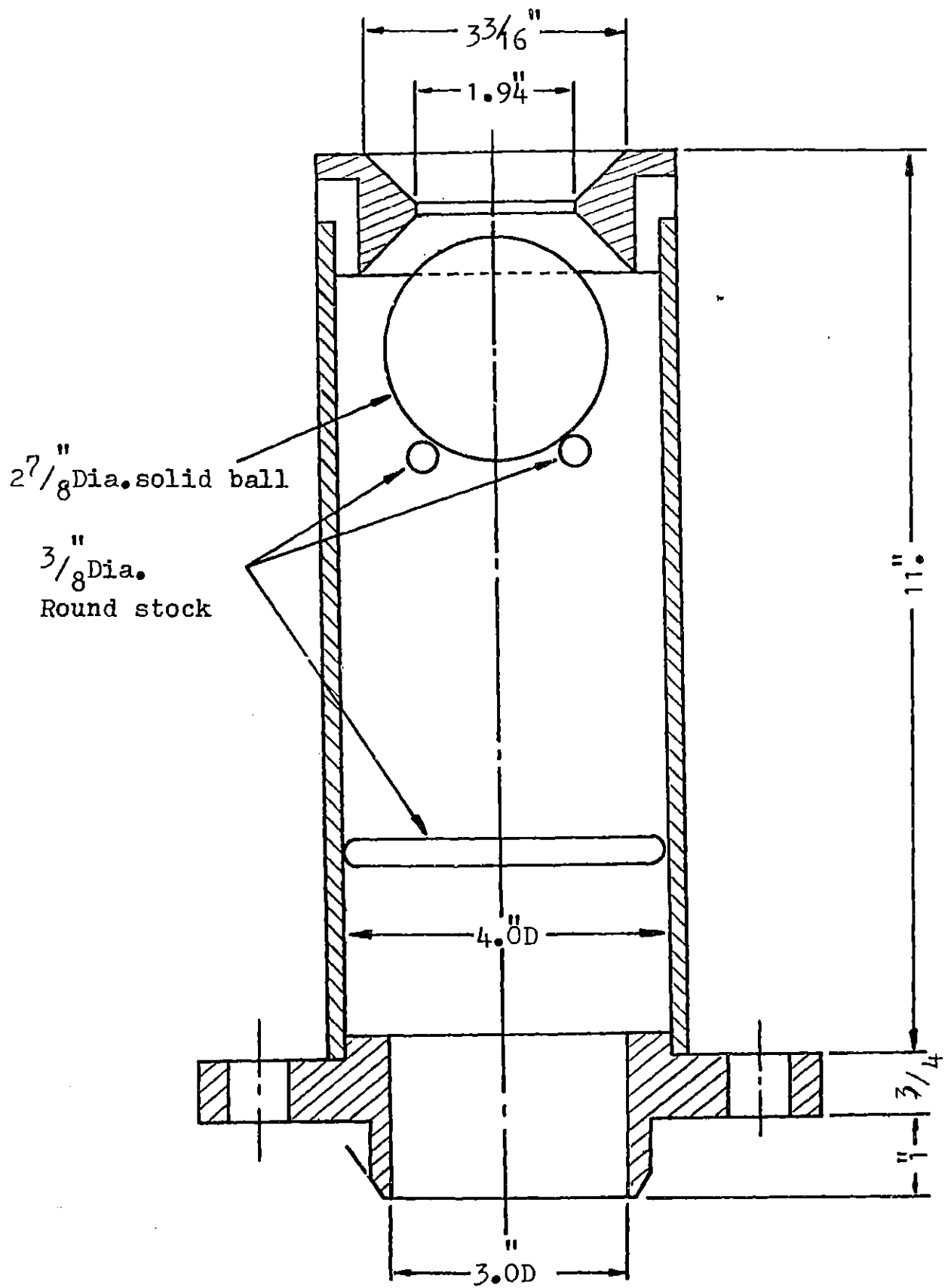
FIG 3.4 Natural Convection Valve

divided into 17 sections. The expansion and contraction coefficients are found (Ref.3.10) from charts for infinitely-wide-gap tube system at a Reynold number of 2000 which is equivalent to a flow rate of about $8 \, lbm/ft^2/sec.$, that is shown to be a good number for natural convection flow. These values are normalized to the down-commer area to be able to use them more easily in loop calculations. The total natural convection form factor is found to be a function of the number of valves open to the flow as follows:

$$K = 190.38/NOVO^2$$

where NOVO is the number of valves open to flow. The numerator is found to be 160.37 for turbulent flow. Therefore even if the natural convection flow is not the same as it was estimated above the pressure drop in the valve will not differ considerably.

For the reverse flow, which might occur after the valves open, the form factor is estimated to be:

$$K_r = 57.88/NOVO^2$$

then the pressure drop could be found from standard equation:

$$\Delta P = KG^2/2\rho g_0$$

where   G   is mass velocity $lbm / ft^2 / sec$

   ρ is density of water lbm / ft^3,   and

   g   is conversion factor, 32.2 $lbm.ft/ lb_f.sec^2$.

The form coefficient at the core inlet was estimated by
Morales (Ref.2.7) to be 1.05, based on the coolant velocity at
the channel inlet.

Assuming that all the kinetic energy is lost at the
channel exit, form factor could be taken as unit at the core
exit.

Friction loss coefficient due to abrupt changes at
cross-sections,are evaluated from Reference 3.11.

The Darcy-Weisbach friction factor, f, is found from the
following general equation:

$$f = n\ Re^{-m} \tag{3.25}$$

where   Re   is Reynold's number   and n and m are defined as

as follows:

for laminar flow in circular pipes; $n = 64$, $m = 1$

for laminar flow in rectangular cross-section

with aspect ratio of 25, $n = 91.5$, $m = 1$

for turbulent flow $4000 \leq Re < 51094$; $n = 0.3164$, $m=0.2$

for turbulent flow $51094 \leq Re$; $n = 0.184$, $m = 0.20$

and in transition region, $2300 < Re < 4000$, linear interpolation
is made on Reynold's number between the turbulent and laminar
values.

All the values given above are for isothermal flow. In non-isothermal conditions, like those in core channels, they should be multiplied by $[\ 1-0.0025\ \Delta\ T_f\ ]$, (Ref.3.12), where ΔT_f is the film temperature drop in $^\circ F$.

For long-term transients where boiling might occur, two-phase friction multiplier is defined in Appendix D.

CHAPTER IV

START-UP NATURAL CONVECTION TEST

4.1 General

To demonstrate that the decay heat resulting from long-term operation at 5 MWth can be removed by natural convective cooling, a series of pump trip transient temperature measurements were made during the MITR-II step-wise startup to full power with Core-4. Decay heat removal performance from only the initial transient was also investigated by short power operations. The time at power was minimized, (about 5 minutes) to keep fission product inventory low. After successfull completion of the short run and transient test, the test was repeated after at least three hours of power operation.

Temperature measurements were made by inserting stainless steel clad chromel-alumel type K thermocouples into various positions. Table 4.1 shows a summary of thermocouples and their places in Core-4. Figure 4.1 also shows the in-core thermocouples.

Thermocouple installation and wiring is shown in construction and startup procedure of MITR-II (Ref.2.14). The main design criteria was to affix the holder so that it could not break free during both primary pumps operation and yet would have minimum effect on the element flow.

Table 4.1

Thermocouple Position in Core -4 Startup Test

T/C number	Position Element	Place
6	C-13	mixed outlet
7	C-15	mixed outlet
8	A-2	mixed outlet
9	B-6	mixed outlet
10	3Gu6	graphite plug
11	spider hole #3	bottom of core inlet
12	A-2	T/C on inside of the last plate 4 " from bottom, toward A-3
13	A-2	T/C On center plate of the element 0.1" from bottom , away from A-3
16		cadmium shutter
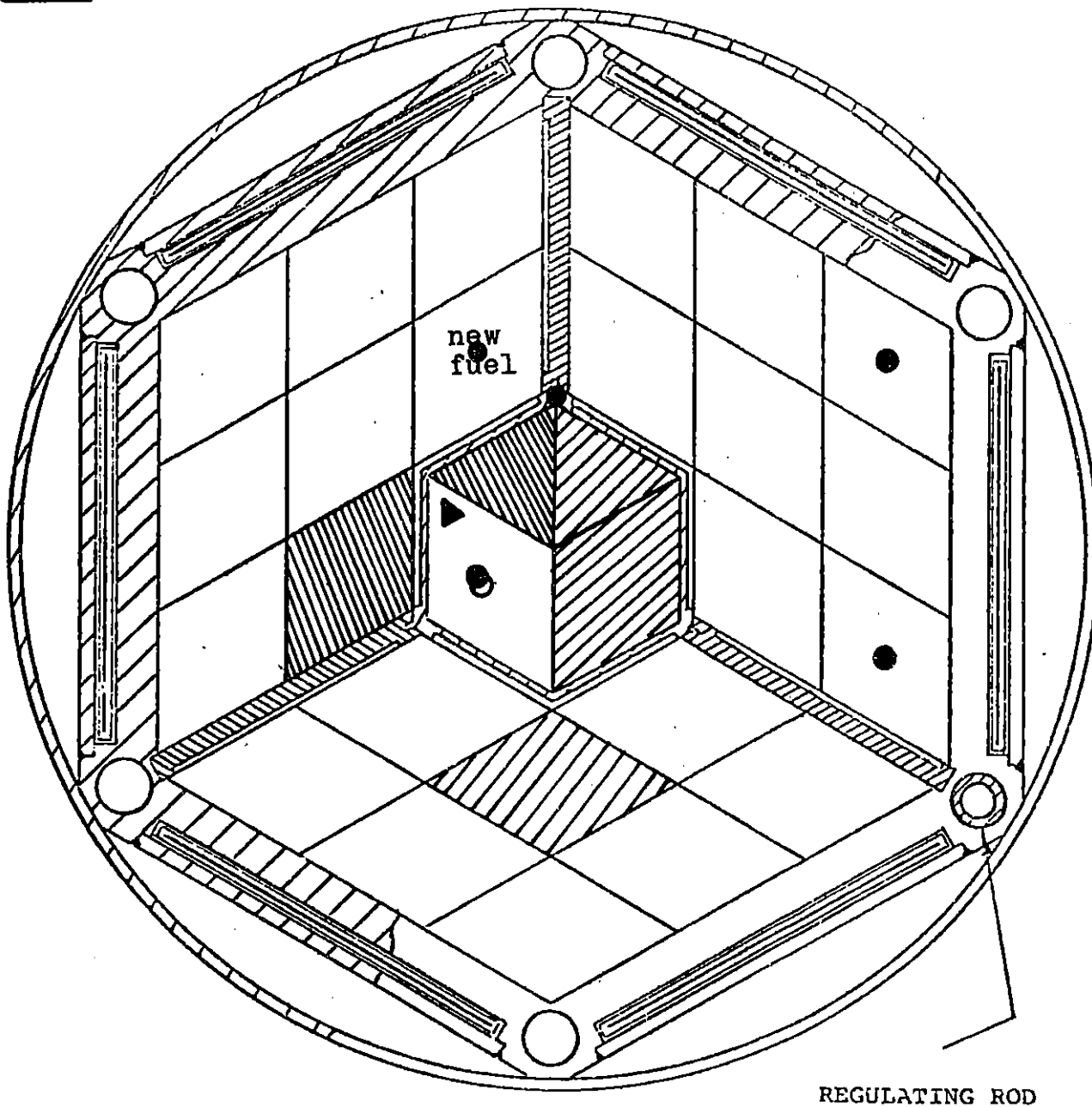
FIG. 4.1 Incore Thermocouple Position

To measure the fuel element outlet temperature the thermocouple tip is positioned in the element exit plenum under the end nozzle bale. Since the distance to channel exit is less than one inch, the measured temperature may not be the mixed mean element outlet temperature.

Fuel plate surface temperature was measured by using a"thermocouple fuel element". The thermocouple fuel element was inserted into position A-2, for Core-4 with two thermocouples fixed on two different plate surfaces at 0.1 and 4.0 inches from the bottom of the fuel, (Table 4.1).

4.2 Experimental Procedure

Addendums number 1 and 2 to subprocedure 5.10.1 provide procedure for raising the reactor power of Core IV to a maximum level of 2.5 and 5 MW respectively.

Both primary pumps were used to prevent overmoderation at the center of the core. An aluminum rod of 1" diameter was installed to fill at least 18" of ISCA thimble from the bottom. It was transferred from flask to core position A-1 and was locked down by the hold-down grid. Fuel element outlet and inlet plenum thermocouples were then installed. Top lid was positioned and prerequisites specified in subprocedure 5.10.1 and 5.11.2 (Ref.4.1) were completed and verified.

Reactor power was raised in steps to 200KW for radiation survey and after approval it was increased to 1 MW. At this power

the specified transient tests in subprocedure 5.10.1 and 5.11.2 were conducted. Power was raised then in 0.5 MW steps to 2.5 MWth following the subprocedures.

To increase the power from 2.5 MW to 5.0 MW three additional thermocouples were installed in graphite plug, blister tank, and medical boron water shutter.

Using the thermocouple data available at each power level, the maximum fuel plate temperature,and temperatures at hot spot during steady state and transient operation were also plotted. Correction factors should be applied as is shown in the following section, to estimate the actual surface temperatu The acceptance criteria was conservatively chosen to account for the uncertainty of fuel plate surface temperature measurement.

At any power level, two sets of measurements were made. Decay heat removal performance from the initial transient of fission power was obtained from short interval operation. The reactor was started up following normal procedure at full core water flow rate of 2000 gpm. Power was raised to 1MW and was kept constant for 5 minutes. Core inlet, outlet,temperature difference along the core,incore temperature,flow rate,and power level were recorded. Shutdown coolant pump MM-2 was stopped The thermocouple corresponding to the fuel surface temperature at 4.0 inches was selected on the recorder at high speed and then booster pumps HM-2 and HM-2.A and secondary pumps HM-1 and HM-1A

were stopped respectively. Primary pumps MM-1 and MM-1A were stopped simultaneously right after the other pumps. At 2 MW and above by using minor scram the reactor was shutdown simultaneously with flow stopping. Data was recorded for about 60 seconds at high speed (12 in./min.), and 15 minutes at low speed (2 in./min.). The results were evaluated with acceptance criteria before proceeding with the tests.

Removing the decay heat resulting from long term operations by natural convective cooling was the other part of the startup tests. It was shown that decay heat buildup after about three hours operation was almost equal to that of infinite operation. Therefore after each short interval operation, core water pumps MM-2,MM-1 and MM-1A were restarted followed by starting up the reactor with normal procedure. The reactor power was kept constant for at least three hours before all temperatures were measured in the same way as for ten-minute operation. Thermocouple number 12 was selected on the recorder to show the transient behavior of fuel surface temperature at 4.0 in. from the bottom while all the pumps were stopped and the reactor was scrammed in the same order as in the short interval operation. This transient was observed long enough to pass the maximum wall temperature which occured at about 30 seconds after the scram. The recorder was then switched to the other thermocouples.

This was repeated for power to increase from 1 MW to 4.9 MW in 0.5 MW steps.

At each power, the level trip was set less than 20% above the next step if the data was approved.

The acceptance criteria for decay heat removal testing is as follows:

" 1. Measured fuel plate temperatures are equal to or less than those calculated in Section 3 of the SAR.

2. Temperatures in the reflector tank are less than $55^{\circ}C$ and minimum flow requirements are established.

3. Temperature in the graphite region are equal to or less than those in the MITR-I.

4. Temperature of medical water shutter is less than $70^{\circ}C$ and minimum flow requirements established.

5. Temperature of D_2O blister tank less than $60^{\circ}C$."

4.3 Preliminary Calculations

Aluminum melts at $660^{\circ}C$ and begins to lose strength at $450^{\circ}C$, so the latter temperature could be a suitable criterion for guarenteeing the structural integrity of the fuel element. Since MITR operates at atmospheric pressure at the pool level, it is estimated that boiling occurs at the core mid-height, at about $107^{\circ}C$.

In startup natural convection tests, the maximum wall temperature in the hottest channel was to be estimated at any power by extrapolating the known data. Therefore from installed thermocouple readings, hot spot temperature had to be evaluated. Thermocouple number 12 measured (Table 4.1) fuel plate wall temperature at a height of 4 in. from the bottom of the element. Actual film temoerature drop $(T_w - T_f)$ at that point could be estimated from thermocouple reading and core average temperature increase:

$$[T_w - T_f]_{act.A-2} = (T_{12} - T_{11}) - F_r Z_q \Delta T_{cav} + \Delta T_{er} \qquad (4.1)$$

where

T_w	is actual wall temperature at the point of thermocouple in A-2-15
T_f	is fluid temperature at 4 in. height in A-2 ,
T_{12}	is maximum transient temperature reading of T/C no.12
T_{11}	is maximum transient temperature reading of T/C no.1
ΔT_{cav}	is the core average temperature increase,
ΔT_{er}	is correction temperature for thermocouple installat:
F_r	is radial peaking factor for fuel element A-2, and
Z_q	is fraction of power produced up to the height of thermocouple.

The wall temperature measured by a thermocouple, relative to the actual fuel surface temperature depends upon the thermocouple attachment effectiveness. A properly attached thermocouple reads a temperature close to the actual surface temperature, while a poorly attached thermocouple reads a temperature that is closer to bulk fluid temperature at that point. Thermocouple installation factor, I, was developed by Szymzak (Ref.4.2) as a function of fin effectiveness, η, and heat transfer coefficient obtained by using the Dittus-Boelter correlation, h:

$$I = (T_0 - T_f)/[Q/A] \qquad (4.2)$$

where,

Q/A is the heat flux at thermocouple location,

T_0 is the temperature observed by the thermocouple, and

T_f is the bulk coolant temperature at the thermocouple location.

The actual fuel surface temperature can be obtained from the measured wall temperature by knowing the calibration factor, Z_c, used by Szymzak (Ref.4.2) as follows:

$$Z_c = [T_w - T_0]/[T_w - T_f] \qquad (4.3)$$

where,

T_w is the actual surface temperature,

T_0 is the temperature measured by the thermocouple, and

T_f is the bulk fluid temperature at the thermocouple tip location.

The calibration factor is plotted against ηh, as defined before, in Figure 4.2. Equation 4.3 can be rearranged to yield:

$$T_w - T_f = (T_0 - T_f)/(1 - z_c) \qquad (4.4)$$

Figure 4.2 shows that for lower values of ηh which would be in natural convection cooling, the thermocouple would read close to the actual wall temperature even if they were poorly installed.

The correction temperature, ΔT_{er}, used in Equation 4.1 was estimated to be about $4.5^\circ C$.

The hot spot temperature in fuel element C-13, could be estimated from Equation 4.1 by evaluating the relative power produced in the hot channel, in fuel element C-13 to that of A-2 at 4" :

$$[T_w - T_f]_{c-13}/[T_w - T_f]_{A-2} = [Fr\ Fa]_{c-13}/[Fr\ Fa]_{A-2} \qquad (4.5)$$

where F_r and F_a are the radial and axial peaking factor respectively, and the subscript C-13 and A-2 refer to their position in the core.

Fluid temperature at the hot spot, $T_{f,C13}$ in Equation 4.5 can be found by heat addition to the hot channel :

$$T_{f,c-13} = T_{in} + \Delta T_{cav} (Fr\ Z_q)_{c-13} \qquad (4.6)$$

FIG . 4.2 Thermocouple Calibration Factor

Y-axis: Clibration Factor $Z_c = (T_w - T_o) / (T_w - T_f)$

X-axis: $\eta h \times 10^{-3}$ (BTU/hr.ft^2.°F)

poorly installed

fairly installed

well installed
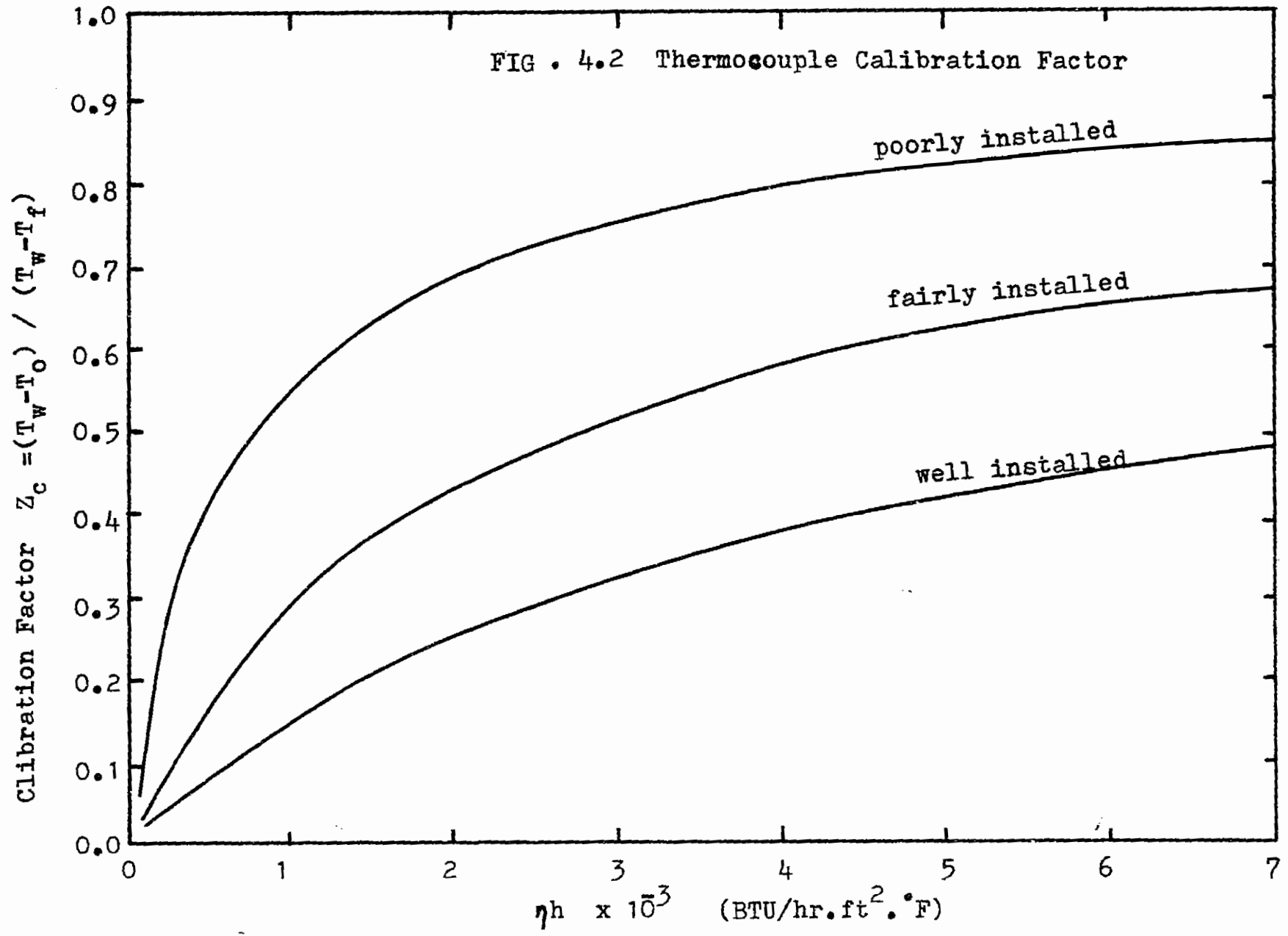
where the term in parenthesis is the fraction of power generated

in the hot channel up to the height of hot spot and T_{in} is

the fluid inlet temperature. Other parameters in Equation 4.6 were

defined before. Assuming that the core outlet scram set is at $55^{\circ}C$,

the core inlet temperature could be found conservatively from power

balance. A temperature difference of $8^{\circ}C$ is evaluated for 5 MWth

power and 2000 gpm flow rate.

4.4 Natural Convection Test Measurements

Transient in-core temperature measurements for 4 MWth power

after 11.5 hours and 10.0 minutes steady state operation are shown

in Figures 4.3 and 4.4. The fuel tip temperature in the first few

minutes after scram was not measured, so the dashed line shows

only the shape that it would follow in short transient. Transient

temperature measurements of the in-core thermocouples for other

power discussed in the earlier section are shown in Appendix E.

The coolant outlet temperature increases for a few degrees

right after the scram signal is initiated because of the scram

delay time. This relative peak could not be measured and recorded

due to delay time of the thermocoupling wiring system and relatively

low speed of the recorder.

Maximum wall temperature in the hottest channel could be

evaluated by combining Equation 4.1, 4.5 , 4.6. These temperatures

are shown in Figure 4.5 based on the peak values of thermocouples

11 and 12, inlet temperature of $47^{\circ}C$ and the following peaking factors

FIG. 4.3 TRANSIENT TEMPERATURE MEASUREMENTS OF
THE INCORE THERMOCOUPLES.

(4 MWth for 11.5 hrs.)

Fuel Tip Temperature (T/C # 13)

Average Outlet Temperature
(T/C # 9)

Wall Temperature at 4" from bottom
(T/C # 12)

Core Inlet Temperature

(T/C # 11)

Temperature (°C)

Time After Accident (Second)

FIG. 4.4 TRANSIENT TEMPERATURE MEASUREMENTS OF
THE INCORE THERMOCOUPLES (4MWth for 10 min.)

Average Outlet Temperature
(T/C # 9)

Wall Temperature at 4" from bottom
(T/C # 12)

Core Inlet Temperature
(T/C # 11)

at hot spot in C-13 element with shim bank and at 10" from

the bottom; $F_r = 1.315$ $F_a = 1.630$

at 4.0 " from the bottom in A-2 with shim bank at a height

of 8"; $F_r = 1.175$ $F_a = 1.050$.

Extrapolation of Figure 4.5 shows that the maximum wall
temperaure in the hottest channel during transient pump coast down
will be much below saturation,even if the steady state power is
6 MWth . Figure 4.6 shows the steady state hot spot temperature
for different powers evaluated from Equation 4.5.

Acceptance criteria for startup of MITR-II requires some
limitations on the out core temperatures. Therefore along with the
in core temperature measurements, thermocouples were installed to
measure the temperatures of graphite, cadmium shutter, boron water
and D_2O shutter tank. Figures 4.7 and 4.8 show the maximum transient
temperatures for different reactor powers. It is shown that all
temperatures are within acceptable limits.

FIG 4.5   WALL TEMPERATURE EVALUATED AT
          HOT SPOT
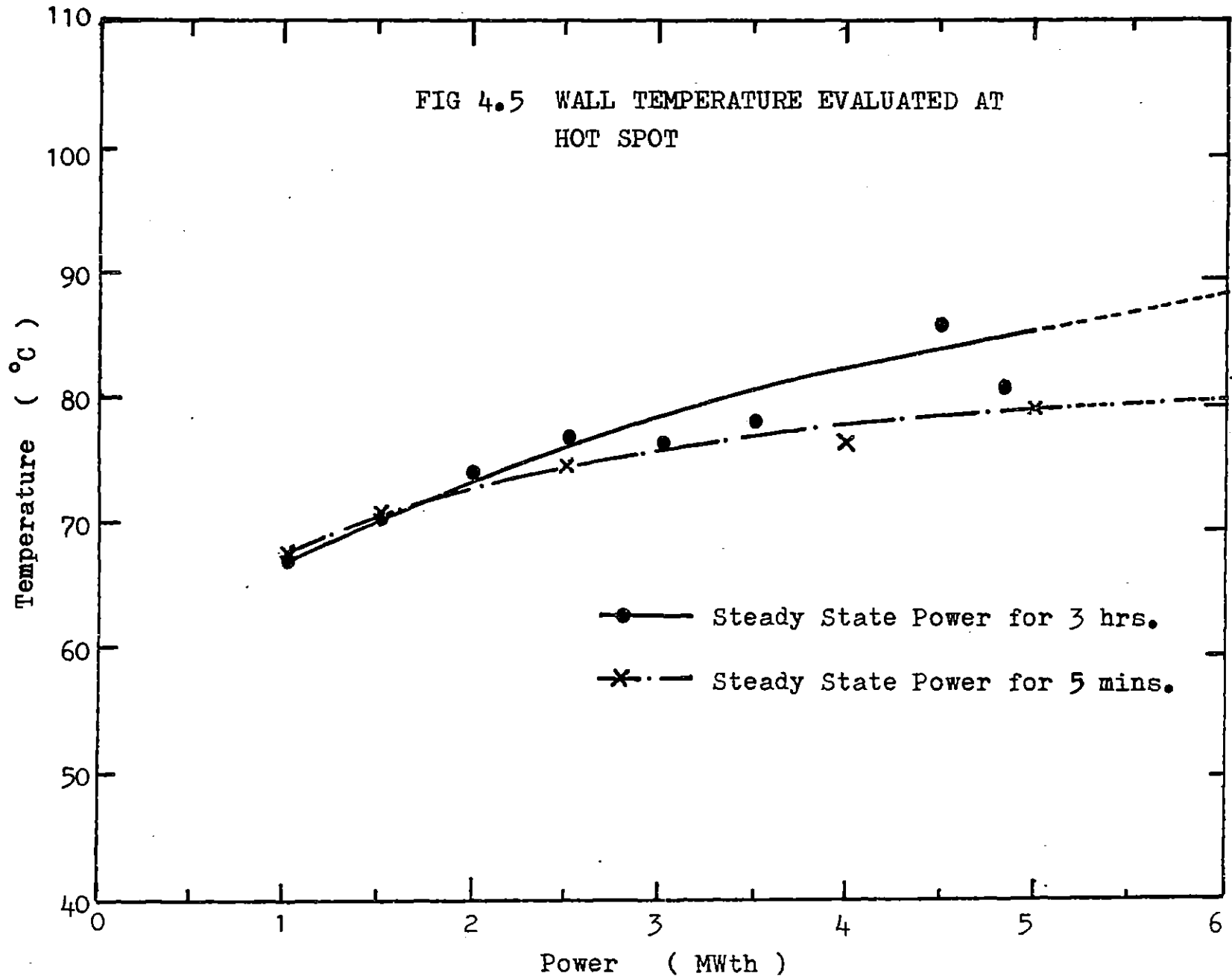
FIG 4.6   WALL TEMPERATURE AT HOT SPOT
          IN FUEL ELEMENT C -13

Legend:
● Temperature at Steady State Operation
○ Steady State Power for 5 mins.

Y-axis: Temperature (°C)
X-axis: Power (MWth)

FIG 4.7   OUTCORE TEMPERATURE MEASUREMENTS

Graphite Temperature for Long -Time Operation

C_d Shutter Temperature for Long-Time Operation
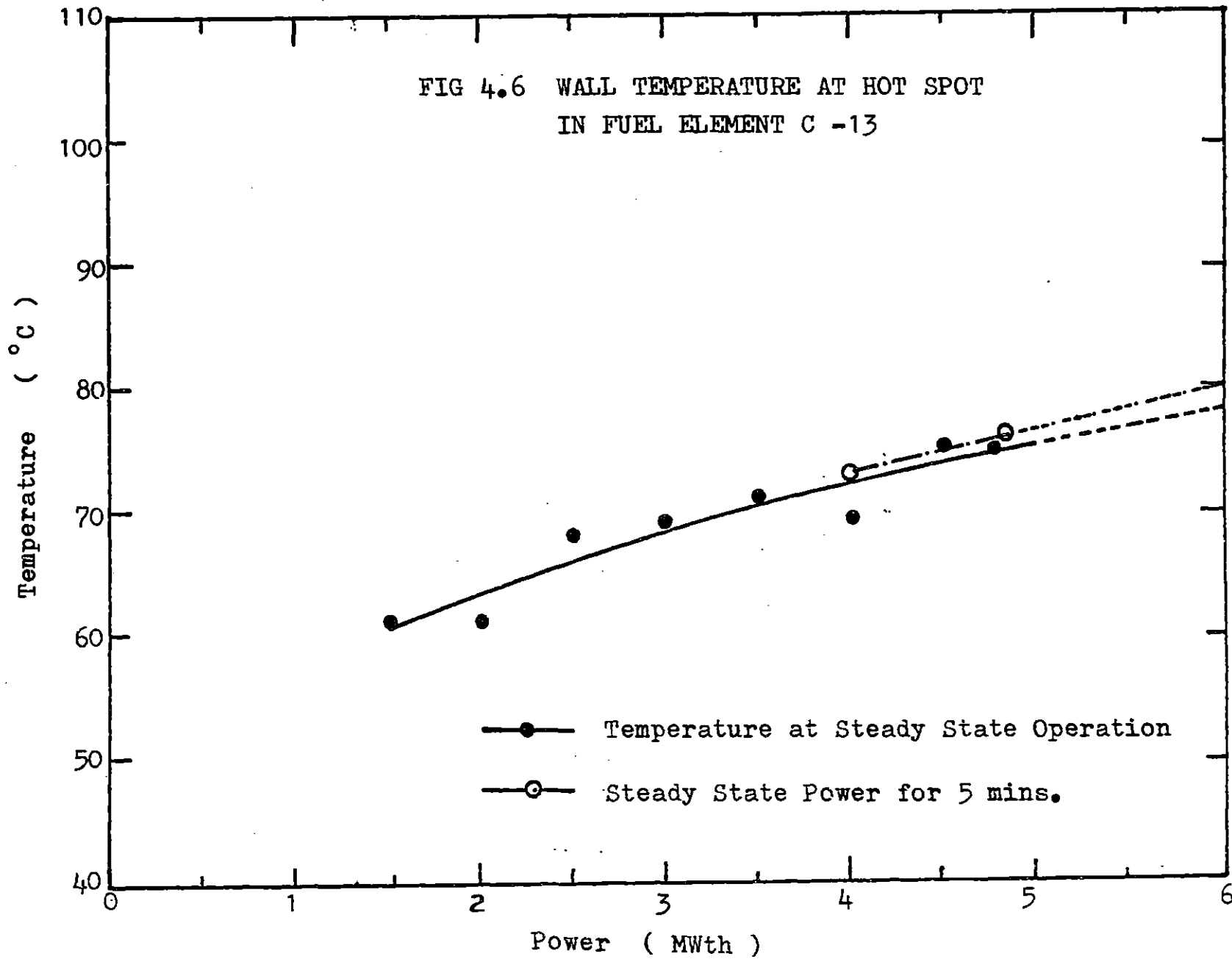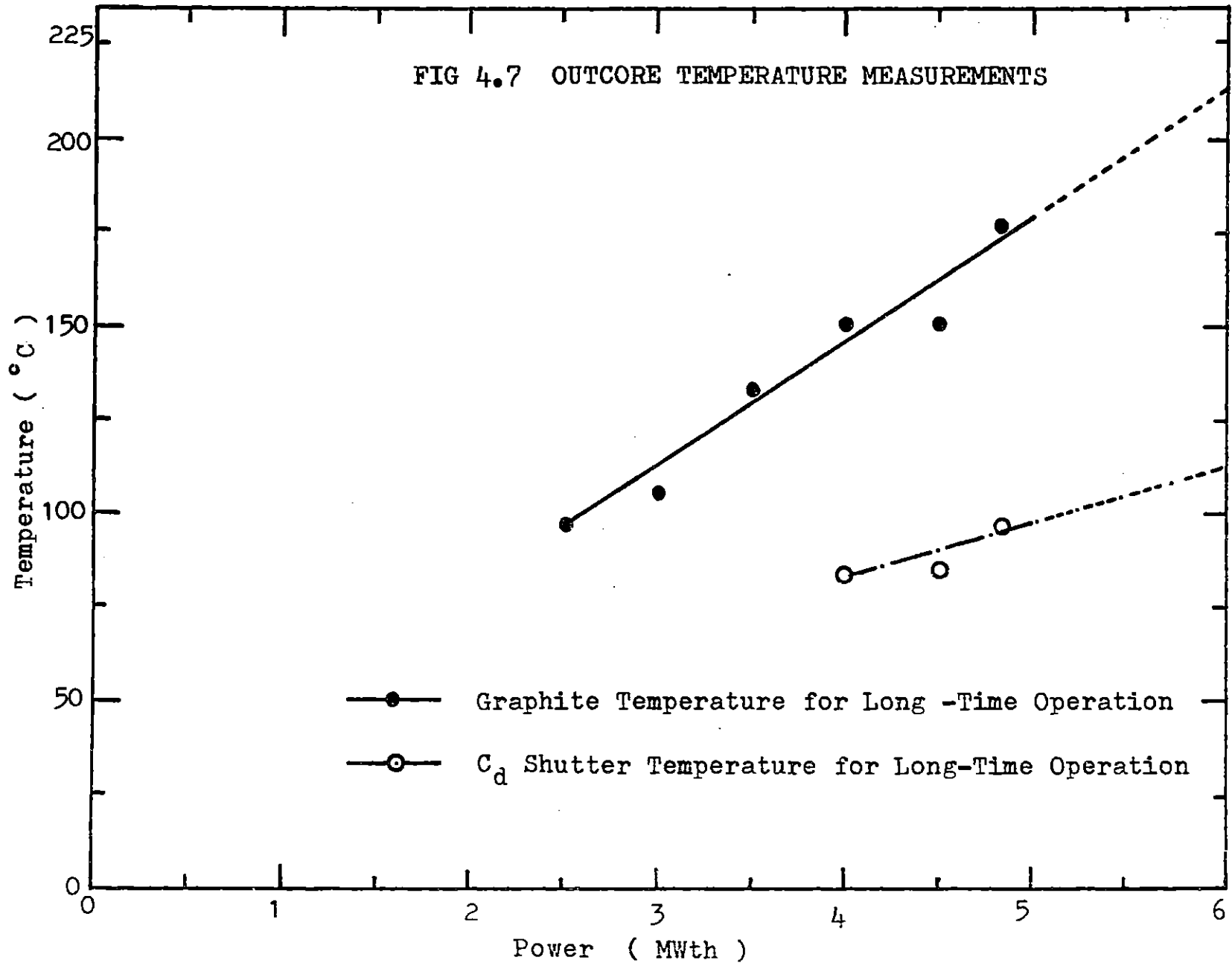
FIG 4.8   MEDICAL FACILITY TEMPERATURE MEASUREMENTS
         FOR LONG - TERM OPERATION
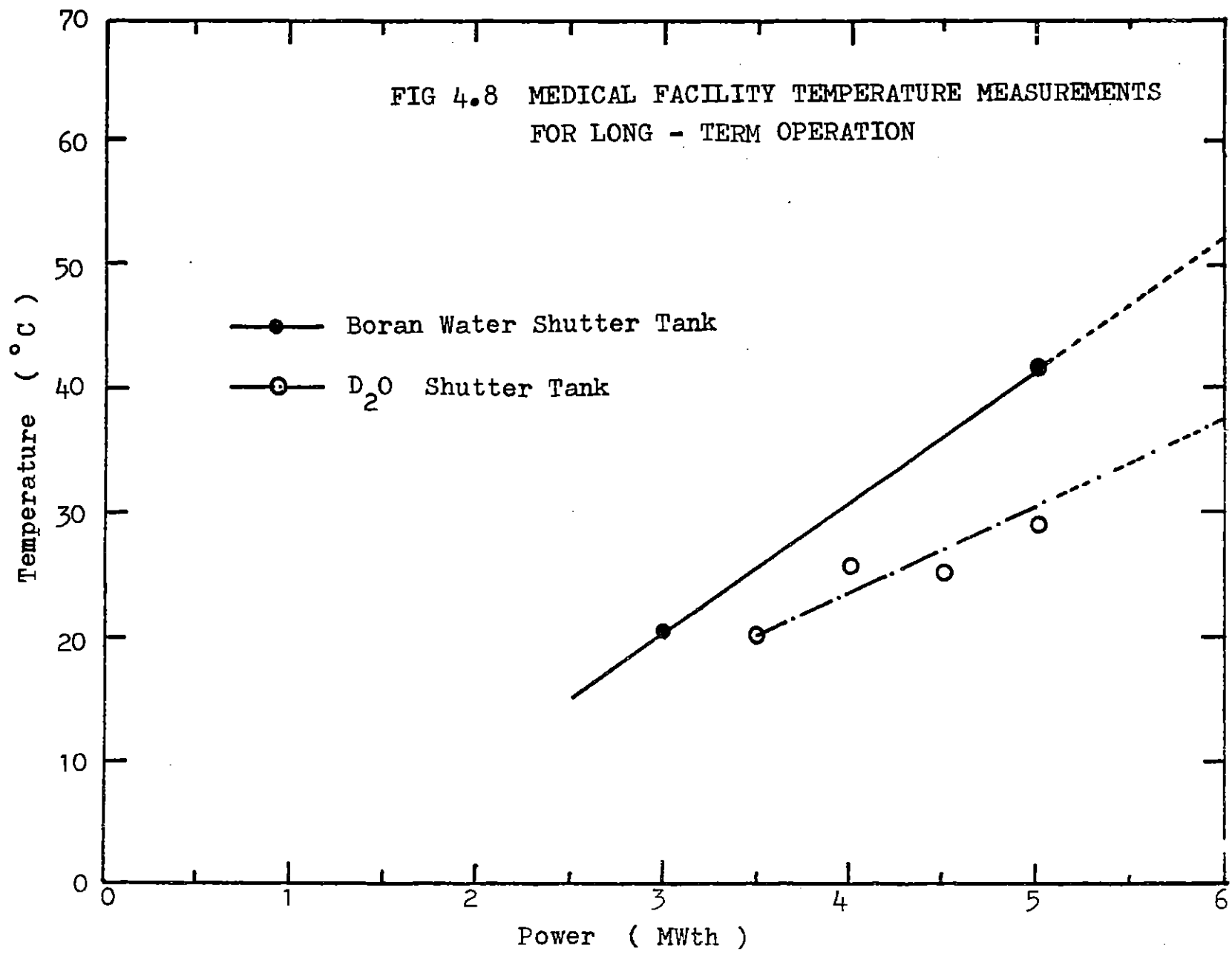
CHAPTER V

COMPUTER RESULTS

5.1 General Assumptions

The Computer Code LOFA is written to analyze the
steady state, forced flow transient, and natural
convection behavior of the MITR-II during a Loss of
Flow Accident. A single channel model is applied to
the equations derived in previous Chapters II and III
to consider the core average power distribution. The
computer code output is compared with the startup
temperature measurements in the fuel element B-6, in
order to be able to use the code in the prediction of
hot channel behavior in natural convective cooling.

The startup natural convection tests above 2MWth
were based on the assumption of loss of electrical
power to the main panel. The same assumption is made
in all the computer code calculations which are made in
this work. In other words, after steady state calculation,
the reactor is scrammed at the same time that both
primary pumps are stopped.

A scram delay time of 0.41 seconds is assumed for
the reactor shut down. Therefore until 0.41 seconds after

the loss of electrical power, the reactor is assumed
to be at full steady state power, whereas the primary
coolant flow starts decreasing as soon as the power
goes off. To be more conservative, the time that it
takes for 80% of the shim bank insertion, is added to
the scram delay time. Thus, it is assumed that a reactiv-
ity of -4.8 beta is inserted at 0.9 seconds after the
accident. This is equivalent to the insertion of 80%
of the shim bank worth at once.

For the time between 0.41 and 1.0 seconds after
the accident, the heat deposition rate in the core is
determined by interpolating on time between the values
at 0.41 and 1.0 seconds.

Delayed photoneutrons produced due to gamma absortion
in the D_2O reflector were discussed in Section 2.3 for
infinite medium. Although those values are used here
conservatively it is seen that the contribution of
delayed photoneutrons to decay power is only a few percent.

In steady state operation, more than 5% of the
fission energy is deposited in the D_2O reflector and
shielding. This energy loss is neglected in the after
scram decay heat deposition in the core.

The heat transfer from the containment tank
by the tank gas system or by conduction through the
wall is neglected in the tank mixed enthalpy calculations.

In Section 2.7 it was found that the heat trans-
ferred from the down commer to the D_2O reflector around
it   is about 33.8 watts. This could be ignored
in comparison to the decay heat produced in the core
which is comparatively large. The decay power at about
three minutes after the scram is approximately 250 KW.

Axial power distribution in the core after
shut down is assumed to be the same as that which is
at steady state operation. Due to gamma ray energy
contribution, the decay energy is actually more
uniformly distributed along the core than normal
steady state power.

Due to the small thickness of fuel plates and
high conductivity of aluminum cladding, no axial or
radial heat conduction is considered in the calculations.

Five percent of the total decay energy is assumed
to be generated directly in the coolant. Heat produced
in the core is presumed to be deposited in the coolant
to allow the fuel plates to be the energy sink if the
heat flux is negligibly small.

For hot channel calculations, a value of 1.265
is taken for the total radial peaking factor, (Ref.5.1).

The antisiphon valves are installed in the reactor
to prevent the containment tank water from flowing out
into the inlet pipes when the pressure in the primary
loop drops below a specified level. As soon as the
natural convection valves open, the cold water in the
shroud and down commer is assumed to be mixed with
the water around the chimney for core inlet calculations.
The water in the primary loop will flow into the shroud
due to the pump leakage, whose effect on the tank mixed
enthalpy calculation is ignored.

Aside from the moderate assumptions discussed
in this section, whenever an uncertainty existed in
calculations or evaluations of input data, the most
conservative values were chosen.

5.2 Pump Coast-Down and Natural Convection Flow

Loss of electrical power to the main panel,
stops both primary pumps at the same time. Due to
momentum conservation in the flywheels, the flow
coasts down as is shown in Figure 2.1. Equation 2.1
is used to evaluate the flow rate due to pump coast-
down for the first few seconds until natural convection
flow dominates.

Although the natural convection valves are closed
during pump coast-down, there is a small contribution
to the flow due to the buoyancy of the hot water in the
core. Natural convection flow increases rapidly as
soon as check valves open and reaches a maximum at the
same time that maximum core outlet temperature occurs.
Figure 5.1 shows the flow behavior after scram for
Core-4 with average power distribution. The maximum
natural convection flow is about 13.65 $(lbm/ft.^2/sec.)$,
which is due to small water density in the core at the
time of peak outlet temperature of $81^{\circ}C$. Thereafter
the natural convection flow decreases slowly with
decay power.

Free convection flow rate decreases less rapidly
when the relatively hot water in the containment tank
reaches the down commer.

5.3 Core Temperature Calculations

A comparison was made between the computer results
and the temperature measurements of the startup
natural convection test for the average core outlet
temperature.

Figure 5.2 shows that the core outlet temperature
increases to a maximum value of $81.6^{\circ}C$ in both cases.

FIG 5.1   CORE FLOW AFTER PUMP COAST-DOWN

FIG 5.2 CORE BULK TEMPERATURE FOR AVERAGE POWER DISTRIBUTION
(Infinite Operation at 5 MWth)

Legend:
- —●—·— Core Outlet Temperature Measurements
- —○——— Core Inlet Temperature Measurements
- ——— Core Outlet Temperature from LOFA

Y-axis: Temperature (°C)

X-axis: Time After Accident (Seconds)
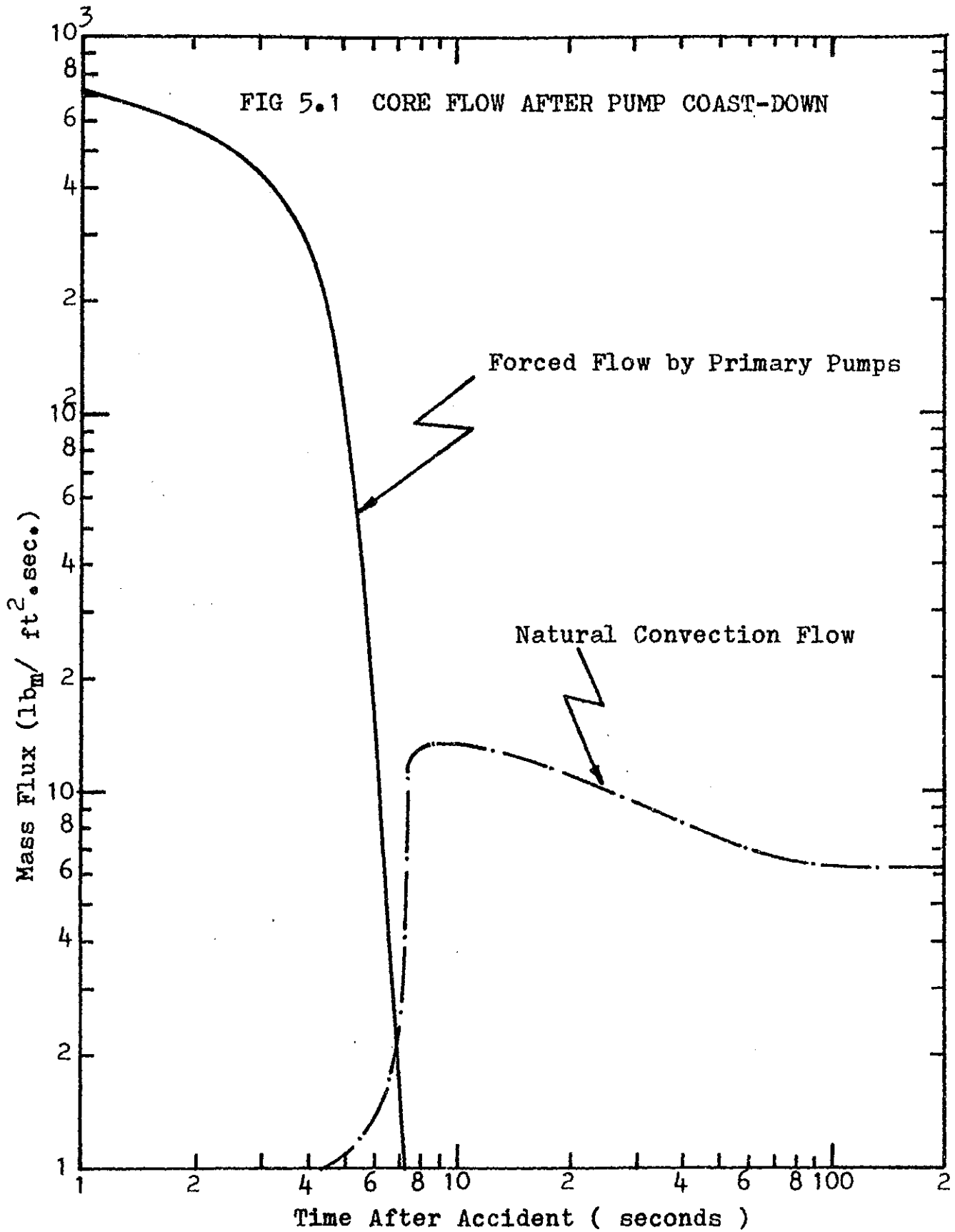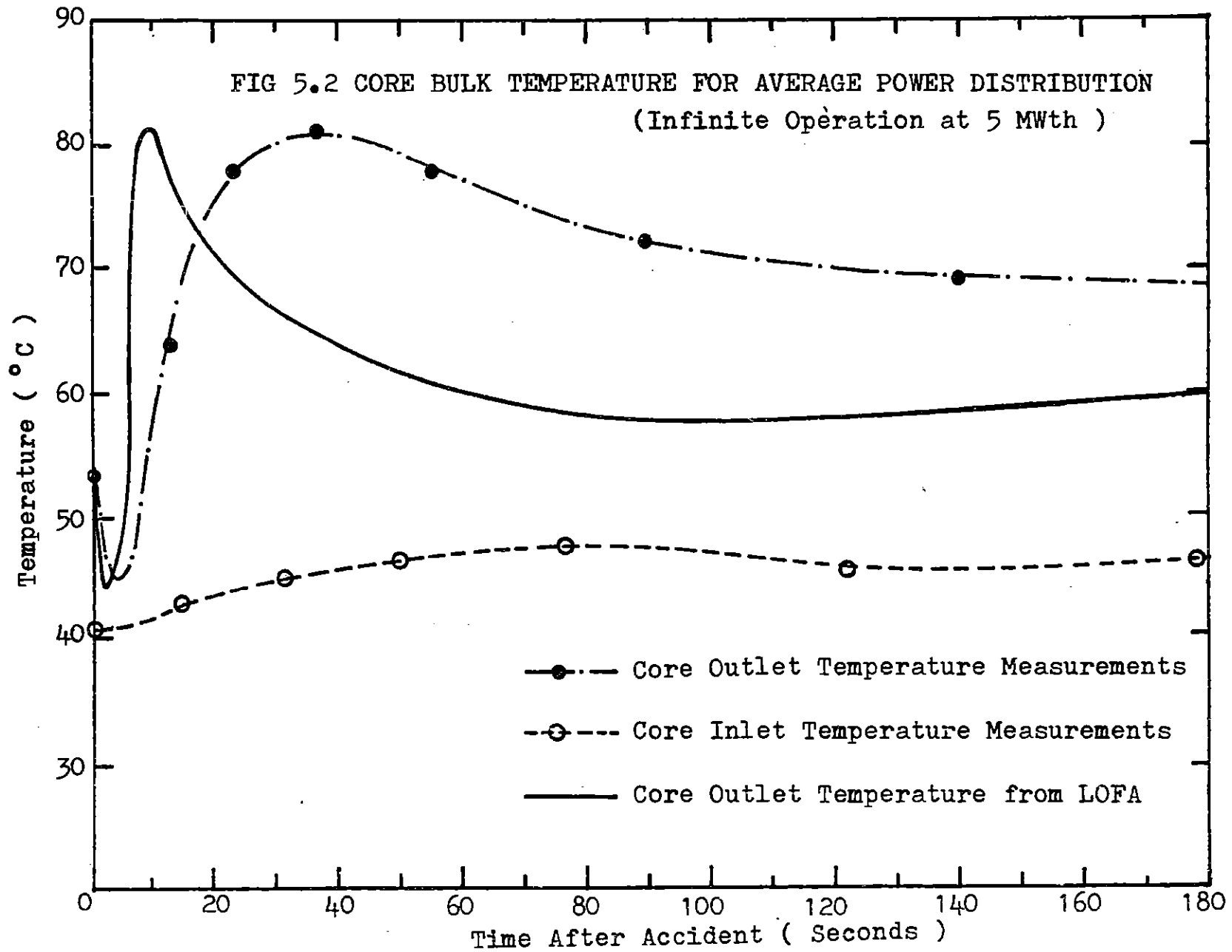
The difference between the computer results and the
experimental values is that the calculated peak temper-
ature values occur at a time af about 10 seconds after
shutdown, while the experimentally measured peak
temperature occured at about 30 seconds. A delay time
of about 20 seconds is observed between the peak
outlet temperatures in Figure 5.2. Considering core
inlet temperature shown in the same figure, it can be
assumed that the relatively rapid increase in the core
inlet temperature after the initiation of natural convec-
tion is due to heat transfer from the core to the
down commer.

Decay heat could be transferred through the
aluminum core housing to the down coming flow during
the high decay energy release period. This would increase
both the core inlet temperature and the heat deposited
in the relatively thick aluminum wall. When the energy
released in the core decreases, the inlet temperature
and heat transfer from the core housing to the coolant
become considerable. This would shift the maximum core
outlet temperaure to a later time than that predicted
by the computer output in which the heat transfer to
the core housing is not considerred.

Figure 5.2 shows that the assumption of no heat
transfer to the down commer and neglecting the energy
deposition and release from the core housing is conser-
vative with regard to the evaluation of the time
that maximum temperature or probably the onset of
nucleation boiling occurs.

Based on the average core outlet temperature
calculations, a single channel model is used to
evaluate the hot channel behavior in five cases of
loss of flow accident in MITR-II, Core-4. In all cases
the reactor is assumed to be at 5 MWth steady state
power long enough to build up decay heat as if it
were at full power for infinite time. The total steady
state **primary flow rate** is **taken to be** 2000gpm and
the containment tank is assumed to be at the core exit
temperature.

Case-1   All the natural convection valves are open
          after the accident. Steady state primary heat
          exchanger outlet temperature is assumed to be
          40°C.

Case-2   Core inlet temperature is the same as in Case-1
          but it is assumed that one valve remains closed

and only three natural convection valves are
open to flow.

Case-3   Only two incore check valves are considered to
open after loss of flow accident for core inlet
temperature of 40°C.

Case-4   The core outlet temperature scram set is
assumed to be at 55°C. For the steady state
power of 5 MWth. This allows the primary
heat exchangers exit temperature to increase
to 47°C. All natural convection valves are
open in this case.

Case-5   The core inlet temperature is considered to
be 52°C, this is equivalent to setting the core
exit temperature scram at 60°C. Four natural
convection valves are allowed to open after
the accident.

1. Case-1 is natural convection analysis of the hot
channel in normal conditions at 40°C inlet temperature
and all the valves open to flow. Figure 5.3 shows the
inlet and outlet transient temperature calculations of
the computer code LOFA for Case-1. The inlet temperature

FIG 5.3 HOT CHANNEL BULK TEMPERATURE FOR CASE -1:
(4 Valves Open and T_{in} =40 °C)

Outlet Temperature
Inlet Temperature

Temperature (°C)

Time After Accident (Seconds)
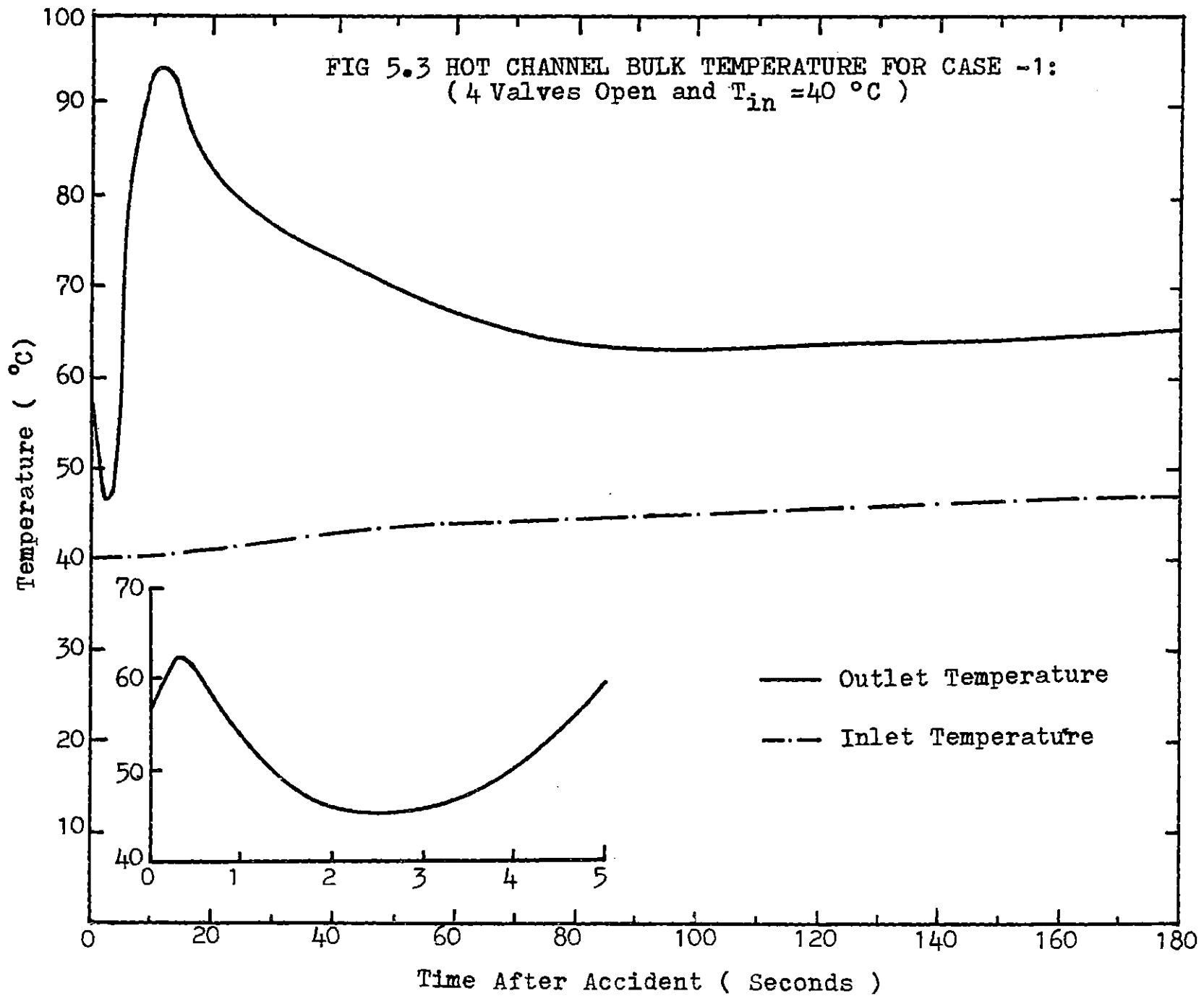
increases slowly after the pump coastdown due to mixing
of the relatively hot water between the chimney and
the shroud and the cold water in the down commer.

The hot channel outlet temperature increases to
a value of about 63°C rapidly right after the accident
due to the scram delay time of 0.41 seconds. It then
decreases with the insertion of the shim bank. When
the coolant flow is not enough to remove the decay
heat due to pump coast-down, the fluid outlet temperature
increases rapidly to an absolute maximum of about 94°C.
This augments the natural convection flow rate to about
11 ($lbm/ft.^2sec.$), which is enough to remove the decay
heat and decreases the channel outlet temperature.
With the decrease in the fluid temperature, the free
convective coolant flow rate decreases to a value
which is not able to remove the decay heat from the
core at the same constant rate. Therefore the fluid
temperature starts increasing with a very small slope
after going through a minimum.

From Figure 5.3 it can be predicted that the
bulk   boiling will occur at about 58 minutes after
the accident at the top of the hot channel assuming no
heat transfer to the D_2O reflector.

Fuel surface temperature calculations for Case-1 are shown in Figure 5.4 for the hot spot and also at a mesh point at four inches from the bottom of the fuel plate.

The maximum fuel surface temperature occurs at the top of fuel plate for Core-4. Figure 2.2 shows the axial power distribution in hot channel for MITR-II Core-4. Due to removal of the fixed absorber, the heat flux at the top of the fuel plate is large compared to the Core-1. This shifts the maximum temperature to the top of the fuel plate unless the heat production per unit area is very small.

At twelve inches from the bottom of the fuel plate, the surface temperature goes to a relative maximum due to the shim bank height.

Figure 5.4 shows that the fuel plate surface temperature follows the same shape as the fluid bulk temperature in the hot channel. The hot spot temperature increases to a maximum of about 98°C at about 10 seconds after the accident. This is still far below saturation temperature. The onset of nucleation boiling on the wall is predicted to occurs at about 64 minutes after loss of flow accident. This is a little later than initiation of bulk boiling at the top of hot channel because the

FIG 5.4 HOT CHANNEL FUEL SURFACE TEMPERATURE FOR CASE-1
(4 Valves Open and T_{in}=40 °C)

T_{Max} at 23" from bottom

T_W at 4" from bottom

Temperature (°C)

Time After Accident (Seconds)

108
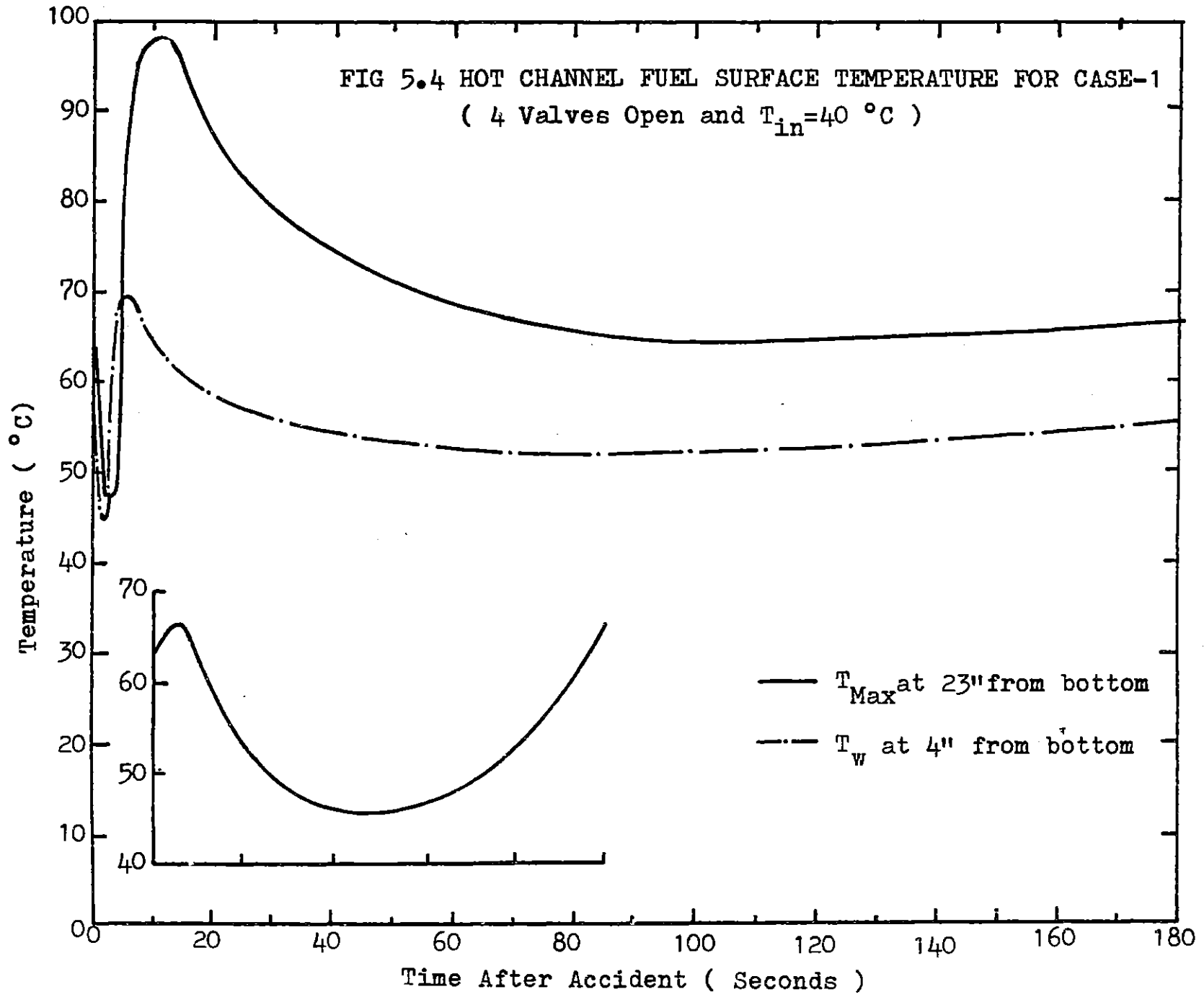
fuel surface temperature increases with a smaller
slope than the fluid bulk temperature.

The top part of the fuel plate changes from heat
source to energy sink after a long time following the
accident. This is due to small contribution of the
heat flux at the top of the fuel plate long after the
accident. This makes the bulk fluid hotter than the
fuel surface at the top of the hot channel.

Figure 5.5 shows the axial fuel surface temperature
and the heat flux distribution in the hot channel at
the peak value.

2. The effect of closing one natural convection
valve is studied in Case-2. The Computer Code LOFA
is used to calculate the hot channel behavior with
a core inlet temperature of 40°C and only three natural
convection valves open to flow.

Figures 5.6 and 5.7 show the transient fuel
surface and fluid bulk temperature for Case-2. The
maximum channel outlet temperature occurs at almost
the same time as in Case-1. However its value is
increased to about 98°C. The combination of increase
in the core enthalpy and pressure drop in the down
commer augment the natural convection flow rate to a

FIG 5.5 HOT CHANNEL TEMPERATURE AND HEAT FLUX DISTRINUTION AT THE PEAK POINT FOR CASE - 1

FIG 5.6 HOT CHANNEL BULK TEMPERATURE FOR CASE -2
(3 Valves Open and $T_{in}=40$ °C)

Temperature (°C)

Time After Accident (Seconds)

Outlet Temperature

Inlet Temperature

FIG 5.7 HOT CHANNEL FUEL SURFACE TEMPERATURE FOR CASE-2
(3Valves Open and T_{in}=40 °C)

Temperature (°C)

Time After Accident (Seconds)

——— T_{Max} at 23" from bottom

—·— T_w at 4" from bottom

value of about 13 (lbm/ft/sec.). The maximum surface temperature, which is at the top of the fuel plate is 97°C. At this point the top of the fuel plate could be considered an energy sink.

The assumption of closing one of the incore check valves, delays the start of natural convection for a few seconds. When there is no forced flow due to pump coast-down, for a very short period of time the water is stagnant in the core and therefore allows the enthalpy to increase. Natural convection begins and increases rapidly as soon as the driving force balances the pressure drop in the loop.

In this case, because of relatively high natural convection flow, long term transient bulk temperature increases with a smaller slope than Case-1. It is predicted that when one natural convection valve remains closed , the bulk boiling occurs after about 87 minutes from the time of the accident.

3. In Case-3 it is supposed that when the accident happens, two of the natural convetion valves remain . closed after pump coast-down. The reactor is assumed to be at steady state power with the primary heat exchanger

outlet temperature of 40°C at the time of loss of electrical power to the main panel.

Closing two of the valves increases the pressure drop in the down commer. To start natural convection flow, this relatively large pressure drop should be balanced by the driving force, which is the density difference between the two legs of the loop.

Computer calculations show that the core flow rate goes to zero with pump coast down, and it takes a while for natural convection to begin. During this short time, the decay heat released into the water increases the bulk temperature rapidly.

Although natural convection starts after a few seconds, the water flow is not enough to remove the decay energy from the core before boiling occurs. About 10 seconds after the accident, fuel surface temperature exceeds saturation at a height of 12 " from the bottom of the fuel plate in the hot channel. The natural convection mass flux at this time is about 7.8 $(lbm/ft.^2 sec.)$. This flow rate is not enough to remove decay heat and boiling proceeds to the top of the channel.

The fuel surface temperature at the time of
boiling is found to be 137.5°C at 12 inches from
the bottom and 145.5°C at the top of the fuel plate.
The sudden increase in the wall temperature is due
to single phase heat convection coefficient used in
the computer code. The correlation between the heat
transfer coefficient of single phase, h_{sp} and two
phase flow, h_{tp} could be shown as follows (Ref.3.5):

$$\frac{h_{tp}}{h_{sp}} = \frac{1}{1-\alpha} \qquad (5.1)$$

where α is the void fraction.

Using the right heat transfer coefficient,
suggested in Appendix D, would give a better and
more correct answer for the fuel surface temperature
above the saturation point.

4. Natural convection behavior of the MITR-II,
Core-4 is also studied for higher core outlet tempera-
ture scram set. In Case-4 it is supposed that scram
point is set at 55°C for an average core exit temper-
ature at steady state power of 5 MWth. This is
equivalent to a maximum temperature of 47°C for the
primary heat exchangers outlet temperature.

Figure 5.8 shows the hot channel inlet and outlet temperatures. Although the fluid outlet temperature reaches 100°C at the very top of the core, boiling does not occur because the saturation temperature at the corresponding pressure is 106°C.

The water temperature passes the peak point at about 10 seconds after the accident. At this time the fuel surface temperature is 104.5°C which is still a few degrees below saturation, Figure 5.9. Natural convection flow rate at the peak temperature is about 12 (lbm/ft.^{2}sec.), which decreases slowly with time.

The hot channel outlet temperature decreases to a minimum of 73°C and then increases slowly as the natural convection flow decreases. It is predicted that bulk boiling will occur at the top of the channel about 27 minutes after the accident.

Fuel surface temperature will reach saturation a few minutes later, about 32 minutes after the accident due to low energy production at the top of the fuel plate.

5. The computer analysis of the hot channel shows that boiling will occur at the top of the fuel plate if the core exit temperature scram set is at 60°C.
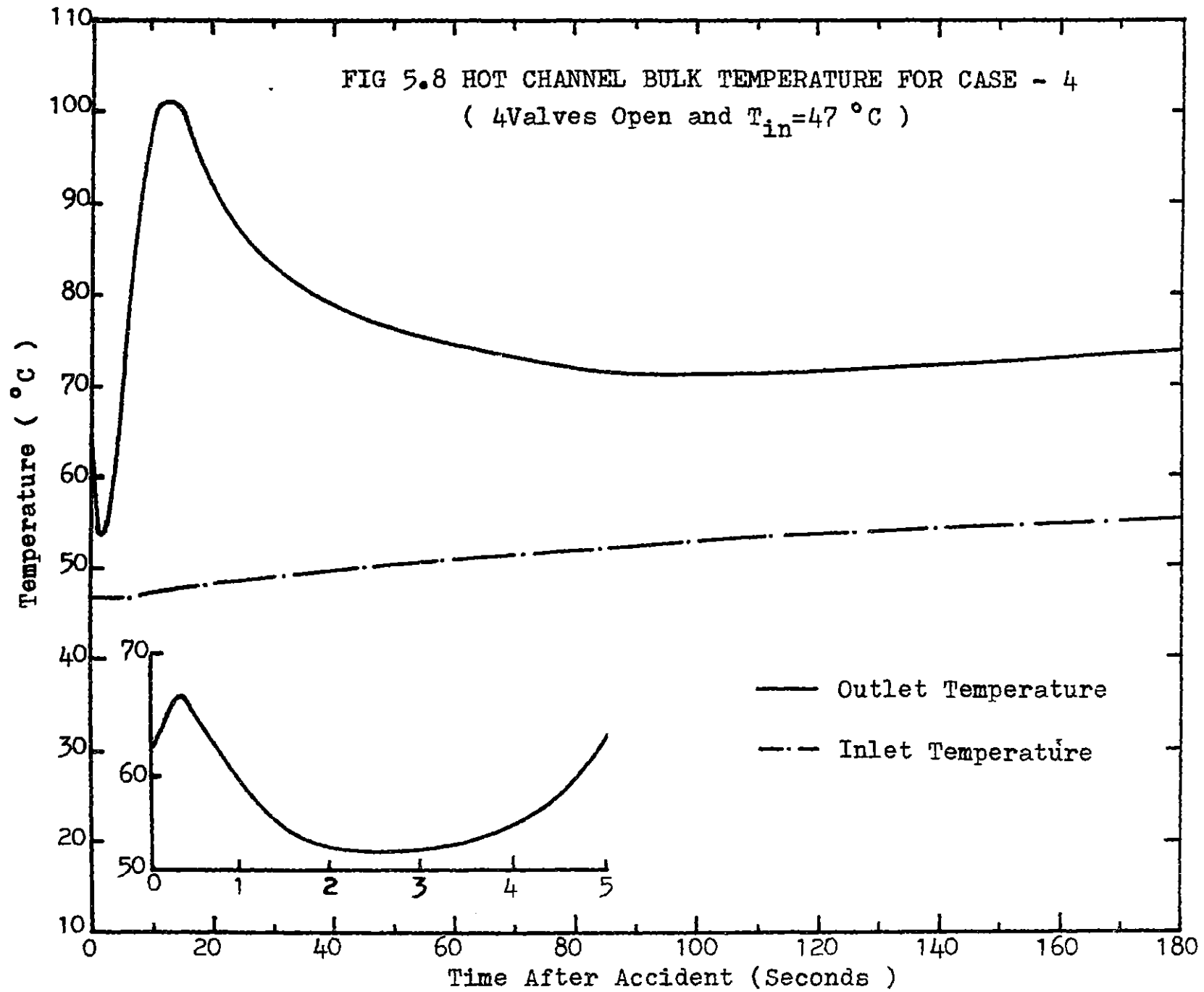
FIG 5.8 HOT CHANNEL BULK TEMPERATURE FOR CASE - 4
(4Valves Open and T_{in}=47 °C)

Temperature (°C)

Time After Accident (Seconds)

———— Outlet Temperature

—·—·— Inlet Temperature

FIG 5.9 HOT CHANNEL FUEL SURFACE TEMPERATURE FOR CASE-4
(4 Valves Open and T_{in} =47 °C)

T_{Max} at 23" from bottom

T_W at 4" from bottom

Temperature (°C)

Time After Accident (Seconds)
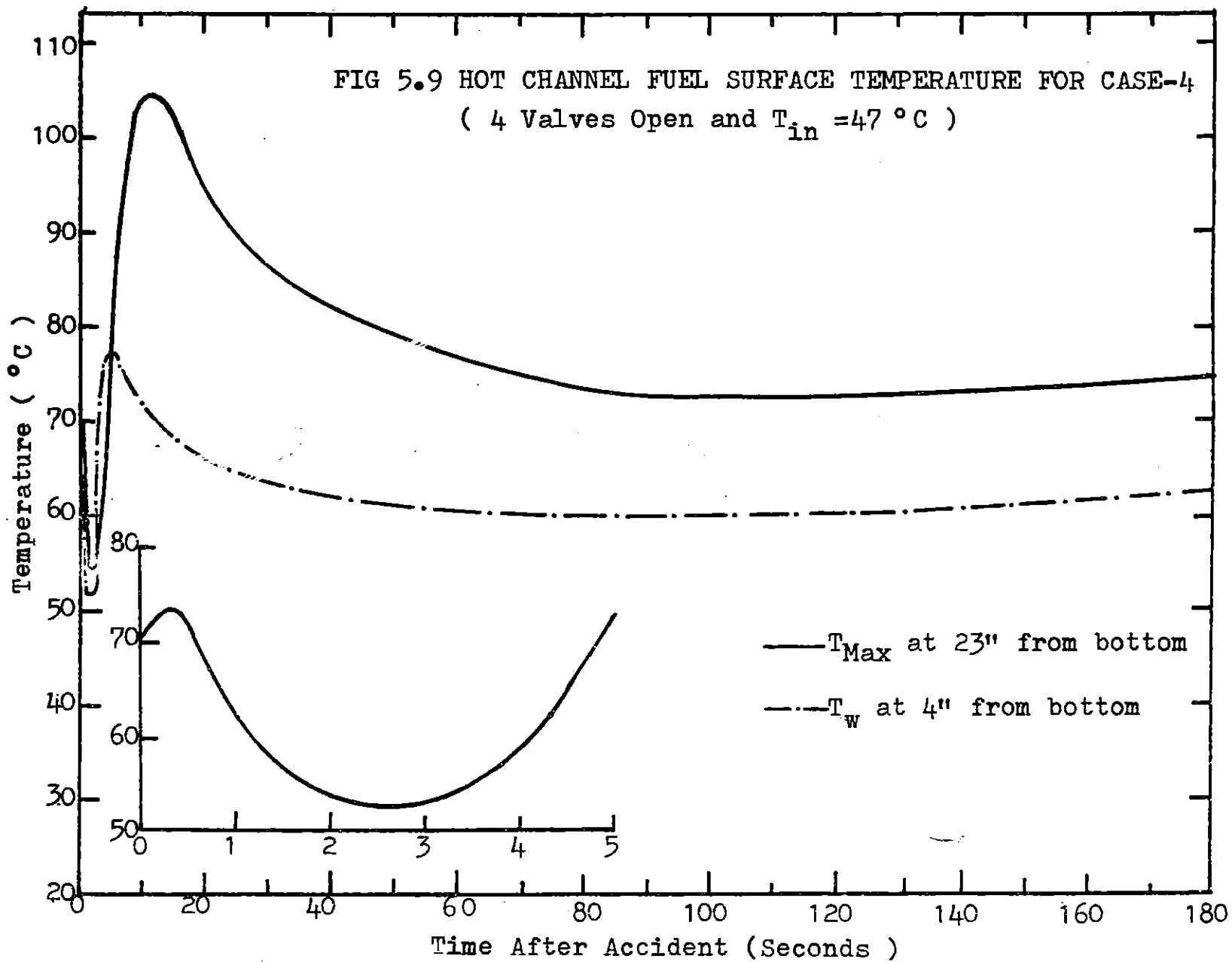
Figures 5.10 and 5.11 show the hot channel transient
calculations for the core inlet temperature of 52°C
which gives an average outlet temperature of 60°C
for 5 MWth steady state power.

Although all the natural convection valves are
open to flow, the fuel surface temperature exceeds
saturation point for one inch at the top of the fuel
plate. Figure 5.11 shows that the wall peak temperature
occurs at about 10 seconds after the accident. It can
be seen in Figure 5.12 that nucleation boiling
. starts at a height of 22 inches from the bottom of
the fuel plate at a temperature of 106.2°C. The
maximum fuel surface temperature, at this time, is 109.1°C
which is at the top of the fuel plate.

Boiling does not proceed in time and the wall
temperature decreases rapidly due to exponential
decay of the after scram heat generation.

The natural convection flow at the peak temp-
erature is about 13.2 (lbm/ft.^{2}sec.) which decreases
with decay heat.

The slow increase in the fluid temperature
due to natural convection flow reduction, leads to
boiling approximately 21 minutes after the accident.
Wall temperature reaches saturation a few minutes
later, at 23.5 minutes after the loss of flow accident.

FIG 5.10 HOT CHANNEL BULK TEMPERATURE FOR CASE - 5
(4 Valves Open and $T_{in}=52$ °C)

FIG 5.11 HOT CHANNEL FUEL SURFACE TEMPERATURE FOR
CASE -5 (4 Valves Open and T_{in}=52 °C)

——— T_{Max} at 23" from bottom

—·—·— T_W at 4" from bottom

Temperature (°C)

Time After Accident (Seconds)

FIG 5.12 HOT CHANNEL FUEL SURFACE TEMPERATURE
DISTRIBUTION AT THE PEAK POINT FOR CASE-5

Saturation Temperature

Temperature (°C)

Inches Along the Fuel Plate

Bottom   2   4   6   8   10   12   14   16   18   20   22 Top

5.4 Steady State Operation with Natural Convective Cooling

The previous section analyzed natural convection and its efficiency during a loss of flow accident.

In order to measure the power removal capacity of the natural convective cooling system in MITR-II, a case will be considered of steady state low power (100 KWth) operation with no forced flow in the core.

To be able to use Computer Code LOFA for this analysis, the initial conditions of a short term operation of 5 MWth is assumed in calculations. That is to say, it is supposed that the reactor was at full power long enough to give a containment tank mixed temperature equal to that of the core exit. Meanwhile, there was not a considerable decay heat buildup in the reactor prior to the test.

The reactor power, it is assumed, is lowered to 100 KWth at the same time that both primary pumps are stopped. Figure 5.13 shows the transient temperature calculation for average core power distribution. The rapid increase in the bulk and fuel surface temperature is due to pump coast-down. The natural convection flow rate increases to a maximum of 4.5 (lbm/ft.^{2}sec.) about 9 seconds after the pumps are stopped. Thereafter it decreases with a very small slope (0.004 lbm/ft.^{2}sec./sec.)

due to the temperature increase in the down commer.

From Figure 5.13 it can be predicted that boiling will begin on the surface at the top of the fuel plate about 49.5 minutes following the low power startup. Bulk boiling occurs one minute later at the top of the channel.

Although Figure 5.13 gives the transient temperature for average core distribution, the onset of nucleation boiling could be assumed to occur at the same time as in the hot channel. Figure 2.2 shows that the heat flux produced at the top of the average core channel is about 1.27 times that of the hot channel. This ratio is almost equal to the radial peaking factor for the hot channel. Therefore it can be assumed that nucleation boiling will occur at the same time in the hot channel as well as in the average core channel on the surface at the top of the fuel plate.

FIG 5.13 AVERAGE CORE CHANNEL TEMPERATURE
FOR NATURAL CONVECTION AT 100 KWth
STEADY STATE POWER OPERATION

------ Maximum Fuel Surface Temperature at 23" from Bottom

———— Average Core Outlet Temperature

—·— Core Inlet Temperature
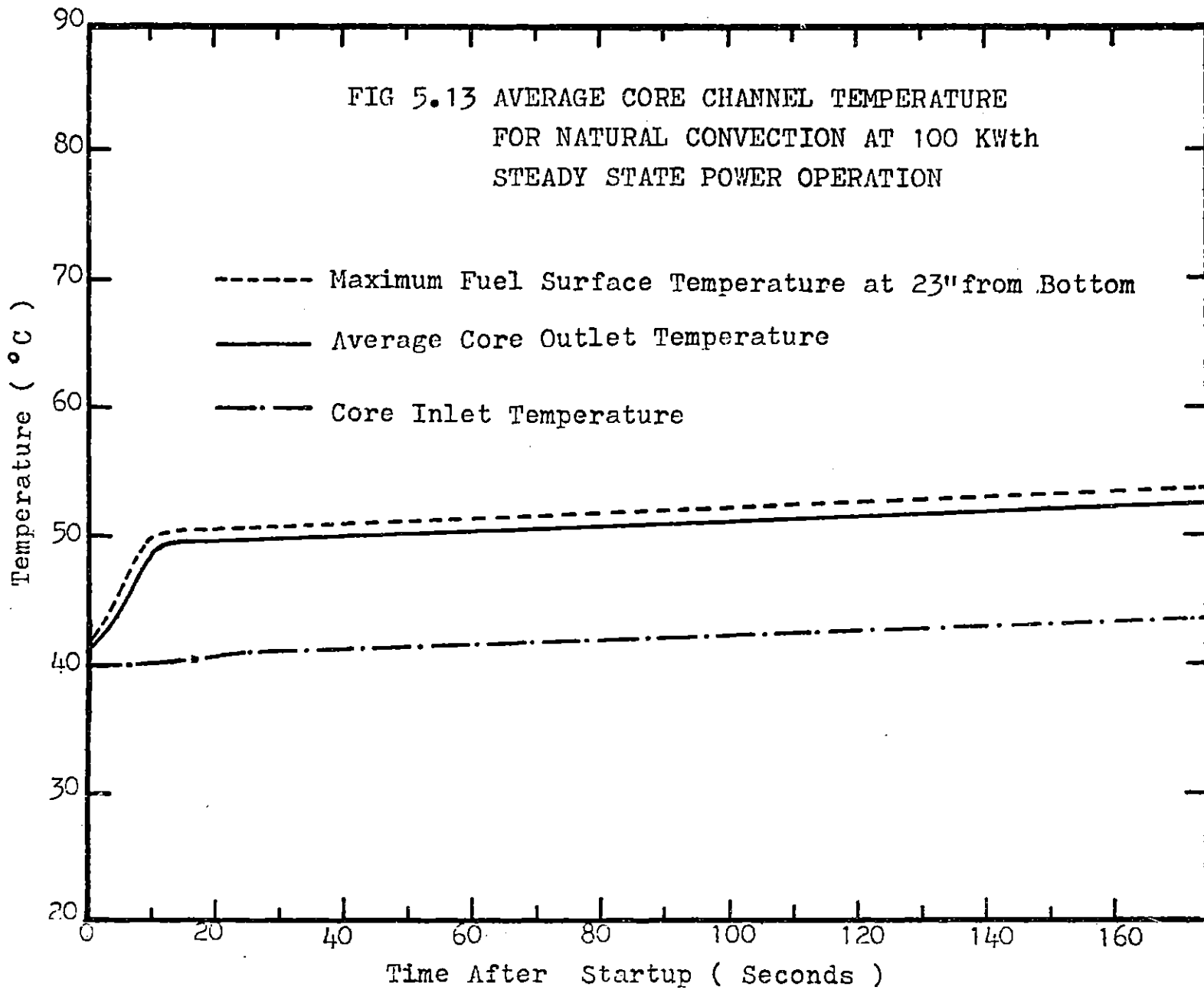
CHAPTER VI

CONCLUSION

6.1 Summary and Conclusion

The comparison between the computer code output
and the startup natural convection test measurements
for 5 MWth steady state power showed that single channel
code LOFA could be used for transient hot channel
calculations following a loss of flow accident.

The maximum temperature in the hot channel due
to loss of flow accident will not exceed saturation
during the first 58 minutes after the accident,even if
one of the natural convection valves remains closed.

For the primary heat exchanger outlet temperature
of 40°C, 5 MWth steady state power and 2000 gpm flow
rate, bulk boiling will start at the top of the hot
channel approximately 58 minutes following the accident,
if all the natural convection valves are openned.

In the case that one valve remains closed, the
hot channel fluid temperature increases immediately
to 98°C, however boiling will not occur any sooner
than 87 minutes after the accident. In this case
natural convection flow goes to zero and then reaches

a maximum of 13 (lbm/ft.^{2}sec.) at about 7 and 10 seconds
respectively after loss of flow.

Boiling will occur about 10 seconds following
the loss of flow accident, if two of the natural
convection valves remain closed. Fuel surface temperature
exceeds saturation point at a height of 12 inches
from the bottom of the fuel plate. For steady state
power of 5 MWth and core inlet temperature of 40°C, the
driving force after pump coast-down is not enough to
dominate the pressure drop in two of the incore check
valves. Boiling starts before natural convection flow
becomes large enough to remove the decay heat.

Changing the core outlet temperature to 55°C will
not cause boiling immediately after loss of flow
accident, if all the natural convection valves are openned
to flow. The maximum bulk temperature occurs about
10 seconds after the accident and is 100°C which corres-
ponds to a wall temperature of 104.5°C which is still
below saturation.

The bulk boiling, for core inlet temperature
47°C at 5 MWth steady state power, begins approximately
27 minutes after the accident.

Increasing the core exit temperature scram set
to 60°C will initiate boiling at the top of the fuel

plate about 10 seconds after loss of flow accident, even if all the natural conevection valves are openned to flow. The fuel surface temperature exceeds saturation by a few degrees C on the uppermost one inch of the top of the fuel plate. This nucleation boiling disappears due to exponential decrease in the decay heat.

Bulk boiling will start about 21.7 minutes following the accident for 5 MWth steady state operation if the containment tank scram set is at 60°C and all the natural convection valves are openned.

It is noted that long term transient boiling occurs in the bulk fluid at the top of the hot channel rather than on the fuel surface due to small contribution of that part of the fuel to the decay heat production.

Natural convective cooling is able to remove the steady state low heat generation in the core as well as the decay heat after loss of flow accident. The MITR-II could be operated for about 49 minutes at a steady state power of 100 KW with no forced flow before nucleation boiling starts. The operating time may be increased by decreasing the containment tank temperature. The time interval is for steady state full power tank temperature.

Low power natural convection steady state oper-
ation leads to nucleation boiling on the fuel surface
at the top of the fuel element.

6.2 Recommendations for Future Works

The natural convection analysis of the MITR-II
was previously studied by D.Choi (Ref.1.1) and by
A.Morales (Ref.2.5). The accidents were considered
to be primary pumps failure and reactor inlet coolant
pipe rupture, respectively.

The present work is one step closer to the final
analysis of the problem. It has the capabilty of
being used as a basis program for future works. The
computer code LOFA is written for single channel
calculations of the MITR-II during Loss of Flow Accident.
This includes loss of primary coolant due to pump trip,
reactor inlet pipe rupture, and failure in the electrical
power to the main panel.

A suitable finite difference model is used to
be able to consider the reverse flow in the case of
multi-channel calculations. It is found that Explicit
Cauchy Polygon Method which is used to intergrate
the energy equation is stable and applicable for both
upflow and reverse flow in the core.

The method used for natural convection flow calculation, allows the coolant channel not to contribute to the flow circulation, partially or as a whole. This happens when the driving force is just enough to balance the friction pressure drop or when the flow oscillation or reversal is about to occur.

A two dimensional array is used for major thermal properties such as enthalpy, temperature, density, vapor quality, heat flux and mass flow rate. The dimensions are on axial mesh points and transient time after the accident. Variables J and I are used for space and time, respectively.

In order not to use too much memory of the computer for long term transient calculations, only 100 spaces are specified for I. The computer program locates the new 100 transient calculations in the past memory storage as they are evaluated. This could be reduced to 20 positions in the memory, but it was found that 100 was the best condition for the down commer temperature and density calculations.

A sensitivity analysis of the computer code showed that 25 mesh points should be taken along the fuel plate to yield the most stable enthalpy calculations. This corresponds to a mesh distance of one inch.

A third dimension could easily be added to the
thermal properties to take into account the multi-
channel **effect. In other words a three-dimensional**
array could be used tor transient variables to
consider; time, axial position, and the corresponding
channel location.

It is found in this work that bulk boiling occurs
in the hot channel about 58 minutes following the
loss of flow accident, even though all of the natural
convection valves are openned to the flow. This
requires two phase flow analysis for long term transient
calculations. In Appendix D two phase flow parameters
are suggested for future work.

A more detailed natural convection analysis of
MITR-II could be made by combining the computer codes
LOFA and COBRA-IV. COBRA-IV is capable of natural con-
vection calculations if the pressure drop along the
core or flow rate is given as input to the code. Since
natural convection flow rate is governed by pressure
drop along the core, neither one could be used as input
to calculate the other one.

The computer code LOFA could be used to complete
an iteration cycle with COBRA-IV. In other words, COBRA-IV
can be used in stead of sub-program TRANS in LOFA for

transient calculations. The iteration cycle is completed in subroutine DOCO where the natural convection flow rate should be checked with the pressure drop along the loop.

Due to radial heat distribution in the core, pressure is not uniform at the top of the core in natural convection. To be able to use uniform pressure distribution in the computer code COBRA-IV, the height of the chimney could be added to the core length. This requires the cross flow calculations of COBRA-IV for the chimney, with zero heat generation, zero fuel thickness and water gap thickness equal to the fuel plate's.

This water gap allows cross flow between the nominal channels in the chimney due to density and pressure variation produced by different heat generations and different core channels.

APPENDIX A

COMPUTER CODE DESCRIPTION AND FLOW CHARTS

APPENDIX A

COMPUTER CODE DESCRIPTION AND FLOW CHARTS

A.1 Code Description

The Computer Code LOFA is written in FORTRAN and is able to follow the behavior of MITR-II after scram due to Loss of Flow Accident. It is capable therefore, of calculating the single channel steady state forced flow transient and natural convection.

Calculations start in Main program by evaluating the steady state operational conditions as is shown in Figure A.1.

Transient primary coolant mass velocity and pressure in the upper plenum is found in subroutine DOCO and the flow characteristic is decided and carried through by two factors NC and FFF. Positive values chosen by Natural Convection and Forced Flow Factor , NC and FFF respectively determine the domination of that flow.

Transient thermal properties in the core are evaluated in subprogram TRANS and based on them,mass velocity is calculated.

Subroutine TANK calculates the containment tank mixed enthalpy and thermal properties at the core entrance.

Time step size is determined in subroutine TIME as the smallest time interval it takes for flow to sweep the corresponding mesh distance.

Subfunctions CP, VISCH and DENSH are used to tabulize constant pressure specific heat,absolute viscosity and density of water against enthalpy respectively.

FIG. A.1 Flow Diagram of MAIN Program
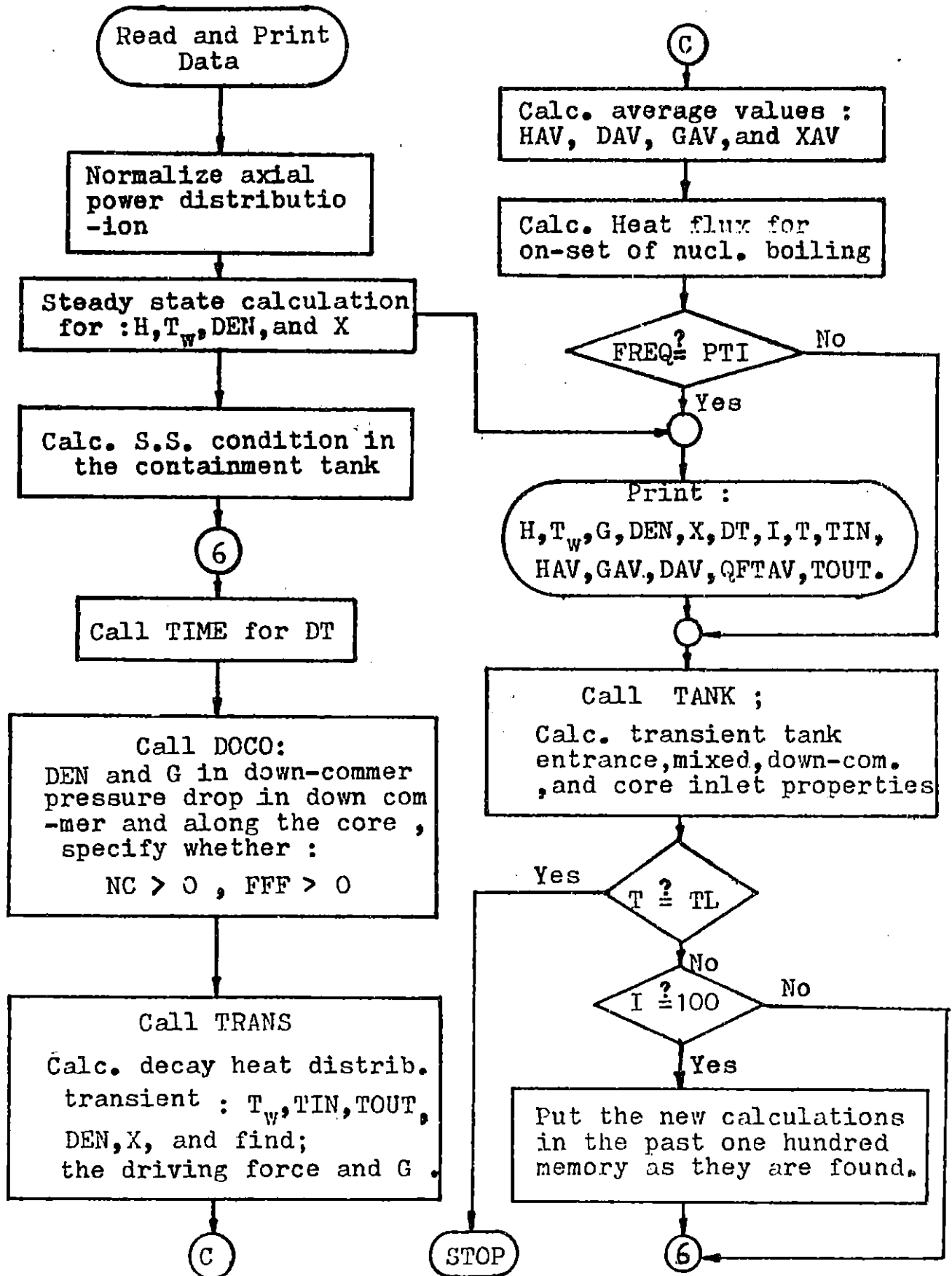
Heat Convection Coefficient is evaluated for different flow regemes in subprogram HCC as a function of enthalpy and mass velocit

Function subprogram PDROP calculates pressure drop in the dowr commer for both forced flow and natural convective cooling.

Friction Coefficient is evaluated in Function FRIC for various flow cross sections, pipe as well as rectangular channels, for different flow regemes.

Average density in the down commer is found in subfunction DAVDC from containment tank mixed density and thermal properties in the lower plenum.

A.2 Transient Pressure Drop in the Down Commer

Starting with the steady state flow conditions at the main flow meter (MF-1), Figure 3.3, Coastdown Equation 2.1 and 2.2 give transient mass velocity and pressure at that point. Subroutine DOCO evaluates the pressure drop along the flow up to the upper plenum. The natural convection valve opens as soon as the static pressure at the top of the ball balances the hydraulic pressure at the bottom. When the ball drops there will be a pressure difference equal to the weight of the ball which causes upflow through the valve, until the driving force becomes zero due to flow coastdown.

The reverse flow in the natural convective valve can be found from conservation of mass and momentum through the valve:

$$G_{rv}^2 + G_{dc}^2 - G_{en}^2 + 2\rho g_c(P_{up} + \Delta P_{rv}) = 0 \qquad (A.1)$$

$$A_{rv}G_{rv} + A_{dc}G_{dc} = A_{en}G_{en} \qquad (A.2)$$

where

G is the mass velocity (lbm/sq.ft./sec.)

P_{up} is the pressure in the upper plenum at the time of ope

P_{rv} is the pressure drop in the valve due to reverse flow

$\Delta P_{rv} = K_{rv}G_{rv}^2/2\rho g_c$, with K being the form factor for rever.
flow,

A is the flow cross sectional area,

ρ is the density of water (lbm/cu.ft.),

g_c is the conversion factor (32.2 lbm.ft./lb$_f$.sec.^{2}),

and subscript rv, en, and dc refer to reverse flow, upper plenum en-
trance and down commer respectively. It is assumed that pressure
at the bottom of the natural convection valve is equal to that of
the entrance of the down commer. Solving Equations A.1 and A.2
simultaneously gives the upflow in the natural convection valve
and mass velocity in the down commer right after the valves open.

Subroutine DOCO is shown as flow diagram in Fiagure A.2 to
solve Equations A.1 and A.2. It also determines, after the valve
opens, when natural convection will occur. The values for natural
convection and forced flow factors, NC and FFF, discussed earlier
in this chapter are also determined in this subprogram.
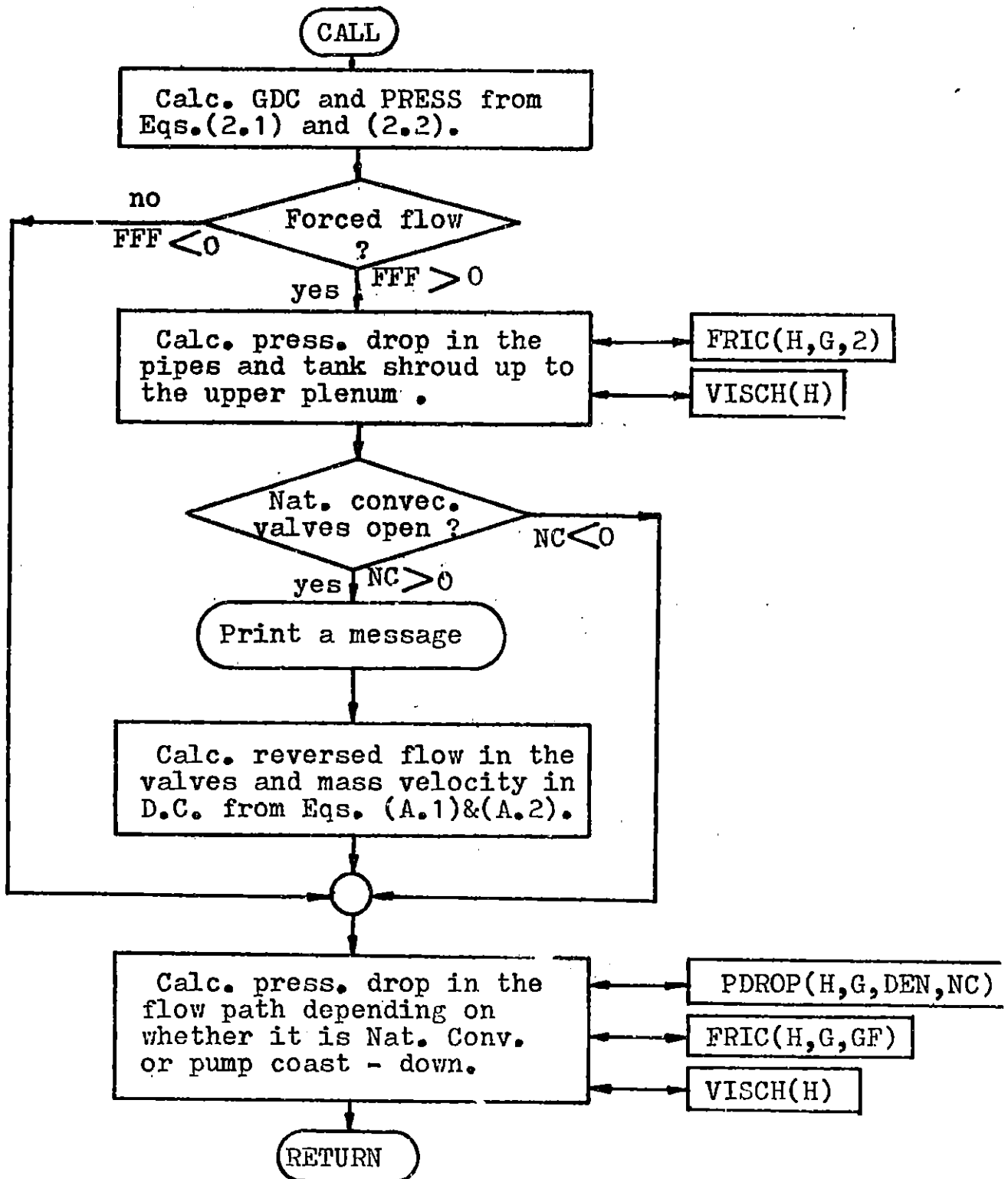
FIG. A.2 Flow Diagram of Subprogram DOCO

A.3 Transient Core Calculations

Decay heat generation is evaluated based on Equations 2.5, 2.7, 2.8 and 2.10 for delayed neutrons, delayed photoneutrons, fission products and activated core materials respectively. Transient core calculations are done in subroutine TRANS, whose flow diagram is shown in Figure A.3.

As discussed before, natural convection flow depends on the pressure drop in the loop as well as the driving force which is the density difference between down-flow and up-flow. These forces might balance and as a result there will be no flow in the loop for a while until the density in the core reduces due to release of decay heat into the water.

Another reason for no flow in the core is when flow reversal happens. For a short period of time there is no flow in the loop until one of the forces dominates and the fluid goes in that direction. Reverse flow is not included in the computer program, but to be conservative, its effect is considered in subprogram TRANS. In the case of reversed flow, the fluid is assumed to be stationary and transient calculations are performed in the direction of the reversed flow. In this case the core inlet properties are assumed to be those right at the top of the core, namely core outlet characteristics in the past time intervals. This yields more conservative values for core calculations and also makes the computer code more suitable for reverse flow transients.
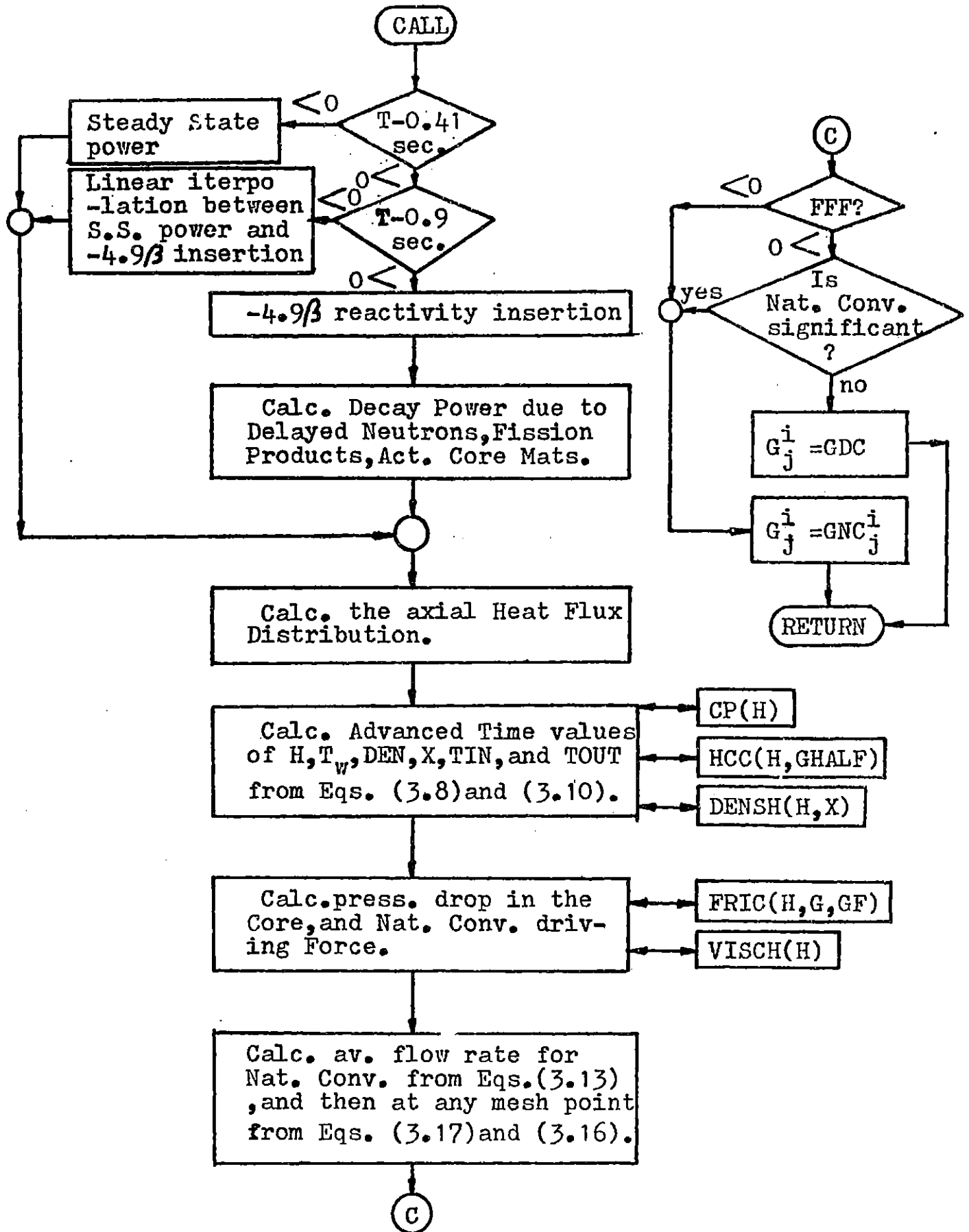
FIG. A.3 Flow Diagram of Subprogram TRANS

At any advanced time interval, t^{i+1} , average natural convective

coolant flow is evaluated from Equation 3.13 by using thermal

properties at time (i+1) and then corresponding mass velocity for

each mesh point is calculated from Equations 3.17 and 3.16 as was

shown in Figure 3.1. If the calculated flow is negative, which

means that the flow is reversed the mass velocity is presumed to

be zero or 0.0001 lbm/sq.ft./sec..

Logic START is used in this subprogram to specify the start

of natural convection only. As soon as natural convection flow

dominates, START picks positive values.

A.4 Calculation of Core Entrance Properties

Using Characteristic Method for enthalpy calculation, needs

the core entrance enthalpy to be evaluated from the loop properties.

Subroutine TANK is written to find the enthalpy and density of

water in the lower plenum at any time to proceed the core calculations

Figure A.4 shows the Subprogram TANK.

In transient forced flow, neglecting the friction power trans-

mission, the core entrance properties are the same as the heat

exchangers outlet.

When natural convection starts, the relatively cold water in

the down commer is removed by the hot water coming down the chimney

through the natural convection valves. At any time interval the amount of water entering the core is the same as that moving down from the containment tank into the chimney.

Stepwise enthalpy rise is considered for the tank mix calculations. A volume of VF(L) is assumed to enter the down flow path at some mixed tank enthalpy of HVF(L). This volume is moved down at constant temperature, by some amount of water VF(L+1) entering in the next time interval with some temperature. This continues until VF(L) reaches the lower plenum and enters the core gradually by natural convection. Depending on the flow rate, the temperature of the water entering the core is constant for a while until the next constant temperature volume of water reaches the lower plenum.

The amount of time it takes for any amount of water to reach the lower plenum is calculated from the down flow path volume, namely the volume between the containment tank and the chimney, VCHY, and the down commer volumes, VDC.

CALL

FFF? — o.< / <o.

Set the Channel Inlet Density and Enthalpy equal to the Heat - exchanger outlet Temp.

Calc. the Total Core Outlet Flow rate ,and Volume;VF(L).

Set the Mixed Tank Enthalpy and Quality equal to those at the Channel Exit condition

Calc. HMIX,XTANK,DTANK
$HVF(L)= HMIX(I+1)$
$DVF(L)=DTANK(I+1)$
$VFT=VFT+VF(L)$

o.< — $VFT \overset{?}{-} VDC$ — ≤ o.

≤ o. — $VFT \overset{?}{-} VCHY$ — o.<

Cold Water flow
$DLP(I+2)=DIN$

S.S. tank water
$H(I+2,1)=H(1,NM)$
$DLP(I+2)=D(1,NM)$

new vol.of water
$H(I+2,1)=HVF(K)$
$DLP(I+2)=DTANK(K)$

≤ o. — $VFL-0.7VF(K-1)$? — o.<

Partially removed
$VFLK=VFLK+VF(L)$

Allremoved togeth.
$VFT=VFT-VF(K-1)$
$H(I+2,1)=HVF(K)$
$DLP(I+2)=DVF(K)$

< o. — $VFLK \overset{?}{-} VF(K-1)$ — o.≤

Old enthalpy enters
$VFT=VFT$
$H(I+2,1)=HVF(K-1)$
$DLP(I+2)=DVF(K-1)$

New enthalpy enters
$VFT=VFT-VF(K-1)$
$H(I+2,1)=HVF(K)$
$DLP(I+2)=DVF(K)$

RETURN

FIG . A.4 Flow Diagram of Subprogram TANK

APPENDIX B

Input Data Cards

Card No.	Variable	Format and Explanation
CARD 1		2I9,3F9.0
	NM	Number of axial mesh points, considering the first one to be in the lower plenum.
	NOV	Number of Natural Convection Valves open to the flow.
	TL	Time Limit for transient calculations, (sec.)
	PTI	Printing Time Interval, every PTI calculation will be printed in output.
	CHN	Total Number of heated channels in the core.
	CDT	Coast-down time which is from pump trip to zero flow of primary pumps, (seconds).
	DTS	Specified time intervals for transient calculations. This will be compared with time intervals determined in subroutine TIME and the minimum will be chosen, (seconds).
	ZL	Total axial length of fuel plates (heated and unheated), (ft.).

Card No.	Variable	Format and Explanation
CARD 2		7E9.5
	THMW	Thermal power of the reactor before scram, (MWth).
	GPM	Total primary flow rate of the reactor before scram, (gpm).
	HIN	Steady state enthalpy at the entrance of the core, (Btu/lbm).
	PIN	Total steady state pressure of the primary coolant measured at the nozzle MF-1, (psia).
	THE	Primary Heat Exchanger outlet temperature, ($^{\circ}$C).
	SPV	Primary Heat Exchanger outlet specific volume, (ft.^{3}/lbm).
	CPP	Primary Heat Exchanger outlet specific heat capacity at constant pressure, (Btu/lb$^{\circ}$F).

Card No.	Variable	Format and Explanation
CARD 3		7E9.5
	HSAT	Saturation liquid enthalpy at the core exit pressure,(Btu/lbm).
	HFG	Latent heat of evaporatiOn of water at the core exit pressure, (Btu/lbm).
	RO	Total negative reactivity insertion, (ΔK/K).
	BEFF	Effective total delayed neutrons fraction, (Beff).
	GAMA	Fraction of heat generated directly in the coolant.
	FR	Radial peaking factor.
	VTANK	Volume of the water in the containment tank, above the core.
CARD 4		6E9.5
	GA,GB, GC,GD	Constants which determine the curve fit to the flow as a function of time after pump coastdown; $G(t)=(GIN)\left[GA/\exp(GB)t + (GC)\ t-(GD)\right]$.
	PA,PB	Constants which determine pressure as a function of time after pump coastdown $PRESS(t)=(PIN)\left[(PA)t+1\ /\ (PB)t+1\right]$.

Card No.	Variable	Format and Explanation
CARD 5		8E9.5
	DSL	Hydraulic diameter of the shroud (shown[*] by cross section A_3),(ft.).
	DP	Primary coolant pipe diameter between nozzle MF-1 and the entrance to the reactor tank (shown as A_1), (ft.).
	DDC	Down Commer hydraulic diameter (shown as A_4), (ft.).
	DSA	Hydraulic diameter for the upper part of the reactor tank (shown as A_2), (ft.).
	DBL	Natural convection ball diameter (ft.).
	DCH	Core flow channel equivalent diameter(ft.).
	DCL	Down Coming flow passway length which is the summation of the height of the chimney, natural convection valve, and the down commer itself,(ft.).
	BP	Base perimeter of the coolant channel used in fin effectiveness calculation, (ft.).

* It is referred to Figure B.1

Card No.	Variable	Format and Explanation
CARD 6		8E9.5
	AP	Cross sectional area of the primary coolant pipe to the reactor, (ft^2).
	ASH	Reactor tank upper part flow pass (shown as A_2), (ft^2).
	ASHL	Flow pass cross sectional area for the shroud (shown as A_3), (ft^2).
	AUP	Upper plenum average cross sectional area (shown as A_6), (ft^2) *.
	AVI	Natural convection valve inlet flow area (ft^2).
	AVO	Natural convection valve outlet flow area (ft^2).
	ACH	Core coolant channel flow area, (ft^2).
	AENT	Upper plenum entrance cross sectional area (shown as A_5), (ft^2) *.

* These values are used for expansion pressure drop in the upper plenum

Card No.	Variable	Format and Explanation
CARD 7		8E9.5
	FKN	Friction coefficient for primary coolant pipe knee bends,(dimensionless).
	FKO	Orifice friction coefficient for flow meter MF-1.
	FKP	Primary coolant pipe surface friction coefficient.
	FKS	Shock friction coefficient for area change in reactor tank (shown as point P_3).
	FKD	Shock friction coefficient for flow entering the upper plenum,(shown as point P_4).
	FEN	Core entrance form coefficient.
	FKV	Form coefficient for the natural convection valve(down flow).
	FKR	Form coefficient for the natural convection valve (up flow).

Card No.	Variable	Format and Explanation
CARD 8		8E9.5
	HTK	Height of water in the tank above the natural convection valve,(ft.).
	HV	Height of the natural convection valve(ft.
	HC	Core height which includes fuel plate and endings,(ft.).
	HSU	Vertical height of the upper part of the reactor tank (shown as P_2P_3),(ft.).
	HSL	Vertical height of the shroud (shown as P_3P_4),(ft.).
	HLP	The length of the primary coolant pipeline from the Main flow meter (MF-1) to the reactor entrance (shown as P_1P_2),(ft.)
	HPI	Vertical height of the reactor entrance to the center line of the main flow meter (shown as H_0H_1),(ft.)
	CHYH	Total height of the chimney,(ft.).

Card No.	Variable	Format and Explanation
CARD 9		8E9.5
	HCH	Core coolant channel half width,(ft.).
	WFIN	Width of the fin(ft.).
	HFIN	Height of the fin,(ft.).
	FEX	Form coefficient of the core channel exit, (dimensionless).
	FKUP	Form coefficient at the exit of the natural convection valve to the upper plenum per unit area ratio.*
	AUC	Down commer flow cross sectional area, $(ft.^2)$.
	ALK	Aluminum thermal conductivity used for fuel cladding, $(Btu/ft.sec.^\circ F)$.
	RSS	Stainless steel density used for natural convection valve,$(lbm/ft.^3)$.

*   Depending on how many valves are openned to flow, the total
    form coefficient is found as follows:

$$K=(1-FKUP \cdot AVO \cdot NOV/AUP)$$

Card No.	Variable	Format and Explanation
CARD 10		8E9.5
	HFGTK	Latent heat of evaporation of water at the average containment tank pressure, (Btu/lbm).
	HSATK	Saturation enthalpy of water at the average containment tank pressure, (Btu/lbm).
	VDC	Total volume of the down commer from the upper plenum to the lower plenum, (cu.ft.).
	VCHY	Total volume of the water between the chimney and the shroud,(cu.ft.).
	VG	Specific volume of saturated vapor at the core exit pressure,(cu.ft./lbm).
	VF	Specific volume of the saturated water at the core exit pressure,(cu.ft./lbm).
	TCF	Thermal conductivity of water at the average core pressure,(Btu/sec./ft./°F).
	CHNT	Total number of channels, heated plus unheated in the core.

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Card No.	Variable	Format and Explanation
CARD 11		12F6.2
		The number of input cards is equal to NM/12
	FQZ	Axial power distribution in the steady state condition. It does not need to be normalized because normalization will be performed in the code. Each valve should show the relative power at the mesh point starting from the lowest point of the fuel plate.
CARD 12		2F8.6 six cards for decay precursors
	BI,DLI	β_i and λ_i in Equation 2.5, namely delayed neutron yield and decay constant of the ith precursor.
CARD 13		2F10.8 eight cards for delayed photoneutrons
	Y,AL	Y_j and λ_j in Equation 2.7, i.e. the total number of photoneutrons and the decay constant of group j per fission of U-235
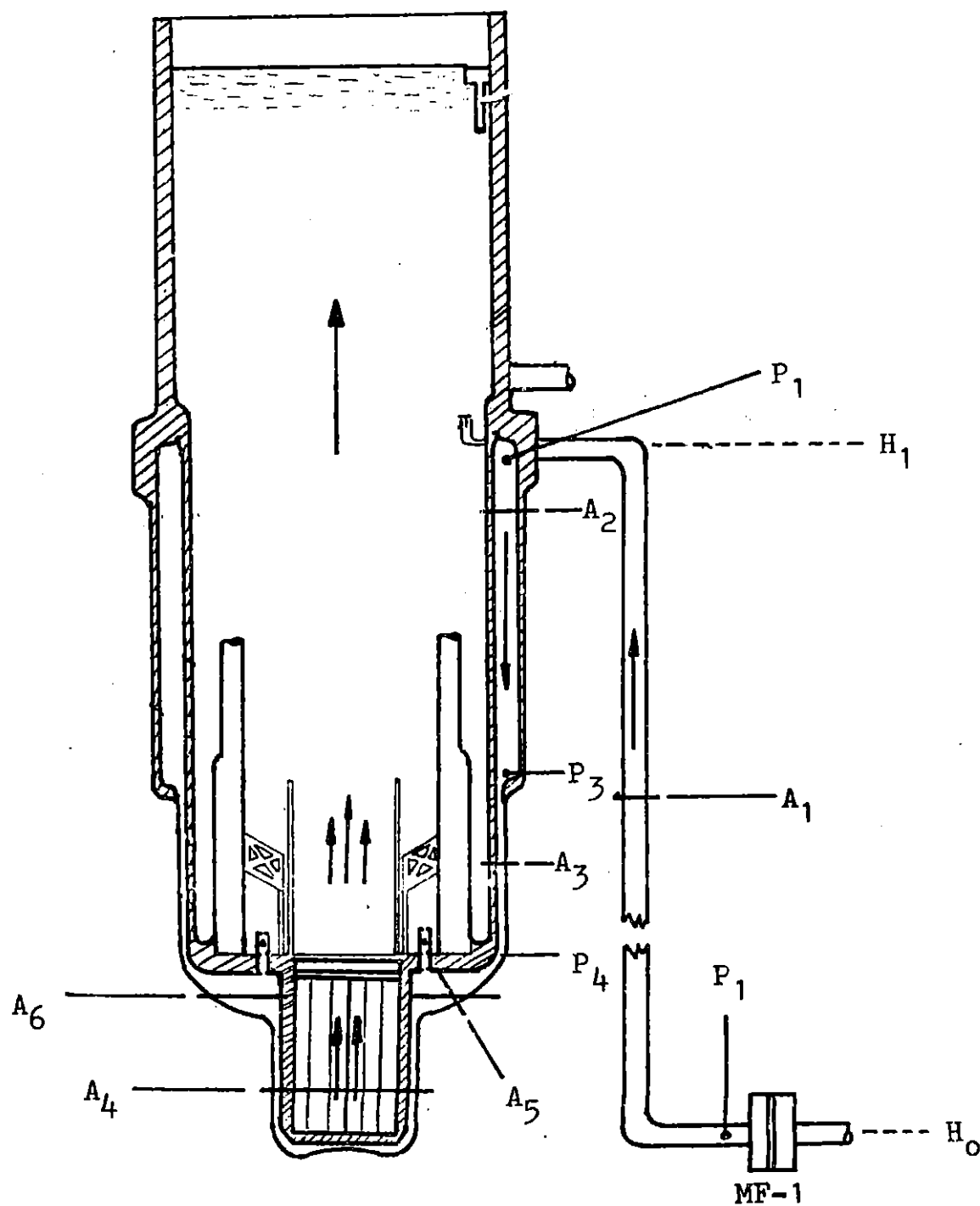
FIG . B-1

Nomenclature to the Computer Code LOFA

Throughout the computer program, the following parameters are used as defined below:

Parameter	Description
I	An array of hundreds of vectors to show time steps.
J	An array of NM vectors for mesh point.
POWER	Steady state thermal power, Btu/sec.
PRMTR	Parameter used in fin efficiency = $\frac{2(HFIN + WFIN/2)}{ALK \times WFIN}$
GIN	Steady state flow rate, $\text{lbm/ft.}^2\text{/sec.}$
GSCR	Scram set flow rate, $\text{lbm/ft.}^2\text{/sec.}$
DZ	Axial mesh distance, ft.
HWV=HTK	Height of water in the tank above the core equal to the height of the tank, ft.
FQZA(J)	Percentage of axial power produced at mesh point j, 1/ft.
QZF(J)	Axial power generated per unit length at mesh point j, Btu/ft/sec.
H(I,J)	Enthalpy at mesh point j at time I, Btu/lbm.

Parameter	Description
TW(IJ)	Wall temperature at mesh point J at time I, (^{o}F).
X(I,J)	Steam quality at mesh point J at time I.
DEN(I,J)	Density at mesh point J at time I($lbm/ft.^3$.)
G(I,J)	Flow rate at mesh point J at time I($lbm/ft.^2/sec.$)
T	Time passed after scram,(sec.)
QZAV	Average axial power deposited in the coolant between two mesh points per unit length, (Btu/ft./sec.).
RENO	Reynold's number.
HCCA	Convection heat coefficient in steady state power calculation, (Btu/ft.^{2}/sec./^{o}F).
ETHA	Fin effectiveness defined in Equation 3.24.
P	Effective perimeter of finned fuel plate, (ft.).
QFAV	Average power flux deposited in the coolant between two mesh points, (Btu/ft.^{2}/sec.).
TIN	Core inlet coolant temperature, (^{o}C).
TOUT	Core outlet coolant temperature,(^{o}C).

Parameter	Description
DTANK(I)	Containment tank average density, $(lbm/ft.^3)$.
T	Time passed after reactor scram, (sec).
DT	Time interval calculated in subroutine TIME from flow speed for transient calculation ,(sec.).
HAV(I) GAV(I) DAV(I)	Average enthalpy, (Btu/lbm), flow rate, $(lbm/ft.^2/sec.)$, and density, $(lbm/ft.^3)$, respectively, over the core length at time step I.
PJ	Absolute pressure at mesh point J, (psia).
TSAT	Saturation temperature at mesh point J, $(^\circ F)$.
QONB	Heat flux for the onset of nucleation boiling, Equation 3.20, $(Btu/sec./ft.^2)$.
HAVR=HAVP GAVR=GAVP DAVR=DAVP	Average enthalpy, (Btu/lbm), flow rate, $(lbm/ft.^2/sec.)$, and density, $(lbm/ft.^3)$, respectively over the length of the core in previous time interval.
HP(I,J) GP(I,J) DENP(I,J)	Enthalpy, (Btu/lbm), flow rate, $(lbm/ft.^2/sec.)$, and density, $(lbm/ft.^3)$, respectively at mesh point J at previous time step I.
HTAV GTAV DTAV	Average containment tank enthalpy, (Btu/lbm), flow rate, $(lbm/ft.^2/sec.)$, and density, $(lbm/ft.^3)$, respectively.

Parameter	Description
FREQ	Frequency of printing interval, computer calculation will be printed out whenever this variable becomes equal to PTI,(input).
DTP	Time interval calculated in the past time step, (sec.).
DELT(J)	Time interval it takes for flow rate to sweep the mesh distance J, J-1.
REF	Reference number, some large number used in subroutine TIME for comparison in order to find the minimum time interval, (sec.).
DTC	Minimum time interval it takes for flow to sweep some mesh distance. This value will be compared with the input time interval, (DTS)and the smaller value will be chosen, (sec.).
FKVO, FKVR	Total friction coefficient calcula ed for the number of natural convection valves open to the flow for downflow and reverseflow.
AVIN, AVOO	Total area open to natural convection at the top (inlet) and at the bottom (outlet) of natural convection valves respectively, $(ft.^2)$.
GDC	Down commers flow rate in pump coast down, (forced flow), $(lbm/ft.^2/sec.)$.

Parameter	Description
PRESS	Absolute pressure in pump coastdown at any time T, ($lbf/ft.^2$).
GDCP	Value of GDC in past time interval.
NC	Logic used for natural convection, it is positive whenever natural convection valves are open and negative when they are closed.
FFF	Forced Flow Factor, a logic which has a positive value when natural convection flow is dominant and it is negative when the flow is forced by a pump.
DPFP DPFS DPFD	Friction pressure drop in leading pipes, shroud of the containment tank, and down commers respectively, ($lbf/ft.^2$).
DPSP DPSS	Shock pressure drop due to area changes in leading pipes and shroud respectively, ($lbf/ft.^2$).
DPAS	Spacial accelleration drop to the upper plenum, ($lbf/ft.^2$).
DPEP DPES	Pressure drop due to elevation in leading pipes and the shroud respectively, (lbf/ft^2).
PHV	Absolute pressure at the top of natural convection valves, (atmospheric plus height of water), ($lbf/ft.^2$).
PBAL	Pressure due to weight of natural convection balls, ($lbf/ft.^2$)

Parameter	Description
AA,BB, RAD,CC	Parameters used to calculate the upflow in the natural convection valves right after opening, if there is any.
GD1, GD2	Calculated valves of flow rate which might upflow through the natural convection valves, $(lbm/ft.^2/sec.)$
GV,GD	Flow rate departed up into the natural convection valve as reverse flow, and down into the down commer right after opening, respectively, $(lbm/ft.^2/sec.)$.
DPV	Friction pressure drop in natural convection valves due to reverse flow (upflow),$(lbf/ft.^2)$.
DPDC	Total pressure drop in the down commer as far as core inlet , $(lbf/ft.^2)$.
QACT	Heat generated due to activated core material, (Btu/sec.).
QDN	Energy reduced by delayed neutrons, (Btu/sec.).

Parameter	Description
QFP	Heat released from fission products after scram, (Btu/sec.).
Q	Total energy produced after the scram per unit time, (Btu/sec.).
QZT (I,J)	Decay power produced at time step I and mesh point J per unit length (Btu/ft. sec·).
GHALF, DHALF	Average flow rate over two mesh points, ($lbm/ft._^2$/sec.) and($lbm/ft._^3$)
QZTAV	Average decay power deposited in the coolant per unit length, (Btu/ft./sec).
QFTAV	Average effective decay power flux deposited in the coolant, ($Btu/ft._^2$/ sec.).
ALFA	Dimensionless factor used in transient enthalpy calculation $= \dfrac{G \ x \ T}{P \ x \ Z}$
FFR	Average friction pressure drop in the core, ($lbf/ft._^2$).
FSH	Shock pressure drop due to area changes at the inlet and outlet of the core, ($lbf/ft._^2$).
FSA	Spacial acceleration pressure drop in the core, ($lbf/ft._^2$).

Parameter	Description
DFDEN	Pressure difference between the down commer and core due to density difference, ($lbf/ft.^2$).
DFCHY	Pressure difference between the two legs of the loop because of density difference in the chimney and the containment tank, ($lbf/ft.^2$).
DH, DDEN	Enthalpy and density difference between two succeeding mesh points.
AAV	Dimensioless factor used to calculate flow rate, $$AAV = \frac{\frac{DDEN}{DH} + DH}{DENAV}$$
AAL	λ, defined in Equation 3.15.
BAV	β, defined in Equation 3.15.
DD	δ, defined in Equation 3.16.
GG	γ, defined in Equation 3.16.
GGAV	$\bar{\gamma}$, defined in Equation 3.17.
DDAV	$\bar{\delta}$, defined in Equation 3.17.
AGRID	Total core cross sectional flow area, ($ft.^2$).
DLP(I)	Density in the lower plenum at time step I, ($lbm/ft.^3$).
HMIX(I)	Mixed containment tank enthalpy at time step I, (Btu/lbm).

Parameter	Description
XTANK(I) DTANK(I)	Containment tank mixed quality and density at time step I, (lbm/ft.^{3}).
AM	Total mass flow rate in the core, (lbm/sec.).
L	Variable used for enthalpy and density calculation in the lower plenum starting with the beginning of natural convection.
K	Variable used to balance the volume of hot water entering the tank and volume of cold water at constant enthalpy in the down commer ready to enter the core.
VF(L)	Volume of hot water entering the tank at time step L, (ft.^{3}).
HVF(L) DVF(L)	Enthalpy and density of hot water entering the down commer at time step L.
TNC	Logic used in subroutine TANK, it is positive if the relatively cold water in the chimney has all passed into the core and negative if it has not yet.
RNF RNH	Reynold's number defined for friction coefficient calculation.

Variable	Description
GF	Geometry factor used for friction coefficient calculation, it has a value of 0 for circular cross sections and 11 for rectangular ones.
F1	Friction coefficient for laminar flow RNF < 2300.
F3	Friction coefficient for transient flow $4000 \leq RNF < 51094$.
DAVDC	Average down commer density, $(lbm/ft.^3)$.
DPFD	Pressure drop in the down commer due to friction, $(lbf/ft.^2)$.
DPVL	Friction pressure drop in natural convection valves, $(lbf/ft.^2)$.
C_p	Constant pressure specific heat, $(Btu/lbm/ F)$.
VISCH	Absolute viscosity, $(lbm/sec./ft.)$.
HCC1 HCC2	Heat convection coefficient for laminar and turbulent flow respectively, $(Btu/ft.^2/sec./°F)$.

APPENDIX C

C.1   Computer Code Listing

C.2   Sample Output for Case-1 (4 In-Core Valves Open)

```
C     *****************************************************************     MAIN0001
C     *                                                               *     MAIN0002
C     *            COMPUTER CODE 'LOFA'                               *     MAIN0003
C     *     FOR NATURAL CONVECTION CALCULATION OF MITR-II             *     MAIN0004
C     *          DURING LOSS OF FLOW ACCIDENT                         *     MAIN0005
C     *                                                               *     MAIN0006
C     *****************************************************************     MAIN0007
      DIMENSION H(100,50),TW(100,50),G(100,50),X(100,50),XAV(100)          MAIN0008
     D  ,FQZA(50),FQZ(50),QZF(50),DEN(100,50),BI(7),DLI(7),DTANK(100),     MAIN0009
     D   GAV(100),DAV(100),HP(100,50),GP(100,50),DENP(100,50),HAV(100),    MAIN0010
     D    DLP(100),QFTAV(100,50),DVF(10000),Y(8),AL(8),QONB(50)            MAIN0011
      COMMON/TS/ITL,DLI,BI,RO,BEFF,POWER,FQZA,HSAT,HPG,GAMA,P,FEN,FEX,BP   MAIN0012
C              ,AL,Y                                                       MAIN0013
      COMMON/TI/H,DTS,DTC                                                  MAIN0014
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF                              MAIN0015
      COMMON/TK/HIN,ACH,CHN,ADC,DCL,VTANK,START,HFGTK,HSATK,VDC,VCHY       MAIN0016
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                    MAIN0017
      COMMON/DK/ DLP,DTANK                                                 MAIN0018
      COMMON/LK/L,K,DVF,TNC                                                MAIN0019
      COMMON/DC/ GA,GB,GC,GD,PA,PB,GIN,PIN,THE,CPP,CDT,RSS,HTK,HV,         MAIN0020
C              HSU,HSL,HLP,HPI,HWV,DSL,DP,DSA,DBL,AP,ASH,ASHL,AENT,        MAIN0021
C              AUP,AVI,AVO,FKN,FKO,FKP,FKS,FKD,FKV,FKR,FKUP,NOV            MAIN0022
      READ(5,510) NM,NOV,TL,PTI,CHN,CDT,DTS,ZL,                           MAIN0023
     R       THMW,GPM,HIN,PIN,THE,SPV,CPP,                                 MAIN0024
     R       HSAT,HPG,RO,BEFF,GAMA,FR,VTANK,                               MAIN0025
     R       GA,GB,GC,GD,PA,PB,                                            MAIN0026
     R       DSL,DP,DDC,DSA,DBL,DCH,DCL,BP,                                MAIN0027
     R       AP,ASH,ASHL,AENT,AUP,AVI,AVO,ACH,                            MAIN0028
     R       FKN,FKO,FKP,FKS,FKD,FEN,FKV,FKR,                              MAIN0029
     R       HTK,HV,HC,HSU,HSL,HLP,HPI,CHYH,                              MAIN0030
     R       HCH,WFIN,HFIN,FEX,FKUP,ADC,ALK,RSS,                          MAIN0031
     R       HFGTK,HSATK,VDC,VCHY,VG,VF,TCF,CHNT                          MAIN0032
      READ(5,520)  (FQZ(M),M=2,NM)                                         MAIN0033
      READ(5,530)  (BI(N),DLI(N),N=1,6)                                    MAIN0034
      READ(5,540)  (Y(N),AL(N),N=1,8)                                      MAIN0035
      WRITE(6,601)                                                         MAIN0036
```

```
      WRITE(6,602)                                                      MAIN0037
      WRITE(6,603)                                                      MAIN0038
      WRITE(6,604)                                                      MAIN0039
      WRITE(6,605)                                                      MAIN0040
      WRITE(6,606)                                                      MAIN0041
      WRITE(6,610)NM,NOV,TL,PTI,CHN,CDT,DTS,ZL,                         MAIN0042
     W       THMW,GPM,HIN,PIN,THE,SPV,CPP,                              MAIN0043
     W       HSAT,HFG,RO,BEFF,GAMA,FR,VTANK,                            MAIN0044
     W       GA,GB,GC,GD,PA,PB,                                         MAIN0045
     W       DSL,DP,DDC,DSA,DBL,DCH,DCL,BP,                             MAIN0046
     W       AP,ASH,ASHL,AENT,AUP,AVI,AVO,ACH,                          MAIN0047
     W       FKN,FKO,FKP,FKS,FKD,FEN,FKV,FKR,                           MAIN0048
     W       HTK,HV,HC,HSU,HSL,HLP,HPI,CHYH,                            MAIN0049
     W       HCH,WFIN,HFIN,FEX,FKUP,ADC,ALK,RSS,                        MAIN0050
     W       HFGTK,HSATK,VDC,VCHY,VG,VF,TCP,CHNT                        MAIN0051
      WRITE(6,620)  (FQZ(M),M=2,NM)                                     MAIN0052
      WRITE(6,630)  (BI(N),DLI(N),N=1,6)                                MAIN0053
      WRITE(6,640) (Y(N),AL(N),N=1,8)                                   MAIN0054
  510 FORMAT(2I9,6F9.4/7E9.5/7E9.5/6E9.5/8E9.5/8E9.5/8E9.5/             MAIN0055
     F       8E9.5/8E9.5/8E9.5)                                         MAIN0056
  520 FORMAT(12F6.2)                                                    MAIN0057
  530 FORMAT(2F8.6)                                                     MAIN0058
  540 FORMAT(2F10.8)                                                    MAIN0059
  601 FORMAT('    NM,NOV,TL,PTI,CHN,CDT,DTS,ZL'/                        MAIN0060
     1        '    THMW,GPM,HIN,PIN,THE,SPV,CPP')                       MAIN0061
  602 FORMAT('    HSAT,HFG,RO,BEFF,GAMA,FR,VTANK'/                      MAIN0062
     2        '    GA,GB,GC,GD,PA,PB')                                  MAIN0063
  603 FORMAT('    DSL,DP,DDC,DSA,DBL,DCH,DCL,BP')                       MAIN0064
  604 FORMAT('    AP,ASH,ASHL,AENT,AUP,AVI,AVO,ACH'/                    MAIN0065
     4        '    FKN,FKO,FKP,FKS,FKD,FEN,FKV,FKR')                    MAIN0066
  605 FORMAT('    HTK,HV,HC,HSU,HSL,HLP,HPI,CHYH'/                      MAIN0067
     5        '    HCH,WFIN,HFIN,FEX,FKUP,ADC,ALK,RSS')                 MAIN0068
  606 FORMAT('    HFGTK,HSATK,VDC,VCHY,VG,VF,TCP,CHNT')                 MAIN0069
  610 FORMAT(2I15,6F15.4/7(3X,E12.5)/7(3X,E12.5)/6(3X,E12.5)/8(3X,E12.5)MAIN0070
     F       /8(3X,E12.5)/8(3X,E12.5)/8(3X,E12.5)/8(3X,E12.5)/8(3X,E12.5))MAIN0071
  620 FORMAT(6(3X,E12.5),2X,'FQZ')                                      MAIN0072
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  630 FORMAT (2(3X,E12.5),2X,'BI,DLI')                                              MAIN0073
  640 FORMAT (2(3X,E12.5),2X,'Y,AL')                                               MAIN0074
      POWER=THMW*3412.2/3.6                                                         MAIN0075
      PRMTR=SQRT(2./(ALK*WFIN))*(HFIN+WFIN/2.)                                      MAIN0076
      GIN=GPM/(SPV*AP*448.86)                                                       MAIN0077
      GSCR=1800./(SPV*AP*448.86)                                                    MAIN0078
      PIN=PIN*144.                                                                  MAIN0079
      TNC=-5.0                                                                      MAIN0080
      TSCR=0.0                                                                      MAIN0081
      DZ=ZL/(NM-2)                                                                  MAIN0082
      HWV=HTK                                                                       MAIN0083
C     *******************************************************************           MAIN0084
C     *   NORMALIZATION OF FUEL AXIAL HEAT FLUX DISTRIBUTION         *              MAIN0085
C     *******************************************************************           MAIN0086
      SUM=-0.5*(FQZ(2)+FQZ(NM))                                                     MAIN0087
      DO 1 J=2,NM                                                                   MAIN0088
    1 SUM=SUM+FQZ(J)                                                                MAIN0089
      DO 2 J=2,NM                                                                   MAIN0090
      FQZA(J)=(FQZ(J)/(SUM*DZ))*FR/CHN                                             MAIN0091
    2 QZF(J)=FQZA(J)*POWER                                                          MAIN0092
      FQZA(1)=-FQZA(2)                                                              MAIN0093
      QZF(1)=-QZF(2)                                                                MAIN0094
C     *******************************************************************           MAIN0095
C     *   STEADY STATE CALCULATIONS                                 *              MAIN0096
C     *******************************************************************           MAIN0097
      H(1,1)=HIN                                                                    MAIN0098
      H(2,1)=HIN                                                                    MAIN0099
      H(3,1)=HIN                                                                    MAIN0100
      X(1,1)=(HIN-HSAT)/HFG                                                         MAIN0101
      X(2,1)=(HIN-HSAT)/HFG                                                         MAIN0102
      G(1,1)=GIN                                                                    MAIN0103
      G(1,NM)=GIN                                                                   MAIN0104
      TW(1,1)=0.0                                                                   MAIN0105
      DEN(1,1)=DENSH(H(1,1),X(1,1))                                                 MAIN0106
      WRITE(6,3)                                                                    MAIN0107
    3 FORMAT(1H1,25X,'BTU/LBM',12X,'O C',9X,'LBM/S/FT**2',9X,'LBM/FT**3'            MAIN0108
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      F              /25X,'H(I,J)',11X,'TW(I,J)',10X,'G(I,J)',11X,'DEN(I,J)',    MAIN0109
      F           9X,'X(I,J)',11X,'FQZA(J)')                                      MAIN0110
       DO 5 J=2,NM                                                                MAIN0111
       GCORE=GIN*AP/(CHNT*ACH)                                                    MAIN0112
       RENO=DCH*GCORE/VISCH(H(1,J-1))                                             MAIN0113
       HCCA=0.000053*(RENO**0.8)*(VISCH(H(1,J-1))**0.333)/DCH                     MAIN0114
       PRMT=PRMTR*SQRT(HCCA)                                                      MAIN0115
       ETHA=0.5+1.5*TANH(PRMT)/PRMT                                              MAIN0116
       P=BP*ETHA                                                                  MAIN0117
       QZAV=0.5*(QZF(J)+QZF(J-1))+0.5*(GAMA*QZF(J)+GAMA*QZF(J-1))                 MAIN0118
       QFAV=QZAV/(BP*0.5)                                                         MAIN0119
       H(1,J)=H(1,J-1)+QFAV*DZ/(HCH*GIN)                                          MAIN0120
       TW(1,J)=(H(1,J)-68.05)/CP(F(1,J))+100.0+QZF(J)/(HCCA*P)                    MAIN0121
       TW(1,J)=(TW(1,J)-32.0)/1.8                                                 MAIN0122
       X(1,J)=(H(1,J)-HSAT)/HFG                                                   MAIN0123
       DEN(1,J)=DENSH(H(1,J),X(1,J))                                             MAIN0124
       G(1,J)=GIN                                                                 MAIN0125
       WRITE(6,4) H(1,J),TW(1,J),G(1,J),DEN(1,J),X(1,J),FQZA(J)                   MAIN0126
    4  FORMAT(2X,'INITIAL CONDITION',6(5X,E12.5)/)                               MAIN0127
    5  CONTINUE                                                                   MAIN0128
       TIN=(((H(1,2)-68.05)/CP(H(1,2))+100.)-32.)/1.8                            MAIN0129
       TOUT=(((H(1,NM)-68.05)/CP(H(1,NM))+100.)-32.)/1.8                         MAIN0130
       WRITE(6,105) TIN,TOUT                                                      MAIN0131
  105  FORMAT(50X,'TIN=',E12.5,5X,'TOUT=',E12.5)                                 MAIN0132
       DTANK(1)=DEN(1,NM)                                                         MAIN0133
       DTANK(2)=DEN(1,NM)                                                         MAIN0134
       T=0.0                                                                      MAIN0135
       DTP=0.006                                                                  MAIN0136
       I=1                                                                        MAIN0137
       FREQ=1.                                                                    MAIN0138
       NC=-5                                                                      MAIN0139
       START=-2.0                                                                 MAIN0140
       DIN=1./SPV                                                                 MAIN0141
       GAVR=0.0                                                                   MAIN0142
       HAVR=0.0                                                                   MAIN0143
       DAVR=0.0                                                                   MAIN0144
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          GO TO 6                                                      MAIN0145
    6     CONTINUE                                                     MAIN0146
C         *****************************************************************  MAIN0147
C         *    EVALUATION OF TIME STEP                               *  MAIN0148
C         *****************************************************************  MAIN0149
          CALL TIME(I,G,DEN,DT,NM)                                    MAIN0150
          IF(DT .LT. 0.0001) GO TO 24                                 MAIN0151
C         *****************************************************************  MAIN0152
C         *    CALCULATION OF AVERAGE VALUES .                       *  MAIN0153
C         *    AND SWITCHING THE CALCULATED VALUES TO PAST DESIGNATIONS  *  MAIN0154
C         *    FO LATER CALL .                                       *  MAIN0155
C         *****************************************************************  MAIN0156
          IF(I-1) 7,7,8                                               MAIN0157
    7     DO 71 J=1,NM                                                MAIN0158
          HAVR=HAVR+H(I,J)                                            MAIN0159
          GAVR=GAVR+G(I,J)                                            MAIN0160
          DAVR=DAVR+DEN(I,J)                                          MAIN0161
          HP(I,J)=H(I,J)                                              MAIN0162
          GP(I,J)=G(I,J)                                              MAIN0163
          DENP(I,J)=DEN(I,J)                                          MAIN0164
   71     CONTINUE                                                    MAIN0165
          GAVP=(DZ/(ZL+2.*DZ))*GAVR                                   MAIN0166
          DAVP=(DZ/(ZL+2.*DZ))*DAVR                                   MAIN0167
          HAVP=(DZ/(ZL+2.*DZ))*HAVR                                   MAIN0168
          GPP=GIN                                                     MAIN0169
          GO TO 10                                                    MAIN0170
    8     GAVP=GAV(I)                                                 MAIN0171
          DAVP=DAV(I)                                                 MAIN0172
          HAVP=HAV(I)                                                 MAIN0173
          DO 9 J=1,NM                                                 MAIN0174
          HP(I,J)=H(I,J)                                              MAIN0175
          GP(I,J)=G(I,J)                                              MAIN0176
          DENP(I,J)=DEN(I,J)                                          MAIN0177
    9     CONTINUE                                                    MAIN0178
          GO TO 10                                                    MAIN0179
   10     CONTINUE                                                    MAIN0180
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      HAVP=HP(I,NM)                                                      MAIN0181
      GTAV=GP(I,NM)                                                      MAIN0182
      DTAV=DAVDC(I,NC)           .                                       MAIN0183
      T=T+DT                                                             MAIN0184
C     ****************************************************************    MAIN0185
C     *   TO FIND FORCED FLOW RATE , OPENNING OF NATURAL CONVECTION- *   MAIN0186
C     *   VALVES AND PRESSURE-DROP ALONG THE DOWN-COMMER            *    MAIN0187
C     ****************************************************************    MAIN0188
      CALL DOCO(I,T,NC,DT,HAVP,GTAV,DTAV,GAVP,GDC,DPTDC,G,FFF)           MAIN0189
      II=I+1                                                             MAIN0190
C     ****************************************************************    MAIN0191
C     *   TRANSIENT CALCULATION AND NATURAL CONVECTION FLOW RATE    *    MAIN0192
C     *   EVALUATION .                                              *    MAIN0193
C     ****************************************************************    MAIN0194
      CALL TRANS(T,DT,I,NM,NC,GDC,DPTDC,HP,GP,DENP,DTP,FFF,              MAIN0195
     T          GAVP,DAVP,HAVP,H,G,DEN,X,TW,QFTAV)                       MAIN0196
      TIN=(((H(I+1,2)-68.05)/CP(H(I+1,2))+100.)-32.0)/1.8                MAIN0197
      TOUT=(((H(I+1,NM)-68.05)/CP(H(I+1,NM))+100.0)-32.)/1.8             MAIN0198
C     ****************************************************************    MAIN0199
C     *   EVALUATION OF NEW AVERAGE VALUES .                        *    MAIN0200
C     ****************************************************************    MAIN0201
      GAVN=0.0                                                           MAIN0202
      DAVN=0.0                                                           MAIN0203
      XAVN=0.0                                                           MAIN0204
      HAVN=0.0                                                           MAIN0205
      GAV(1)=GAVP                                                        MAIN0206
      DAV(1)=DAVP                                                        MAIN0207
      HAV(1)=HAVP                                                        MAIN0208
      XAV(1)=0.0                                                         MAIN0209
      DO 17 J=1,NM                                                       MAIN0210
      GAVN=GAVN+G(I+1,J)                                                 MAIN0211
      DAVN=DAVN+DEN(I+1,J)                                               MAIN0212
      HAVN=HAVN+H(I+1,J)                                                 MAIN0213
   17 CONTINUE                                                           MAIN0214
      DO 18 J=2,NM                                                       MAIN0215
   18 XAVN=XAVN+X(I+1,J)                                                 MAIN0216
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      GAV (I+1) = (DZ/ (ZL+2.*DZ)) *GAVN                                      MAIN0217
      DAV (I+1) = (DZ/ (ZL+2.*DZ)) *DAVN                                      MAIN0218
      HAV (I+1) = (DZ/ (ZL+2.*DZ)) *HAVN                                      MAIN0219
      XAV (I+1) = (DZ/ (ZL+1.*DZ)) *XAVN                                      MAIN0220
C     ******************************************************************      MAIN0221
C     *     EVALUATION OF ON-SET OF NUCLIATION BOILING                 *     MAIN0222
C     ******************************************************************      MAIN0223
      DO 318 J=2,NM                                                          MAIN0224
      HSATL=HSAT-2.8* (J-2) / (NM-2)                                         MAIN0225
      TSAT= (HSATL-68.05) /CP (HSATL) +100.                                  MAIN0226
      TW (I+1,J) =TW (I+1,J) *1.8+32.                                        MAIN0227
      DTSAT=TW (I+1,J) -TSAT                                                 MAIN0228
      IF (DTSAT) 118,118,218                                                 MAIN0229
  118 QONB (J) =-0.1E-10                                                     MAIN0230
      GO TO 318                                                              MAIN0231
  218 PJ=19.35-0.85* (J-2) / (NM-2)                                          MAIN0232
      A=0.00433* (PJ**1.156)                                                 MAIN0233
      B=2.3/ (PJ**0.0234)                                                    MAIN0234
      QONB (J) =A* (DTSAT**B)                                                MAIN0235
      GO TO 318                                                              MAIN0236
  318 TW (I+1,J) = (TW (I+1,J) -32.) /1.8                                    MAIN0237
      RATIO=FREQ/PTI                                                         MAIN0238
C     ******************************************************************      MAIN0239
C     *     PRINTING OF TRANSIENT VALUES .                             *     MAIN0240
C     ******************************************************************      MAIN0241
      IF (RATIO-1.)  16,11,11                                                MAIN0242
   11 WRITE (6,12) II,T,DT                                                   MAIN0243
   12 FORMAT (1H1,2X,I4,3X,'T=',F10.5,10X,'DT=',E12.5)                       MAIN0244
      WRITE (6,13)                                                           MAIN0245
   13 FORMAT (/9X,'BTU/S/FT**2.',9X                                          MAIN0246
     P           ,'BTU/LBM',12X,'O C',11X,'LBM/S/FT**2',7X,'LBM/FT**3'       MAIN0247
     P           ,19X,'HSAT=194.4 BTU/LBM'/3X,'INCH',8X,'QPTAV',12X,         MAIN0248
     P            'H(I,J)',10X,'TW(I,J)',10X,'G(I,J)',11X,'DEN(I,J)',         MAIN0249
     P        9X,'X(I,J)',11X,'QONB(I,J)')                                   MAIN0250
      DO 14 J=2,NM                                                           MAIN0251
      JJ=J-2                                                                 MAIN0252
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14   WRITE(6,15)JJ,QFTAV(I+1,J),H(I+1,J),TW(I+1,J),G(I+1,J),DEN(I+1,J)     MAIN0253
   W            ,X(I+1,J),QONB(J)                                          MAIN0254
15   FORMAT(/4X,I2,7(5X,E12.5))                                           MAIN0255
     WRITE(6,19) II,T,DT,HAV(I+1),GAV(I+1),DAV(I+1),TIN,TOUT              MAIN0256
19   FORMAT(32X,60('='),18X,'HSAT=191.6 BTU/LBM'                          MAIN0257
   F            /2X,I3,2X,'T=',F7.3,3X,'DT=',E12.5,7X,'HAV=',             MAIN0258
   F        E12.5,1X,'GAV=',E12.5,1X,'DAV=',E12.5,1X,'TIN=',E12.5,2X,     MAIN0259
   F            'TOUT=',E12.5)                                            MAIN0260
     FREQ=0.0                                                             MAIN0261
     GO TO 16                                                             MAIN0262
16   FREQ=FREQ+1.                                                         MAIN0263
     III=I+2                                                              MAIN0264
C    ***********************************************************************     MAIN0265
C    *  TO CALCULATE THE CORE INLET ENTHALPY AND DENSITY FOR FUETURE  *   MAIN0266
C    *  NEEDS :                                                       *   MAIN0267
C    ***********************************************************************     MAIN0268
     CALL TANK(I,NM,NC,DT,H,G,DEN,X,FFF)                                  MAIN0269
     DTP=DT                                                               MAIN0270
     I=I+1                                                                MAIN0271
     IF(T-TL) 20,20,999                                                   MAIN0272
C    ***********************************************************************     MAIN0273
C    *  TO SAVE MEMORY SPACE AND SPECIFY OLD SPACES TO NEW           *   MAIN0274
C    *  CALCULATIONS :                                               *   MAIN0275
C    ***********************************************************************     MAIN0276
20   IF(I-100) 6,21,21                                                    MAIN0277
21   I=10                                                                 MAIN0278
     H(9,NM+1)=H(99,NM)                                                   MAIN0279
     DO 22 J=1,NM                                                         MAIN0280
     H(10,J)=H(100,J)                                                     MAIN0281
     G(10,J)=G(100,J)                                                     MAIN0282
     DEN(10,J)=DEN(100,J)                                                 MAIN0283
22   CONTINUE                                                             MAIN0284
     DO 23 J=2,NM                                                         MAIN0285
     TW(10,J)=TW(100,J)                                                   MAIN0286
     X(10,J)=X(100,J)                                                     MAIN0287
23   CONTINUE                                                             MAIN0288
```

```
        XAV(10)=XAV(100)                                                    MAIN0289
        GAV(10)=GAV(100)                                                    MAIN0290
        DAV(10)=DAV(100)                                                    MAIN0291
        HAV(10)=HAV(100)                                                    MAIN0292
        GO TO 6                                                             MAIN0293
   24   WRITE(6,25)                                                         MAIN0294
   25   FORMAT(3X,'TIME INTERVAL IS LESS THAN 0.001')                      MAIN0295
        GO TO 999                                                           MAIN0296
  999   STOP                                                               MAIN0297
        END                                                                MAIN0298
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```
      SUBROUTINE TIME(I,G,DEN,DT,NM)                                        TIME0001
      DIMENSION DELT(50),G(100,50),DEN(100,50),H(100,50)                    TIME0002
      COMMON/TI/H,DTS,DTC                                                   TIME0003
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF                               TIME0004
C     **********************************************************************TIME0005
C     *   CALCULATION OF DIFFERENT TIME INTERVALS WHICH TAKES FOR FLOW   * TIME0006
C     *   TO PASS THE MESH SPACES .                                      * TIME0007
C     **********************************************************************TIME0008
      DO 2 J=2,NM                                                           TIME0009
    2 DELT(J)=DZ*(DEN(I,J)+DEN(I,J-1))/(G(I,J)+G(I,J-1))                   TIME0010
      REF=1.E+30                                                            TIME0011
C     **********************************************************************TIME0012
C     *   EVALUATION OF THE MIN. VALUES FOR TIME INTERVALS .             * TIME0013
C     **********************************************************************TIME0014
      DO 4 J=2,NM                                                           TIME0015
      IF(DELT(J)-REF) 3,4,4                                                 TIME0016
    3 REF=DELT(J)                                                           TIME0017
    4 CONTINUE                                                              TIME0018
      DTC=REF                                                               TIME0019
C     **********************************************************************TIME0020
C     *   SELECTION OF THE SMALLER VALUE OF THE MIN. TIME INTERVAL AND   * TIME0021
C     *   THE SPECIFIED ONE AS INPUT TO THE CODE .                       * TIME0022
C     **********************************************************************TIME0023
      IF(DTC-DTS) 5,5,6                                                     TIME0024
    5 DT=DTC                                                                TIME0025
      GO TO 7                                                               TIME0026
    6 DT=DTS                                                                TIME0027
      GO TO 7                                                               TIME0028
    7 RETURN                                                                TIME0029
      END                                                                   TIME0030
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      SUBROUTINE DOCO(I,T,NC,DT,HAVP,GTAV,DTAV,GAVP,GDC,DPTDC,G,FFP)      DOCO0001
      DIMENSION DAV(100),G(100,50)                                        DOCO0002
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCP                              DOCO0003
      COMMON/TK/HIN,ACH,CHN,ADC,DCL,VTANK,START,HFGTK,HSATK,VDC,VCHY      DOCO0004
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                   DOCO0005
      COMMON/DC/ GA,GB,GC,GD,PA,PB,GIN,PIN,THE,CPP,CDT,RSS,HTK,HV,        DOCO0006
    C          HSU,HSL,HLP,HPI,HWV,DSL,DP,DSA,DBL,AP,ASH,ASHL,AENT,       DOCO0007
    C          AUP,AVI,AVO,FKN,FKO,FKP,FKS,FKD,FKV,FKR,FKUP,NOV           DOCO0008
      ABL=0.785*DBL**2.                                                   DOCO0009
      FKVO=FKV/(NOV**2.)                                                  DOCO0010
      FKVR=FKR*((AVI/ADC)**2.)                                            DOCO0011
      AVOO=AVO*NOV                                                        DOCO0012
      AVIN=AVI*NOV                                                        DOCO0013
      ALPA=AVO/AVI                                                        DOCO0014
      SPV=1./DIN                                                          DOCO0015
C     ********************************************************************  DOCO0016
C     *   FLOW RATE AND PRESSURE FORCED VALUES AT MF1 AFTER PUMP      *   DOCO0017
C     *   COAST-DOWN .                                                *   DOCO0018
C     ********************************************************************  DOCO0019
      GDC=GIN*(GA/(EXP(GB*T))+GC*T-GD)                                    DOCO0020
      PRESS=PIN*(PA*T+1.)/(PB*T+1.)                                       DOCO0021
      IF(GDC .LE. 0.0001) GO TO 7                                         DOCO0022
      GDCP=GIN*(GA/(EXP(GB*(T-DT)))+GC*(T-DT)-GD)                         DOCO0023
      IF(T-CDT) 20,20,7                                                   DOCO0024
   20 IF(NC) 1,1,30                                                       DOCO0025
   30 DGG=GDCP-GAVP                                                       DOCO0026
      IF(DGG) 7,8,8                                                       DOCO0027
C     ********************************************************************  DOCO0028
C     *   PRESSURE DROP CALCULATION IN THE SYSTEM FROM MF1 TO THE     *   DOCO0029
C     *   UPPER PLENUM .                                              *   DOCO0030
C     ********************************************************************  DOCO0031
    1 FFP=+5.0                                                            DOCO0032
      IF(GDC-GSCR) 21,21,41                                               DOCO0033
   21 IF(TSCR) 31,31,41                                                   DOCO0034
   31 TSCR=T                                                              DOCO0035
   41 CONTINUE                                                            DOCO0036
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      FRC=FRIC(HAVP,GTAV,2.)                                             DOC00037
      DPFP=HLP*FRC*SPV*(GDC**2.)/(2.*DP*32.2)                            DOC00038
      DPSP=SPV*(GDC**2.)*(FKN+0.5*FKO)/32.2                              DOC00039
      DPEP=HPI/SPV                                                       DOC00040
      DPTP=DPFP+DPSP+DPEP                                                DOC00041
      PRESS=PRESS-DPTP                                                   DOC00042
      DPFS=FRC*SPV*(GDC**2.)*(HSU/DSA+HSL/DSL)/64.4                      DOC00043
      DPSS=SPV*(GDC**2.)*(FKP+FKS+FKD)/64.4                              DOC00044
      DPES=-(HSU+HSL)/SPV                                                DOC00045
      DPAS=SPV*(GDC**2.)*0.7761/32.2                                     DOC00046
      DPTS=DPFS+DPSS+DPES+DPAS                                           DOC00047
      PRESS=PRESS-DPTS                                                   DOC00048
      PHV=144.*14.7+HWV/SPV                                              DOC00049
      PC=PHV+(RSS-(1./SPV))*3.14*(DBL**3.)/6.*AVI                        DOC00050
      DPC=PRESS-PC                                                       DOC00051
C     *********************************************************************  DOC00052
C     *  BALANCING THE PRESSURES TO SEE IF THE VALVES ARE OPENND .     *  DOC00053
C     *********************************************************************  DOC00054
      IF(DPC-10.) 2,2,8                                                  DOC00055
    2 NC=+5                                                              DOC00056
C     *********************************************************************  DOC00057
C     *EVALUATION OF THE REVERSE FLOW IN THE VALVES RIGHT AFTER        *  DOC00058
C     *  OPENNING , IF THERE IS ANY .                                  *  DOC00059
C     *********************************************************************  DOC00060
      SD=ADC/AVIN                                                        DOC00061
      SV=AENT/AVIN                                                       DOC00062
      AA=(ALFA+FKVR)*SD**2.+1.                                           DOC00063
      BB=SD*SV*(ALFA+FKVR)*GDC                                           DOC00064
      CC=((ALFA+FKVR)*SV**2.-1.)*(GDC**2.)+2.*32.2*PHV/SPV              DOC00065
      RAD=(BB**2.-AA*CC)                                                 DOC00066
      IF(RAD) 5,3,3                                                      DOC00067
    3 GD1=(BB+RAD**0.5)/AA                                               DOC00068
      GD2=(BB-RAD**0.5)/AA                                               DOC00069
      IF(GD1 .GE. GDC) GO TO 9                                           DOC00070
      IF(GD1 .GE. 0.0 .AND. GD1 .LT. GDC) GD=GD1                         DOC00071
      IF(GD1 .GE. GDC .AND. GD2 .LT. GDC) CONTINUE                       DOC00072
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        IF(GD2 .GE. 0.0 .AND. GD2 .LE. GDC) GD=GD2                      DOC00073
        GV=GDC*SV-GD*SD                                                 DOC00074
        DPV=FKVO*SV*(GV**2.)/64.4                                       DOC00075
        PVO=PRESS-DPV                                                   DOC00076
        PP=PVO-PHV                                                      DOC00077
        IF(PP) 5,5,4                                                    DOC00078
   4    GDC=GD                                                          DOC00079
        GO TO 5                                                         DOC00080
   5    WRITE(6,6)                                                      DOC00081
   6    FORMAT(//3X,'NATURAL CONVECTION VALVE OPENS'/32('****'))        DOC00082
        GDC=GDC                                                         DOC00083
        GO TO 7                                                         DOC00084
C       *****************************************************************DOC00085
C       *   DOWN-COMMER  PRESSURE DROP CALCULATION FOR NATURAL CONVECTION * DOC00086
C       *****************************************************************DOC00087
   7    FFF=-5.0                                                        DOC00088
        IF(GTAV .LE. 0.0001) GTAV=0.0001                               DOC00089
        DPDC=PDROP(I,HAVP,GTAV,DTAV,NC,DT)                             DOC00090
        DPTDC=DPDC                                                      DOC00091
        GO TO 11                                                        DOC00092
C       *****************************************************************DOC00093
C       *   DOWN-COMMER PRESSURE DROP EVALUATION FOR FORCED FLOW .    * DOC00094
C       *****************************************************************DOC00095
   8    FFF=+5.0                                                        DOC00096
        IF(GDC .LE. 0.0001) GDC=0.0001                                 DOC00097
        DPDC=PDROP(I,HIN,GDC,DIN,NC,DT)                                DOC00098
        DPTDC=PRESS-DPDC                                                DOC00099
        IF(DPTDC) 7,7,11                                                DOC00100
   9    WRITE(6,10)                                                     DOC00101
  10    FORMAT(3X,'NEGATIVE FLOW')                                      DOC00102
        GO TO 11                                                        DOC00103
  11    RETURN                                                          DOC00104
        END                                                             DOC00105
```

```
      SUBROUTINE TRANS(T,DT,I,NM,NC,GDC,DPTDC,HP,GP,DENP,DTP,FFF,        TRNS0001
     T              GAVP,DAVP,HAVP,H,G,DEN,X,TW,QFTAV)                   TRNS0002
      DIMENSION H(100,50),G(100,50),DEN(100,50),TW(100,50),X(100,50),   TRNS0003
     D       FQZA(50),QZT(100,50),GG(100,50),DD(100,50),GAV(100,50),    TRNS0004
     D       HP(100,50),GP(100,50),DENP(100,50),DTANK(100),DLP(100),    TRNS0005
     D         GT(100,50),BI(7),DLI(7),QFTAV(100,50),DVF(10000),        TRNS0006
     D         DAV(100),GNC(100,50),Y(8),AL(8)                          TRNS0007
      COMMON/TS/ITL,DLI,BI,RO,BEFF,POWER,FQZA,HSAT,HFG,GAMA,P,FEN,FEX,BP TRNS0008
     C         ,AL,Y                                                    TRNS0009
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                 TRNS0010
      COMMON/TK/HIN,ACH,CHN,ADC,DCL,VTANK,START,HFGTK,HSATK,VDC,VCHY    TRNS0011
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF                           TRNS0012
      COMMON/DK/ DLP,DTANK                                              TRNS0013
      COMMON/LK/L,K,DVF,TNC                                             TRNS0014
      COMMON/DC/ GA,GB,GC,GD,PA,PB,GIN,PIN,THE,CPP,CDT,RSS,HTK,HV,      TRNS0015
     C         HSU,HSL,HLP,HPI,HWV,DSL,DP,DSA,DBL,AP,ASH,ASHL,AENT,     TRNS0016
     C         AUP,AVI,AVO,FKN,FKO,FKP,FKS,FKD,FKV,FKR,FKUP,NOV         TRNS0017
      TSCR=0.0                                                          TRNS0018
      DTSCR=TSCR+0.41                                                   TRNS0019
      IF(T .LT. DTSCR) GO TO 3                                          TRNS0020
C     ******************************************************************* TRNS0021
C     *   EVALUATION OF THE DECAY HEAT .                              *  TRNS0022
C     ******************************************************************* TRNS0023
      STI=T-0.9                                                         TRNS0024
      IF(STI .LT. 0.1) STI=0.1                                          TRNS0025
      QACT=0.000341*EXP(-0.0052*STI)                                    TRNS0026
      QACT=QACT*POWER                                                   TRNS0027
      QDN=0.0                                                           TRNS0028
      IF(STI .GT. 59.) GO TO 2                                          TRNS0029
      DO 1 N=1,6                                                        TRNS0030
    1 QDN=QDN+(BI(N)/(RO+BEFF))*EXP(-RO*DLI(N)*STI/(RO+BEFF))          TRNS0031
    2 CONTINUE                                                          TRNS0032
      QDN=QDN*POWER*1.153                                               TRNS0033
      IF(STI .LE. 10.) QFP=0.06025*(STI**(-0.0639))                    TRNS0034
      IF(STI .GT. 10. .AND. STI .LE. 150.) QFP=0.07655*(STI**(-0.1807)) TRNS0035
      IF(STI .GT. 150.) QFP=0.1301*(STI**(-0.2834))                    TRNS0036
```

```
      QFP=QFP*POWER                                                   TRNS0037
      QDPHN=0.0                                                       TRNS0038
      DO 102 N=1,8                                                    TRNS0039
  102 QDPHN=QDPHN+Y(N)*(1.-EXP(-AL(N)*STI))                          TRNS0040
      QDPHN=QDPHN*POWER                                               TRNS0041
      Q=QACT+QDN+QFP+QDPHN                                            TRNS0042
      IF(T .GT. 0.41 .AND. T .LE. 1.0) Q=POWER-(POWER-Q)*(T-0.41)/0.59  TRNS0043
      GO TO 4                                                         TRNS0044
    3 Q=POWER                                                         TRNS0045
      GO TO 4                                                         TRNS0046
    4 CONTINUE                                                        TRNS0047
C     ***************************************************************  TRNS0048
C     *DECAY POWER DISTRIBUTION CALCULATION .                      *  TRNS0049
C     ***************************************************************  TRNS0050
      DO 5 J=2,NM                                                     TRNS0051
    5 QZT(I+1,J)=FQZA(J)*Q                                            TRNS0052
      QZT(I+1,1)=-QZT(I+1,2)                                          TRNS0053
      DO 6 J=1,NM                                                     TRNS0054
      H(I,J)=HP(I,J)                                                  TRNS0055
      G(I,J)=GP(I,J)                                                  TRNS0056
      DEN(I,J)=DENP(I,J)                                              TRNS0057
    6 CONTINUE                                                        TRNS0058
      IF(I .GT. 1) H(I,NM+1)=H(I-1,NM)                                TRNS0059
      DTANK(1)=DEN(1,NM)                                              TRNS0060
      DTANK(2)=DEN(1,NM)                                              TRNS0061
      DO 7 J=2,NM                                                     TRNS0062
      IF(GAVP-0.0001) 26,26,27                                        TRNS0063
C     ***************************************************************  TRNS0064
C     *   TRANSIENT CALCULATION FOR REVERSED OR NON FLOW ,         *  TRNS0065
C     ***************************************************************  TRNS0066
   26 JR=NM-J+2                                                       TRNS0067
      H(I,NM+1)=H(I-1,NM)                                             TRNS0068
      H(I+1,NM+1)=H(I,NM)                                             TRNS0069
      DEN(I,NM+1)=DEN(I-1,NM)                                         TRNS0070
      G(I,NM+1)=GAVP                                                  TRNS0071
      QZT(I+1,NM+1)=-QZT(I+1,NM)                                      TRNS0072
```

```
      GHALF=0.5* (G (I,JR) +G (I,JR-1) )                                       TRNS0073
      DHALF=0.5* (DEN (I,JR) +DEN (I,JR-1) )                                   TRNS0074
      QZTAV=0.5* ((QZT (I+1,JR) +QZT (I+1,JR-1) ) +GAMA* (QZT (I+1,JR) +       TRNS0075
     Q      QZT (I+1,JR-1) ))                                                  TRNS0076
      QPTAV (I+1,JR) =QZTAV/ (BP*0.5)                                          TRNS0077
      ALFA=GHALF*DT/ (DHALF*DZ)                                               TRNS0078
      IF (PPP .GT. 0.0)  ALFA=ALFA*ADC/ (CHNT*ACH)                            TRNS0079
C     ***************************************************************          TRNS0080
C     *   EXPLICIT - CAUCHY POLYGON METHOD                          *         TRNS0081
C     ***************************************************************          TRNS0082
      H (I+1,JR) =H (I,JR) -ALFA* (H (I,JR+1) -H (I,JR) ) +2.*DT* (QPTAV (I+1,JR)  TRNS0083
     H       )/ (DHALF*HCH)                                                    TRNS0084
      H (I+1,JR) =0.5* (H (I+1,JR) +H (I+1,JR-1) )                             TRNS0085
      X (I+1,JR) = (H (I+1,JR) - (HSAT-2.8* (JR-2) / (NM-2) ))/HPG             TRNS0086
      DEN (I+1,JR) =DENSH (H (I+1,JR) ,X (I+1,JR) )                            TRNS0087
      TWH= (H (I+1,JR) -68.05)/CP (H (I+1,JR) ) +100.0                         TRNS0088
      IF (PPP .LT. 0.0)  TWH= (H (I+1,JR-1) -68.05)/CP (H (I+1,JR-1) ) +100.   TRNS0089
      TW (I+1,J) =TWH+QZT (I+1,JR) / (HCC (H (I+1,JR) ,GAVP) *P)               TRNS0090
      TW (I+1,JR) = (TW (I+1,JR) -32.)/1.8                                     TRNS0091
      GO TO 7                                                                  TRNS0092
C     ***************************************************************          TRNS0093
C     *   TRANSIENT CALCULATION FOR UPFLOW IN THE CORE ,            *         TRNS0094
C     ***************************************************************          TRNS0095
   27 GHALF=0.5* (G (I,J) +G (I,J-1) )                                         TRNS0096
      DHALF=0.5* (DEN (I,J) +DEN (I,J-1) )                                     TRNS0097
      QZTAV=0.5* ((QZT (I+1,J) +QZT (I+1,J-1) ) +GAMA* (QZT (I+1,J) +          TRNS0098
     Q      QZT (I+1,J-1) ))                                                   TRNS0099
      QPTAV (I+1,J) =QZTAV/ (BP*0.5)                                           TRNS0100
      ALFA=GHALF*DT/ (DHALF*DZ)                                               TRNS0101
      IF (PPP .GT. 0.0)  ALFA=ALFA*ADC/ (CHNT*ACH)                            TRNS0102
C     ***************************************************************          TRNS0103
C     *   EXPLICIT - CAUCHY POLYGON METHOD                          *         TRNS0104
C     ***************************************************************          TRNS0105
      H (I+1,J) =H (I,J) -ALFA* (H (I,J) -H (I,J-1) ) +2.*DT* (QPTAV (I+1,J) )/  TRNS0106
     H        (DHALF*HCH)                                                      TRNS0107
      H (I+1,J) =0.5* (H (I+1,J) +H (I+1,J-1) )                                TRNS0108
```

```
      X(I+1,J)=(H(I+1,J)-(HSAT-2.8*(J-2)/(NM-2)))/HFG              TRNS0109
      DEN(I+1,J)=DENSH(H(I+1,J),X(I+1,J))                          TRNS0110
      TWH=(H(I+1,J)-68.05)/CP(H(I+1,J))+100.0                      TRNS0111
      IF(FFF .LT. 0.0) TWH=(H(I+1,J-1)-68.05)/CP(H(I+1,J-1))+100.  TRNS0112
      TW(I+1,J)=TWH+QZT(I+1,J)/(HCC(H(I+1,J),GAVP)*P)              TRNS0113
      TW(I+1,J)=(TW(I+1,J)-32.)/1.8                                TRNS0114
    7 CONTINUE                                                     TRNS0115
      DEN(I+1,1)=DENSH(H(I+1,1),X(I+1,1))                          TRNS0116
      IF(FFF .LT. 0.0)GAVPC=GAVP                                   TRNS0117
      IF(NC) 17,17,107                                             TRNS0118
  107 IF(START) 207,207,307                                        TRNS0119
  207 GAVPC=0.0                                                    TRNS0120
      START=START+4.                                               TRNS0121
      GO TO 307                                                    TRNS0122
  307 CONTINUE                                                     TRNS0123
      IF(FFF .GT. 0.0) GAVP=GAVP*ADC/(CHNT*ACH)                    TRNS0124
      ANOV=NOV                                                     TRNS0125
C     *******************************************************************   TRNS0126
C     *   NATURAL CONVECTION FLOW EVALUATION .                      *     TRNS0127
C     *******************************************************************   TRNS0128
      GAVC=GAVP                                                    TRNS0129
      FFR=ZL*FRIC(HAVP,GAVC,11.)*(GAVC**2.)/(2.*DCH*DAVP)          TRNS0130
      FSH=(FEN+FEX)*(GAVC**2.)/(2.*DAVP)                           TRNS0131
      FSA=0.0                                                      TRNS0132
      DPTC=FFR+FSH+FSA                                             TRNS0133
      DFDEN=ZL*(DAVDC(I,NC)-DAVP)*32.2                             TRNS0134
      DFCHY=CHYH*(DAVDC(I,NC)-DTANK(I))*32.2                       TRNS0135
      GAVNC=GAVPC+(DT/2.*(HC+0.00))*((DFDEN+DFCHY)-(DPTC+DPTDC))   TRNS0136
      GG(I+1,1)=1.0                                                TRNS0137
      DD(I+1,1)=0.0                                                TRNS0138
      DO 11 J=2,NM                                                 TRNS0139
      DH=H(I+1,J)-H(I+1,J-1)                                       TRNS0140
      IF(DH-0.1) 8,9,9                                             TRNS0141
    8 DH=H(I+1,2)-H(I+1,NM)                                        TRNS0142
      DDEN=DEN(I+1,2)-DEN(I+1,NM)                                  TRNS0143
      GO TO 10                                                     TRNS0144
```

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9     DH=H(I+1,J)-H(I+1,J-1)                                      TRNS0145
      DDEN=DEN(I+1,J)-DEN(I+1,J-1)                                 TRNS0146
      GO TO 10                                                     TRNS0147
10    DRDH=DDEN/DH                                                 TRNS0148
      DENAV=0.5*(DEN(I+1,J)+DEN(I+1,J-1))                          TRNS0149
      AAV=DRDH*DH/DENAV                                            TRNS0150
      AAL=(2.+AAV)/(2.-AAV)                                        TRNS0151
      BAV=2.0*DRDH*QPTAV(I+1,J)*DZ/(DENAV*(2.-AAV))               TRNS0152
      GG(I+1,J)=AAL*GG(I+1,J-1)                                    TRNS0153
11    DD(I+1,J)=AAL*DD(I+1,J-1)+BAV                                TRNS0154
      GGAV=0.0                                                     TRNS0155
      DDAV=0.0                                                     TRNS0156
      GGS=-0.5*GG(I+1,NM)                                          TRNS0157
      DDS=-0.5*DD(I+1,NM)                                          TRNS0158
      DO 12 J=2,NM                                                 TRNS0159
      GGAV=GGAV+GG(I+1,J)                                          TRNS0160
12    DDAV=DDAV+DD(I+1,J)                                          TRNS0161
      GGAV=(DZ/(ZL+2.*DZ))*(GGAV+GGS)                              TRNS0162
      DDAV=(DZ/(ZL+2.*DZ))*(DDAV+DDS)                              TRNS0163
      GNC(I+1,1)=(1./GGAV)*(GAVNC-DDAV)                            TRNS0164
      DO 14 J=2,NM                                                 TRNS0165
      GNC(I+1,J)=GG(I+1,J)*GNC(I+1,1)+DD(I+1,J)                    TRNS0166
14    CONTINUE                                                     TRNS0167
      DO 15 J=1,NM                                                 TRNS0168
15    IF(GNC(I+1,J) .LE. 0.0001) GNC(I+1,J)=0.0001                 TRNS0169
      GO TO 16                                                     TRNS0170
16    IF(FFF) 19,19,17                                             TRNS0171
17    DO 18 J=1,NM                                                 TRNS0172
18    G(I+1,J)=GDC                                                 TRNS0173
      GO TO 21                                                     TRNS0174
19    DO 20 J=1,NM                                                 TRNS0175
20    G(I+1,J)=GNC(I+1,J)                                          TRNS0176
      GAVPC=GAVNC                                                  TRNS0177
      GO TO 21                                                     TRNS0178
21    RETURN                                                       TRNS0179
      END                                                          TRNS0180
```

```
      SUBROUTINE TANK(I,NM,NC,DT,H,G,DEN,X,FFF)                              TANK0001
      DIMENSION H(100,50),HMIX(100),DEN(100,50),DAV(100),HVF(10000),         TANK0002
     D DVF(10000),XTANK(100),DTANK(100),DLP(100),X(100,50),G(100,50),        TANK0003
     D    VF(10000)                                                          TANK0004
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                       TANK0005
      COMMON/TK/HIN,ACH,CHN,ADC,DCL,VTANK,START,HFGTK,HSATK,VDC,VCHY          TANK0006
      COMMON/DK/ DLP,DTANK                                                    TANK0007
      COMMON/LK/L,K,DVF,TNC                                                   TANK0008
      COMMON/DC/ GA,GB,GC,GD,PA,PB,GIN,PIN,THE,CPP,CDT,RSS,HTK,HV,            TANK0009
     C          HSU,HSL,HLP,HPI,HWV,DSL,DP,DSA,DBL,AP,ASH,ASHL,AENT,          TANK0010
     C          AUP,AVI,AVO,FKN,FKO,FKP,FKS,FKD,FKV,FKR,FKUP,NOV              TANK0011
      IF(I .GE. 99) I99=100                                                   TANK0012
      IF(I .GE. 99) I=9                                                       TANK0013
      III=I+2                                                                 TANK0014
      VSH=ASH*HSU+ASHL*HSL                                                    TANK0015
      VDCS=VDC+VCHY+VSH                                                       TANK0016
      AGRID=CHNT*ACH                                                          TANK0017
      IF(FFF)9,1,1                                                            TANK0018
C     *********************************************************************    TANK0019
C     *   EVALUATION OF THE TANK MIXED PROPERTIES DURING PUMP          *      TANK0020
C     *   COAST-DOWN .                                                 *      TANK0021
C     *********************************************************************    TANK0022
    1 IF(III-10) 2,2,4                                                        TANK0023
    2 DO 3 N=1,III                                                           TANK0024
      H(N,1)=HIN                                                              TANK0025
      DLP(N)=DIN                                                              TANK0026
      HMIX(N)=H(1,NM)                                                         TANK0027
      XTANK(N)=X(1,NM)                                                        TANK0028
    3 DTANK(N)=DEN(1,NM)                                                      TANK0029
      GO TO 8                                                                 TANK0030
    4 IF(III-100) 5,5,7                                                       TANK0031
    5 DO 6 N=10,III                                                          TANK0032
      H(N,1)=HIN                                                              TANK0033
      DLP(N)=DIN                                                              TANK0034
      XTANK(N)=X(1,NM)                                                        TANK0035
      HMIX(N)=H(1,NM)                                                         TANK0036
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      6   DTANK(N)=DEN(1,NM)                                              TANK0037
          GO TO 8                                                         TANK0038
      7   H(11,1)=HIN                                                     TANK0039
          DLP(11)=DIN                                                     TANK0040
          XTANK(11)=X(1,NM)                                               TANK0041
          HMIX(11)=H(1,NM)                                                TANK0042
          DTANK(11)=DEN(1,NM)                                             TANK0043
          GO TO 8                                                         TANK0044
      8   M=1                                                             TANK0045
          L=0                                                             TANK0046
          K=1                                                             TANK0047
          IF(I .LT. 99) I99=0                                             TANK0048
          VPT=0.0                                                         TANK0049
          GO TO 25                                                        TANK0050
C         **************************************************************  TANK0051
C         *   EVALUATION OF TRANSFERING COLD WATER FROM D. C. TO THE LOWER  *  TANK0052
C         *   PLENUM AFTER N. C. VALVES ARE OPENNED .                   *  TANK0053
C         **************************************************************  TANK0054
      9   L=L+1                                                           TANK0055
          HMIX(9)=HMIX(99)                                                TANK0056
          DTANK(9)=DTANK(99)                                              TANK0057
          AM=G(I+1,NM)*AGRID                                              TANK0058
          VP(L)=G(I+1,NM)*AGRID*DT/DEN(I+1,NM)                            TANK0059
          HMIX(I+1)=HMIX(I)+(AM*DT/(DTANK(I)*VTANK))*(H(I+1,NM)-HMIX(I))  TANK0060
          XTANK(I+1)=(HMIX(I+1)-HSATK)/HFGTK                              TANK0061
          DTANK(I+1)=DENSH(HMIX(I+1),XTANK(I+1))                          TANK0062
          HVP(L)=HMIX(I+1)                                                TANK0063
          DVP(L)=DTANK(I+1)                                               TANK0064
          VPT=VPT+VP(L)                                                   TANK0065
          IF(VPT-VDCS)11,11,14                                            TANK0066
C         **************************************************************  TANK0067
C         *   COLD WATER IS STILL MOVING DOWN .                         *  TANK0068
C         **************************************************************  TANK0069
     11   H(I+2,1)=(VPT/VDCS)*(HVF(K)-HIN)+HIN                            TANK0070
          DLP(I+2)=(VPT/VDCS)*(DTANK(K)-DIN)+DIN                          TANK0071
          TNC=-0.5                                                        TANK0072
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            GO TO 25                                                           TANK0073
C           ********************************************************************   TANK0074
C           *   TANK HOT WATER REACHES THE LOWER PLENUM .                    *   TANK0075
C           ********************************************************************   TANK0076
     14     IF (M-1)  15,15,17                                                  TANK0077
     15     H (I+2,1)=HVF (K)                                                   TANK0078
            DLP (I+2)=DTANK (K)                                                 TANK0079
            TNC=+5.0                                                           TANK0080
            M=M+1                                                              TANK0081
            K=K+1                                                              TANK0082
            K1=1                                                              TANK0083
            VFLK=0.0                                                           TANK0084
            GO TO 25                                                           TANK0085
     17     VFV=0.7*VF (K-1)                                                   TANK0086
            TNC=+5.0                                                           TANK0087
            IF (VF (L)-VFV) 19,21,21                                           TANK0088
C           ********************************************************************   TANK0089
C           *   THE VOLUME ENTERRED THE TANK IS LESS THAN THE HOT WATER      *   TANK0090
C           *   VOLUME ENTERING THE CORE AT CONSTANT TEMP. .                 *   TANK0091
C           ********************************************************************   TANK0092
     19     IF (K1-1) 119,119,219                                              TANK0093
    119     VFK1=VF (K- 1}                                                     TANK0094
            HVFK1=HVF (K-1)                                                    TANK0095
            DVFK1=DVF (K-1)                                                    TANK0096
            GO TO 219                                                          TANK0097
    219     VFLK=VFLK+VF (L)                                                   TANK0098
            IF (VFLK-VFK1) 319,419,419                                         TANK0099
    319     K1=K1+1                                                           TANK0100
            VFT=VFT                                                           TANK0101
            H (I+2,1)=HVFK1                                                    TANK0102
            DLP (I+2)=DVFK1                                                    TANK0103
            GO TO 25                                                           TANK0104
    419     K1=1                                                              TANK0105
            VFT=VFT-VFK1                                                       TANK0106
            H (I+2,1)=HVF (K)                                                  TANK0107
            DLP (I+2)=DVF (K)                                                  TANK0108
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```
      K=K+1                                                         TANK0109
      GO TO 25                                                      TANK0110
C     *****************************************************************  TANK0111
C     *   THE VOLUME ENTERED THE TANK IS EQUAL TO OR LARGER THAN THE   *  TANK0112
C     *   VOLUME ENTERING THE CORE AT CONSTANT TEMP. .                *  TANK0113
C     *****************************************************************  TANK0114
   21 VFT=VFT-VF(K-1)                                               TANK0115
      H(I+2,1)=HVF(K)                                               TANK0116
      DLP(I+2)=DVF(K)                                               TANK0117
      K=K+1                                                         TANK0118
      GO TO 25                                                      TANK0119
   25 IF(I .LE. 9 .AND. I99 .GE. 100) I=99                          TANK0120
      RETURN                                                        TANK0121
      END                                                           TANK0122
```

```
      FUNCTION FRIC(HF,GAVP,GF)                                        FRIC0001
      DIMENSION DAV(100)                                               FRIC0002
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                FRIC0003
      COMMON/PN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF                          FRIC0004
      IF(GF-5.) 1,1,2                                                  FRIC0005
C     ************************** *** ***********************************************  FRIC0006
C     *   FRICTION FACTOR CALCULATION FOR CIRCULAR CROSS SECTION          *  FRIC0007
C     ***************************************************************************  FRIC0008
    1 RNF=GAVP*DDC/VISCH(HF)                                          FRIC0009
      F1=64./RNF                                                       FRIC0010
      GO TO 3                                                          FRIC0011
C     ***************************************************************************  FRIC0012
C     *   FRICTION FACTOR CALCULATION FOR RECTANGULAR CROSS SECTION .    *  FRIC0013
C     ***************************************************************************  FRIC0014
    2 RNF=GAVP*DCH/VISCH(HF)                                          FRIC0015
      F1=91.5/RNF                                                      FRIC0016
      GO TO 3                                                          FRIC0017
    3 F3=0.3164/(RNF**0.25)                                           FRIC0018
      IF(RNF .LT. 2300.) FRIC=F1                                       FRIC0019
      IF(RNF .GE. 2300. .AND. RNF .LT. 4000.) FRIC=F1+((F3-F1)/(4000.-  FRIC0020
C        2300.))*(RNF-2300.)                                          FRIC0021
      IF(RNF .GE. 4000. .AND. RNF .LT. 51094.) FRIC=F3                FRIC0022
      IF(RNF .GE. 51094.) FRIC=0.184/(RNF**0.2)                       FRIC0023
      RETURN                                                          FRIC0024
      END                                                             FRIC0025
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```
      FUNCTION DAVDC(I,NC)                                              DVDC0001
      DIMENSION  DLP(100),DTANK(100),DAV(100),DVF(10000)               DVDC0002
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                 DVDC0003
      COMMON/DK/ DLP,DTANK                                             DVDC0004
      COMMON/LK/L,K,DVF,TNC                                            DVDC0005
      DLP(1)=1./0.0161                                                 DVDC0006
      IF(NC)  1,1,2                                                    DVDC0007
    1 DAVDC=DIN                                                        DVDC0008
      GO TO 5                                                          DVDC0009
    2 DAVDC=0.5*(DTANK(I)+DLP(I))                                      DVDC0010
      GO TO 5                                                          DVDC0011
    5 RETURN                                                           DVDC0012
      END                                                             DVDC0013
```

```
      FUNCTION PDROP(I,HAVP,GTAV,DTAV,NC,DT)                                      PDOP0001
      DIMENSION DAV(100)                                                          PDOP0002
      COMMON/PD/HC,DDC,DIN,FKVO,CHYH,DAV,TSCR,GSCR,CHNT                           PDOP0003
      COMMON/TK/HIN,ACH,CHN,ADC,DCL,VTANK,START,HFGTK,HSATK,VDC,VCHY              PDOP0004
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF                                      PDOP0005
      COMMON/DC/ GA,GB,GC,GD,PA,PB,GIN,PIN,THE,CPP,CDT,RSS,HTK,HV,                PDOP0006
     C          HSU,HSL,HLP,HPI,HWV,DSL,DP,DSA,DBL,AP,ASH,ASHL,AENT,             PDOP0007
     C          AUP,AVI,AVO,FKN,FKO,FKP,FKS,FKD,FKV,FKR,FKUP,NOV                 PDOP0008
      IF(NC) 1,2,2                                                                PDOP0009
    1 DPFD=(FRIC(HIN,GTAV,2.)/DTAV)*(GTAV**2.)*(HC+30.*DDC)/2.0                   PDOP0010
      DPTD=DPFD                                                                   PDOP0011
      GO TO 4                                                                     PDOP0012
    2 DENS=DAVDC(I,NC)                                                            PDOP0013
      ANOV=NOV                                                                    PDOP0014
      GDC=(CHNT*ACH*GTAV)/(ADC*ANOV/4.0)                                          PDOP0015
      DPFD=(FRIC(HAVP,GDC,2.)/DENS)*(GDC**2.)*(HC+30.*DDC)/(2.0*DDC)             PDOP0016
      DPVL=FKVO*(GDC**2.)/(2.00*DENS)                                             PDOP0017
      DPUP=(1.-FKUP*NOV*AVO/AUP)*(GDC**2.)/(2.*DENS)                             PDOP0018
      DPTD=DPFD+DPVL+DPUP                                                         PDOP0019
      GO TO 4                                                                     PDOP0020
    4 PDROP=DPTD                                                                  PDOP0021
      RETURN                                                                      PDOP0022
      END                                                                         PDOP0023
```

```
      FUNCTION CP(HCP)                                              CPCP0001
       IF(HCP .LT. 68.05) CP=0.9976                                 CPCP0002
       IF(HCP .GE. 68.05 .AND. HCP .LT. 117.95)                     CPCP0003
      I   CP=0.9976+0.00004*(HCP-68.05)                             CPCP0004
       IF(HCP .GE. 117.95 .AND. HCP .LT. 168.05)                    CPCP0005
      I   CP=0.9996+0.0001*(HCP-117.95)                             CPCP0006
       IF(HCP .GE. 168.05 .AND. HCP .LT. 218.52)                    CPCP0007
      I   CP=1.0047+0.00019*(HCP-168.05)                            CPCP0008
       IF(HCP .GE. 218.52 .AND. HCP .LT. 269.61)                    CPCP0009
      I   CP=1.0142+0.00029*(HCP-218.52)                            CPCP0010
       IF(HCP .GE. 269.61) CP=1.0289+0.00048*(HCP-269.61)           CPCP0011
       RETURN                                                       CPCP0012
       END                                                          CPCP0013
```

```
      FUNCTION VISCH (HV)                                          VISC0001
       IF(HV .LE. 65.)                                            VISC0002
      1    VISCH=(4.3E-04)-(0.1E-06)*(HV-65.)                     VISC0003
       IF(HV .GT. 65. .AND. HV .LE. 120.)                        VISC0004
      2    VISCH=(4.6E-04)-(3.27E-06)*(HV-65.)                    VISC0005
       IF(HV .GT. 120. .AND. HV .LE. 175.)                       VISC0006
      3    VISCH=(2.8E-04)-(1.81E-06)*(HV-120.)                   VISC0007
       IF(HV .GT. 175.)                                          VISC0008
      4    VISCH=(1.8E-C4)-(0.29E-06)*(HV-175.)                   VISC0009
       RETURN                                                     VISC0010
       END                                                        VISC0011
```

```
      FUNCTION DENSH (HD,XD)                          DENS0001
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF          DENS0002
      IF (HD-194.4)  3,3,1                            DENS0003
3     DENSH=62.5-0.0167* (HD-18.06)                   DENS0004
      GO TO 2                                         DENS0005
1     VH=XD*VG+ (1.-XD) *VF                           DENS0006
      DENSH=1./VH                                     DENS0007
      GO TO 2                                         DENS0008
.2    RETURN                                          DENS0009
      END                                             DENS0010
```

```
      FUNCTION HCC(HH,GH)                                            HCCH0001
      COMMON/FN/DCH,HCH,DZ,ZL,ETHA,VG,VF,TCF                         HCCH0002
      VISC=VISCH(HH)                                                 HCCH0003
      RNH=GH*DCH/VISC                                                HCCH0004
      IF(RNH-2300.)  3,1,1                                           HCCH0005
3     HCC=7.0*TCF/DCH                                                HCCH0006
      GO TO 2                                                        HCCH0007
1     HCC1=7.0*TCF/DCH                                               HCCH0008
      HCC2=0.023*(GH**0.8)*(CP(HH)**0.33)*(TCF**0.66)/((DCH**0.2)*(VISC  HCCH0009
     C       **0.47))                                                HCCH0010
      IF(RNH-4000.)  4,5,5                                           HCCH0011
4     HCC=HCC1+((HCC2-HCC1)/(4000.-2300.))*(RNH-2300.)              HCCH0012
      GO TO 2                                                        HCCH0013
5     HCC=HCC2                                                       HCCH0014
      GO TO 2                                                        HCCH0015
2     RETURN                                                         HCCH0016
      END                                                            HCCH0017
```

```
NF,NCV,TL,PTI,CHN,COT,CTS,ZL
THPH,GPM,HIN,PIN,THE,SPV,CPP
HSAT,HFG,RC,DEEF,GAMA,FR,VTANK
GA,SP,GC,GC,PA,PE
DSL,DF,DDC,DSA,DBL,DCH,DCL,PP
AP,ASH,ASHL,AENT,AUP,AVI,AVO,ACH
FKA,FKG,FKP,FKS,FKD,FEN,FKV,FKR
HTK,HV,HC,HSU,HSL,HLP,HPI,CHYH
HCH,HFIN,HFIN,FEX,FKUP,ADC,ALK,BSS
HFGTK,HSATK,VDC,VCHY,VG,VF,TCF,CHNT
```

25	4	180.0000	50.0000	322.0000	7.7000	0.1000	1.9166
0.50000E+01	0.20000E+04	0.72050E+02	0.73200E+02	0.40000E+02	0.16100E-01	0.12000E+01	
0.19440E+03	0.96260E+03	0.37300E-01	0.78600E-02	0.50000E-01	0.12650E+01	0.10180E+03	
0.22830E+01	0.10000E+00	0.22830E-01	0.12F30E+01	0.48000E+00	0.20000E+01		
0.20640E+00	0.62500E+00	0.13000E+00	0.58550E+00	0.23960E+00	0.73400E-02	0.55000E+01	0.36670E+00
0.30680E+00	0.36480E+01	0.1193CF+01	0.35550E+00	0.22060E+01	0.20600E-01	0.49100E-01	0.14100E-02
0.31100E+00	0.10450F+01	0.84000E+00	0.30000E+00	0.45000E+00	0.10500E+01	0.19040E+03	0.57880E+02
0.20400E+01	0.10000E+01	0.23500E+01	0.40000E+01	0.22500E+01	0.24000E+02	0.15000E+02	0.25000E+01
0.40000E-02	0.833CE-03	0.83300E-03	0.10000E+01	0.190E0E+01	0.31000E+00	0.2486CE-01	0.49330E+03
0.95390E+03	0.19040E+03	0.89170E+00	0.60370E+01	0.20090E+02	0.16800E-01	0.10900E-03	0.40500E+03
0.12400E+02	0.75000E+01	0.60590E+01	0.55000E+01	0.59200E+01	0.585CCE+01	FQZ	
0.372C0E+01	0.54000E+01	0.51000E+01	0.46500E+01	0.42500E+01	0.38000E+01	FCZ	
0.35500E+01	0.34000E+01	0.33800E+01	0.33000E+01	0.31200E+01	0.28500E+01	FCZ	
0.25500E+01	0.21500E+01	0.18000E+01	0.18500E+01	0.24000E+01	0.33000E+01	FCZ	
0.21500E-03	0.12400E-01	DI,DLI					
0.14200E-02	0.30500E-01	BI,DLI					
0.12740E-02	0.11100E+00	PI,DLI					
0.25690E-02	0.30100F+00	PI,DLI					
0.74800E-03	0.11400E+01	BI,DLI					
0.27300E-03	0.30100E+01	DI,DLI					
0.15800E-02	0.27700E+00	Y,AL					
0.49500E-03	0.16900E-01	Y,AL					
0.17000E-03	0.48100E-02	Y,AL					
0.814CCE-04	0.15000E-02	Y,AL					
0.50100E-04	0.42800CF-03	Y,AL					
0.56500E-04	0.11700E-03	Y,AL					
0.78000E-05	0.43700E-04	Y,AL					
0.25000E-05	0.36300E-05	Y,AL					

	PTU/LBM	O C	LBM/S/FT**2	LDM/FT**3		
	P(I,J)	TW(I,J)	G(I,J)	DEN(I,J)	X(I,J)	FCZA(J)
INITIAL CONDITICN	C.7205CE+02	C.69679E+02	C.90207E+03	0.61598E+02	-0.127C8E+C0	C.59422E-C2
INITIAL CCNDITICN	0.75039E+02	C.59617E+C2	C.90207E+C3	0.61548E+02	-0.12397E+C0	C.35941E-02
INITIAL CONDITICN	C.77C73E+02	0.57131F+02	C.90207E+C3	0.61514E+02	-C.12186E+C0	C.28592E-02
INITIAL CCNDITICN	0.78868E+02	0.57675E+02	C.90207E+03	0.61464E+02	-0.120C0E+00	0.28273E-02
INITIAL CONDITICN	0.8C643E+02	0.58621E+C2	0.90207E+C3	0.61455E+02	-C.11815E+C0	C.28365E-C2
INITIAL CCNDITICN	C.82417E+C2	C.59450E+02	C.90207E+03	0.61425E+02	-0.11631E+C0	0.28225E-02
INITIAL CONDITICN	C.8416CE+C2	0.59939E+02	C.90207E+03	0.61396E+C2	-0.11450E+C0	0.27411E-02
INITIAL CCNDITICN	0.85830E+02	0.60049E+02	C.9C207E+C3	0.61368E+02	-0.11276E+00	0.25877E-02
INITIAL CCNDITICN	C.87497E+02	C.60165E+02	C.90207E+C3	0.61342E+02	-0.11113E+00	C.2444CE-C2
INITIAL CCNDITICN	0.88872E+02	0.59891E+C2	C.90207E+03	0.61317E+02	-0.10961E+00	C.22283E-02
INITIAL CCNDITICN	0.90209E+02	0.59674E+02	C.90207E+03	0.61295E+02	-0.1C822E+00	0.2C366E-02
INITIAL CONDITICN	C.91417E+02	C.59288E+C2	0.90207E+03	0.61275E+02	-0.10696E+C0	C.18210E-02
INITIAL CONDITICN	C.92521E+02	C.59304E+02	0.9C2C7E+03	0.61257E+02	-C.10582E+00	0.17012E-C2
INITIAL CCNDITICN	0.93565E+02	0.59517E+02	0.90207E+03	0.61239E+02	-0.10473E+C0	C.16293E-02
INITIAL CCNDITICN	C.94583E+02	0.6CC07E+02	0.90207E+03	0.61222E+02	-0.10367E+C0	0.16197E-C2
INITIAL CCNDITICN	0.95586E+02	0.60357E+02	0.90207E+03	0.612C5E+02	-C.1C263E+CC	C.15814E-02
INITIAL CCNDITICN	C.96550E+02	0.60469E+02	C.90207E+03	0.61189E+02	-0.10163E+C0	0.14951E-02
INITIAL CCNDITICN	C.97447E+02	0.60350E+02	0.90207E+C3	0.61174E+02	-0.1C07GE+C0	C.13657E-02
INITIAL CCNDITICN	0.98258E+02	0.60125E+02	0.90207E+03	0.61161E+02	-0.59857E-C1	0.1222CE-02
INITIAL CCNDITICN	0.98964E+02	0.59631E+02	0.90207E+03	0.61149E+02	-C.59124E-C1	0.1C303E-C2
INITIAL CCNDITICN	0.99957E+02	0.59191E+02	0.90237E+03	0.61139E+02	-C.98508E-01	C.86258E-C3
INITIAL CONDITICN	C.1CC1CE+03	0.59593E+02	C.90207E+C3	0.61130E+02	-0.97938E-01	0.88654E-03
INITIAL CCNDITICN	0.10074E+03	C.61121E+02	C.90207E+03	0.61119E+02	-0.97275E-01	C.11501E-C2
INITIAL CCNDITICN	0.1016CE+03	0.63512E+02	0.90207E+03	C.611C5E+02	-C.96386E-01	C.15814E-02

TIN= 0.40C05E+02   TOUT= C.56436E+C2

```
   51    T=   0.29C07          DT= 0.59727E-02
```

	BTU/S/FT**2.	BTU/LBM	C C	LBM/S/FT**2	LBM/FT**3		FSAT=194.4 BTU/LBM
INCH	QFTAV	H(I,J)	Th(I,J)	G(I,J)	DEN(I,J)	X(I,J)	CONB(I,J)
0	0.0	0.72C50E+C2	0.57646E+C2	0.84916E+C3	0.61598E+02	-0.12708E+C0	-0.1CCCCE-10
1	0.12941E+03	0.76132E+02	0.52792E+C2	0.84916E+03	0.61530E+02	-0.12271E+00	-0.1CC00E-10
2	0.88114E+02	0.78505E+C2	0.52218E+C2	0.84916E+03	0.61484E+02	-0.11970E+30	-C.1CCCCE-1C
3	0.77709E+02	C.81257E+C2	0.53297E+02	0.84916E+03	0.61443E+02	-0.11703E+C0	-0.1CC0CE-10
4	0.76864E+02	C.83778E+C2	0.54596E+02	0.84916E+C3	0.61403E+02	-0.11439E+C0	-0.1CCCCE-1C
5	0.76799E+02	0.86195E+C2	0.55824E+02	0.84916E+C3	0.61362E+02	-0.11175E+00	-0.1CCCQE-1C
6	0.75458E+02	0.88570E+C2	0.56843E+02	0.84916E+03	0.61322E+02	-0.10916E+00	-C.1CC0CE-10
7	0.72312E+02	0.90844E+C2	0.57612E+02	0.84916E+03	0.61285E+02	-0.10667E+C0	-0.1CCCCE-1C
8	0.58280E+02	0.92595E+C2	0.58348E+02	0.84916E+03	0.61249E+02	-0.10432E+C0	-C.1CCC0E-10
9	0.634C3E+02	0.94579E+C2	0.58812E+02	0.84916E+03	0.61215E+02	-0.1C212E+00	-0.1CCCCE-1C
10	0.57876E+02	0.96793E+C2	0.59256E+02	0.84916E+03	0.61185E+02	-0.1CC11E+C0	-0.1CC0CE-10
11	0.52348E+02	0.98431E+C2	0.59550E+02	0.84916E+03	0.6115PE+02	-0.98285E-01	-0.1CCCCE-10
12	0.47796E+02	0.99524E+C2	0.6C028E+02	0.84916E+03	0.61133E+02	-0.96609E-C1	-0.1CC00E-10
13	0.45195E+02	C.10133E+C3	0.60593E+02	0.84916E+03	0.61109E+02	-0.95018E-C1	-C.1CCCCE-10
14	0.44089E+02	0.10271E+C3	0.61304E+C2	0.84916E+C3	0.61C86E+02	-0.93465E-C1	-0.1CCCCE-10
15	0.43439E+02	C.10406E+C3	0.61929E+02	0.84916E+03	0.61C64E+02	-0.91934E-01	-C.1CCCCE-1C
16	0.41748E+02	0.10536E+C3	C.62401E+02	0.84915E+C3	0.61042E+02	-0.9C459E-01	-C.1CCCCE-10
17	0.38922E+02	C.10656E+C3	0.62714E+02	0.84916E+03	0.61C22E+02	-0.89C81E-01	-0.1CCCCE-1C
18	0.35116E+02	0.10765E+C3	0.6293CE+C2	0.84916E+03	0.61C04E+02	-0.87826E-C1	-0.1CCCCE-1C
19	0.30563E+02	C.10859E+C3	0.62949E+02	0.84916E+03	0.6C986E+02	-0.86722E-C1	-0.1CCCCE-10
20	0.256P6E+02	C.10938E+C3	0.62948E+C2	0.84916E+03	0.60975E+02	-0.85780E-C1	-0.1CCCCE-1C
21	0.23735E+02	C.11C10E+C3	0.63403E+02	0.84916E+03	0.60963E+02	-0.849C2E-C1	-0.1CCCCE-10
22	0.27637E+02	C.11C95E+C3	0.64529E+02	0.84916E+03	0.60949E+02	-0.83896E-C1	-0.10C0CE-10
23	0.37066E+02	C.11209E+C3	0.66230E+02	0.84916E+03	0.6093CE+02	-C.82579E-Q1	-C.1CCCCE-1C

```
                      =============================================================          FSAT=191.6 BTU/LBM
  51  T=  0.290   DT= 0.59727E-02       HAV= 0.55671E+C2 GAV= 0.849,6E+03 DAV= 0.61204E+02 TIN= 0.4C0C5E+02 TOUT= C.62261E+C2
```

INCH	BTU/S/FT**2. QETAV	BTU/LBM H(I,J)	C C T(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCAB(I,J)
0	0.0	0.72C50E+C2	0.5281CE+C2	0.79481E+03	0.61599E+02	-0.12709E+C0	-0.1CCCCE-1C
1	0.97662E+02	0.75208E+C2	0.45421E+02	0.79481E+03	0.61546E+02	-0.12367E+C0	-0.1CCCCE-1C
2	0.66499E+02	0.77723E+C2	0.45284E+02	0.79481E+03	0.61504E+02	-0.12093E+C0	-0.1CCCCE-1C
3	C.58647E+02	C.80C5CE+C2	0.5C375E+02	0.79481E+03	0.61465E+02	-0.11839E+C0	-0.1CCCCE-1C
4	0.58009E+02	0.82360E+C2	0.51628E+02	0.79481E+03	0.61426E+02	-0.11586E+C0	-0.1CC00E-1C
5	0.57959E+02	C.84665E+C2	0.52829E+02	0.79481E+03	0.61388E+02	-0.11334E+C0	-0.1CCCCE-1C
6	0.56978E+02	C.86935E+C2	0.53874E+02	0.79481E+03	0.6135CE+02	-0.11086E+C0	-0.1CC00E-1C
7	0.54573E+02	C.89118E+C2	0.54729E+02	0.79481E+03	0.61313E+02	-0.1C846E+C0	-C.1CCCCE-1C
8	0.51530E+02	C.91179E+C2	0.55543E+C2	0.79481E+C3	0.61279E+02	-0.10620E+C0	-0.1CC00E-1C
9	0.47950E+02	C.93C86E+C2	0.56136E+02	C.79481E+03	0.61247E+02	-0.1C409E+C0	-C.1CCCCE-1C
10	0.43678E+02	C.94610E+C2	0.56683E+02	0.79481E+03	0.61218E+02	-0.1C217E+00	-0.1CC00E-1C
11	0.395C7E+02	C.96337E+C2	C.57C83E+C2	0.79481E+03	0.61193E+02	-0.1C046E+C0	-0.1CCCCE-1C
12	0.36071E+02	0.97683E+C2	0.57576E+C2	0.79481E+03	0.6117CE+02	-0.98936E-01	-0.1CC00E-1C
13	0.341C8E+02	0.98894E+C2	0.58092E+02	0.79481E+03	0.61150E+02	-0.91553E-01	-0.1CCCCE-1C
14	0.33274E+02	0.10C01E+C3	0.58677E+C2	0.79481E+03	0.61131E+02	-0.9626EE-C1	-0.10C00E-1C
15	0.32783E+02	C.10105E+C3	0.59167E+02	0.79481E+03	0.61114E+02	-0.95C6CE-C1	-0.1CCCCE-1C
16	0.315C7E+02	C.102CCE+C3	0.59517E+02	0.79481E+03	0.61098F+02	-0.93947E-C1	-0.1CCC0E-1C
17	0.29259E+02	C.10283E+C3	0.59723E+02	0.79481E+03	0.61C84E+02	-0.92955E-01	-0.1CCCCE-1C
18	0.265C1E+C2	C.10354E+C3	0.59832E+02	0.79481E+03	0.61073E+02	-0.92098E-01	-0.1CCCCE-1C
19	0.23066E+02	C.10405E+C3	0.59771E+02	0.79481E+03	0.61063E+02	-0.91396E-C1	-0.1CCCCE-1C
20	-0.19365E+02	0.10449E+C3	0.59673F+02	0.79481E+03	0.61C57E+02	-0.9C852E-C1	-C.1CCCCE-1C
21	C.17913E+02	0.10482E+C3	0.59896E+02	0.794R1E+03	0.61051E+02	-0.9C388E-C1	-0.1CCC0E-1C
22	0.20858E+02	0.10522E+C3	0.60614E+02	0.79481E+03	0.61C44E+02	-0.89842E-01	-C.1CCCCE-1C
23	0.27974E+02	0.10587E+C3	0.61776E+C2	0.79481E+03	0.61C34E+02	-0.89045E-C1	-0.1CCCCE-1C

INCH	BTU/S/FT**2. QFTAV	BTU/LBM H(I,J)	C C Ik(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCAP(I,J)
C	C.0	0.72C50E+C2	0.46350E+02	0.73827E+03	0.61598E+02	-0.12708E+C0	-0.1CC00E-10
1	0.41624E+02	C.73577E+C2	0.44672E+02	0.73827E+03	0.61573E+02	-0.12536E+C0	-0.1CCCCE-1C
2	0.28342E+02	C.74643E+C2	0.44516E+02	0.73827E+03	0.61555E+02	-0.12413E+C0	-0.1CCCCE-10
3	0.24995E+02	0.75604E+C2	0.44964E+02	0.73827E+03	0.61539E+C2	-0.12301E+C0	-0.1CCCCE-10
4	0.24723E+02	0.76571E+C2	0.45502E+02	0.73827E+03	0.61523E+02	-0.12188E+00	-C.1CCCCE-10
5	0.24702E+02	0.77552E+C2	0.46C22E+02	0.73827E+03	0.61506E+02	-0.12073E+C0	-0.1CCC0E-1C
6	0.24284E+02	C.78532E+C2	0.46472E+02	0.73827E+03	0.61490E+02	-0.11959E+00	-0.1CCCE-10
7	0.23259E+02	0.79491E+C2	0.46835E+02	0.73827E+03	0.61474E+02	-0.11846E+CC	-0.1CCC0E-10
8	0.21962E+02	C.80415E+C2	0.47192E+02	0.73827E+03	0.61459E+02	-0.11739E+C0	-C.1CCCCE-10
9	0.20394E+02	0.81296E+C2	0.47451E+02	0.73827E+03	0.61444E+02	-0.11634E+00	-0.1CCC0E-10
10	0.18616E+02	0.82123E+C2	0.47706E+02	0.73827E+03	0.6143CE+02	-0.11535E+C0	-0.1CCC0E-10
11	0.16838E+02	0.82697E+C2	0.47905E+02	0.73827E+03	0.61417E+02	-0.11442E+C0	-0.1CCC0E-1C
12	0.15374E+02	C.83626E+C2	0.48187E+02	0.73827E+03	0.61405E+02	-0.11354E+C0	-0.1CCCCE-10
13	0.14537E+02	0.84335E+C2	0.485C3E+02	0.73827E+03	0.61393E+02	-0.11267E+C0	-0.1CCC0E-1C
14	0.14181E+02	0.85C38E+C2	0.48880E+02	0.73827E+03	0.61381E+02	-0.11182E+C0	-0.1CCCCE-10
15	0.13972E+02	0.85742E+C2	0.49228E+02	0.73827E+03	0.6137CE+02	-0.11096E+C0	-0.1CCCCE-1C
16	0.13428E+02	C.86434E+C2	0.49521E+02	0.73827E+03	0.61358E+02	-0.11011E+C0	-C.1CCCCE-10
17	0.12487E+02	0.871C3E+C2	0.49757E+02	0.73827E+03	0.61347E+02	-0.10930E+C0	-0.1CCC0E-10
18	0.11295E+02	C.87729E+C2	0.49958E+02	0.73827E+03	0.61337E+02	-0.10852E+C0	-C.1CCCCE-10
19	0.98307E+01	0.88310E+C2	0.5CC86E+02	0.73827E+03	0.61327E+02	-0.10779E+C0	-0.1CCCCE-10
2C	0.92620E+01	C.88839E+C2	0.5C21CE+02	0.73827E+03	0.61319E+02	-0.10711E+C0	-0.1CCCCE-1C
21	0.76345E+01	0.89349E+C2	0.5C516E+02	0.73827E+03	0.61309E+02	-0.10645E+C0	-0.1CC00E-10
22	0.88955E+01	C.89910E+C2	0.51C88E+02	0.73827E+03	0.6130CE+02	-0.10575E+C0	-0.1CCC0E-1C
23	0.11922E+02	0.90587E+C2	0.51891E+02	0.73827E+03	0.61289E+02	-0.1C492E+C0	-C.1CC00E-10

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=====================================================================
                                                            HSAT=191.6 ETU/LBM
61 T= 0.930  DT= 0.69C69E-02    HAV= 0.82152E+02 GAV= 0.73827E+03 DAV= 0.6143CE+02 TIN= 0.4C005E+02 TOUT= C.50317E+02
```

	21 T= 1.2E893	DT= 0.74937E-02					
	BTU/S/FT**2.	DTU/LBM	C C	LBM/S/FT**2	LBM/FT**3		HSAT=194.4 BTU/LBM
INCH	GFTAV	H(I,J)	Tb(I,J)	G(I,J)	DEN(I,J)	X(I,J)	CCRE(I,J)
C	C.0	0.72C5CE+C2	0.44487E+02	0.67956E+03	0.61598E+02	-0.127C8E+CC	-0.1CCCCE-10
1	0.27521E+02	0.73137E+C2	0.43311E+02	0.67956E+C3	0.6158CE+02	-0.12582E+C0	-0.1CC0CE-10
2	0.18739E+02	0.7387FE+C2	0.43195E+02	0.67956E+03	0.61568E+02	-0.12493E+C0	-0.1CC0CE-10
3	0.16527E+02	0.7453CE+C2	0.43409E+02	0.67956E+03	0.61557E+02	-0.12412E+00	-0.1CC00E-10
4	0.16347E+02	C.75176E+C2	0.43861E+02	0.67956E+03	0.61546E+02	-0.12332E+C0	-0.1CC0CE-10
5	0.16333E+02	0.75E22E+C2	0.44205E+C2	0.67956E+03	0.61535E+02	-0.12253E+C0	-0.1CC0CE-10
6	0.16056E+02	0.76460E+C2	0.44495E+02	0.67956E+03	0.61525E+02	-0.12174E+C0	-0.1CC0CE-10
7	C.15379C+02	0.77C77E+C2	0.4472CE+02	0.67956E+03	0.61514E+02	-0.120975+00	-0.1CC0CE-10
8	0.14521E+02	0.77676E+C2	0.44943E+02	0.67956E+03	0.61504E+02	-0.12022E+00	-0.1CCCCE-10
9	C.13484E+02	0.78262E+C2	0.45106E+02	0.67956E+03	0.61495F+02	-0.11949E+00	-0.1CC0CE-10
1C	0.123C9E+02	0.79847F+C2	0.45207E+02	0.67956E+03	0.61485C+02	-0.11875E+CC	-0.1CCCCE-10
11	0.11133E+02	2.79455E+C2	C.45463E+02	0.67956E+03	0.61475E+02	-0.118C0E+C0	-0.1CC0CE-10
12	0.10165E+02	0.E0116E+C2	0.45740E+02	0.67956E+03	0.61464E+02	-0.11718E+C0	-0.1CC0CE-10
13	0.96117C+01	C.80E67E+C2	0.46102E+02	0.67956E+03	0.61451F+02	-0.11628E+C0	-0.1CC0CE-10
14	0.93766E+01	C.81739E+C2	0.46576E+02	0.67956E+03	0.61437E+02	-0.11524E+C0	-C.1CC0CE-10
15	C.92383E+01	0.82742E+C2	0.47101E+02	0.67956E+03	0.6142CE+02	-0.114C8E+C0	-0.1CC0CE-10
16	0.88787E+01	0.83F69E+C2	0.47661E+02	0.67956E+03	0.61401E+02	-0.11278E+C0	-0.1CC0CE-1C
17	0.82564E+01	0.851C0E+C2	0.48248E+02	0.67956E+03	0.6138CE+02	-0.11137E+C0	-C.1CC0CE-10
18	0.74681E+01	0.86416E+C2	0.48872E+C2	0.67956E+03	0.6135BE+02	-0.10988E+00	-0.1CC0CE-10
19	0.65CC0E+01	0.87797E+C2	0.49493E+02	0.67956E+03	0.61336E+02	-0.1C833E+00	-0.10C00E-10
20	0.54528E+01	0.89186E+C2	0.5C148E+02	0.67956E+03	0.61312E+02	-0.10675E+00	-0.1CC0CE-1C
21	0.50479E+01	C.90612E+C2	C.5C954E+02	0.67956E+03	0.61288E+02	-0.1C514E+C0	-0.1CCCCE-10
22	0.59777E+01	0.92C89E+C2	0.5195FE+02	0.67956E+03	0.61264E+02	-0.1C348E+C0	-C.1CCCCE-1C
23	0.78830C+01	0.93635E+C2	0.53111E+02	0.67956E+03	0.61238E+02	-0.10175E+C0	-0.1CCCCE-10

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========================================================          HSAT=151.6 BTU/LBM
21 T= 1.289  DT= 0.74937E-02     HAV= 0.8C743E+02 GAV= 0.67956E+03 DAV= 0.61453F+02 TIN= 0.4C005E+02 TOUT= C.52014E+C2
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71   T=   1.68312   DT= C.82686E-02

INCH	BTU/S/FT**2. QETAV	BTU/LBM H(I,J)	C C TH(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CONB(I,J)
0	0.0	0.72C50E+C2	0.44490E+02	0.6177CE+03	0.61598E+02	-0.127C8E+00	-0.1CCCOE-10
1	0.25521E+02	0.73161E+C2	0.43326E+02	0.61770E+03	0.61580E+02	-0.1258CE+C0	-0.1CCCCE-10
2	0.17377E+02	0.7351FE+C2	0.43218E+C2	0.61770E+03	0.61567E+02	-0.12488E+C0	-0.1CCCCE-10
3	0.15325E+02	C.74584E+C2	0.4353CE+02	0.61770E+03	0.61556E+02	-0.12407E+C0	-0.1CCCCE-10
4	0.15159E+02	0.75243E+C2	0.43859E+02	0.61770E+03	0.61545E+02	-0.12325E+00	-0.1CCC7E-10
5	0.15146C+02	C.75502E+C2	0.44250E+02	0.61770E+03	0.61534E+02	-0.12244E+C0	-0.1CCC0E-10
6	0.14889E+02	0.76549E+C2	0.44545E+02	0.61770E+03	0.61523E+02	-0.12165E+C0	-0.1CCC0E-10
7	0.14261E+02	0.77169E+C2	0.44771E+02	0.61770E+03	0.61513E+02	-0.12C88E+00	-0.1CCC0E-10
8	0.13466E+02	0.77753C+C2	0.44986E+C2	0.6177CE+03	0.61503E+02	-0.12014E+C0	-C.1CCC0E-1C
9	0.12504C+02	0.78296E+C2	0.45126E+02	0.61770E+03	0.61494E+02	-0.11945E+CC	-0.1CCC0E-10
10	0.11414E+02	0.78791E+C2	0.45257E+02	0.61770E+03	0.61486E+02	-0.11891E+00	-0.1CCCCE-10
11	0.10324E+02	C.79238E+C2	0.45345E+02	0.61770E+03	0.61478E+02	-0.11822E+C0	-0.1CCCCE-1C
12	0.94261E+01	0.79646E+C2	0.45482E+02	0.6177CE+03	0.61472E+02	-0.11767E+C0	-0.1CCC0E-10
13	C.89131E+01	C.80C32E+C2	0.45642E+02	0.61770E+03	0.61465E+02	-0.11714E+C0	-0.1CCC0E-10
14	C.86351C+01	0.8040EE+C2	0.45842E+02	0.6177CE+03	0.61459E+02	-0.11663E+C0	-C.1CCC0E-10
15	0.85668E+01	C.80778E+C2	0.46C1FE+02	0.61770E+03	0.61453E+02	-0.11612E+C0	-C.1CCCCE-1C
16	0.82334E+01	C.81133E+C2	0.46152E+02	0.6177CE+03	0.61447E+02	-0.11562E+C0	-0.1CCC0E-10
17	0.76563E+01	C.81464E+C2	0.46240E+02	0.61770E+03	0.61441E+02	-0.11515E+C0	-0.1CC3CE-1C
18	0.69253E+01	C.81762E+C2	0.4630CE+02	0.61770E+03	0.61436E+02	-0.11471E+00	-0.1CCC0E-10
19	C.60276E+01	C.82C21E+C2	0.463C4E+02	0.61770E+03	0.61432E+02	-0.11432E+C0	-0.1CCCCE-1C
20	0.50657E+01	C.82238E+C2	0.46302E+02	0.6177CE+03	0.61428E+02	-0.11397E+C0	-0.1CCCCE-10
21	0.46810E+01	C.82439E+C2	0.4643CE+02	0.61770E+03	0.61425C+02	-0.11363E+C0	-0.1CCCCE-1C
22	0.54505E+01	0.82673F+C2	C.46751E+02	0.61770E+03	0.61421E+02	-0.11326E+C0	-0.1CCC0E-10
23	0.73100E+01	C.82588E+C2	C.47236E+02	0.61770E+03	0.61416E+02	-0.11281E+C0	-0.1CCCCE-1C

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HSAT=191.6 PTU/LBM

71 T= 1.683   DT= 0.82686E-02   HAV= 0.78491E+02 GAV= 0.61770E+03 DAV= 0.61491E+02 TIN= 0.4CCC5E+02 TCUT= C.46091E+C2

INCH	BTU/S/FT**2. QETAY	BTU/LBM H(I,J)	C C Th(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCAB(I,J)
0	0.0	0.72C50E+02	0.44597E+02	0.55283E+03	0.61598E+02	-0.12708E+00	-0.1CCCCE-10
1	0.23921E+02	0.73213E+02	0.43419E+02	0.55283E+03	0.61579E+02	-0.12574E+00	-0.1CCCCE-10
2	0.16288E+02	0.74CC4E+02	0.43318E+02	0.55283E+03	0.61566E+02	-0.12479E+00	-0.1CCCCE-10
3	0.14364E+02	0.74701E+02	0.43645E+02	0.55283E+03	0.61554E+02	-0.12394E+00	-0.1CCCCE-10
4	0.14208E+02	0.75390E+02	0.44031E+02	0.55283E+03	0.61543E+02	-0.12310E+00	-0.1CCCCE-10
5	0.14196E+02	0.76C78E+02	0.44397E+02	0.55283E+03	0.61531E+02	-0.12226E+00	-0.1CCCCE-10
6	0.13956E+02	0.76753E+02	0.44706E+02	0.55283E+03	0.61520E+02	-0.12143E+00	-0.1CCCCE-10
7	0.13367E+02	0.77400E+02	0.44944E+02	0.55283E+03	0.61509E+02	-0.12064E+00	-0.1CCCCE-10
8	0.12621E+02	0.78C09E+02	0.45171E+02	0.55283E+03	0.61499E+02	-0.11988E+00	-0.1CCCCE-10
9	0.11720E+02	0.78575E+02	0.45318E+02	0.55283E+03	0.61489E+02	-0.11916E+00	-0.1CCCCE-10
10	0.10698E+02	0.79C9GE+02	0.45458E+02	0.55283E+03	0.61481E+02	-0.11850E+00	-0.1CCCCE-10
11	0.95764E+01	0.79555E+02	0.45591E+02	0.55283E+03	0.61473E+02	-0.11789E+00	-0.1CCCCE-10
12	0.88350E+01	0.79979E+02	0.45695E+02	0.55283E+03	0.61466E+02	-0.11732E+00	-0.1CCCCE-10
13	0.83542E+01	0.80379E+02	0.45862E+02	0.55283E+03	0.61459E+02	-0.11678E+00	-0.1CCCCE-10
14	0.81498E+01	0.80769E+02	0.46070E+02	0.55283E+03	0.61453E+02	-0.11625E+00	-0.1CCCCE-10
15	0.80296E+01	0.81155E+02	0.46254E+02	0.55283E+03	0.61446E+02	-0.11572E+00	-0.1CCCCE-10
16	0.77171E+01	0.81526E+02	0.46394E+02	0.55283E+03	0.61440E+02	-0.11521E+00	-0.1CCCCE-10
17	0.71762E+01	0.81675E+02	0.46490E+02	0.55283E+03	0.61434E+02	-0.11472E+00	-0.1CCCCE-10
18	0.64910E+01	0.82194E+02	0.46560E+02	0.55283E+03	0.61429E+02	-0.11427E+00	-0.1CCCCE-10
19	0.56496E+01	0.82481E+02	0.46576E+02	0.55283E+03	0.61424E+02	-0.11384E+00	-0.1CCCCE-10
20	0.47480E+01	0.82739E+02	0.46594E+02	0.55283E+03	0.61420E+02	-0.11345E+00	-0.1CCCCE-10
21	0.43874E+01	0.82598E+02	0.46755E+02	0.55283E+03	0.61416E+02	-0.11305E+00	-0.1CC0CE-10
22	0.51087E+01	0.8332CE+02	0.47129E+02	0.55283E+03	0.61410E+02	-0.11259E+00	-0.1CCCCE-10
23	0.68516E+01	0.83762E+02	0.47693E+02	0.55283E+03	0.61403E+02	-0.11200E+00	-0.1CCCCE-10

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HSAT=151.6 BTU/LBM
31 T= 2.116 CT= 0.92332E-02   HAV= 0.78802E+02 GAV= 0.55282E+03 DAV= 0.61485E+02 TIN= 0.40005E+02 TCUT= C.46522E+02

INCH	BTU/S/FT**2. OFTAV	BTU/LBM H(I,J)	C C Th(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCRE(I,J)
C	0.0	0.72050E+02	0.44818E+02	0.48271E+03	0.61598E+02	-0.12708E+00	-0.10000E-10
1	0.22500E+02	0.73302E+02	0.43600E+02	0.48271E+03	0.61577E+02	-0.12565E+00	-0.10000E-10
2	0.15320E+02	0.74153E+02	0.43506E+02	0.48271E+03	0.61563E+02	-0.12464E+00	-0.10000E-10
3	0.13511E+02	0.74502E+02	0.43859E+02	0.48271E+03	0.61551E+02	-0.12374E+00	-0.10000E-10
4	0.13364E+02	0.75643E+02	0.44273E+02	0.48271E+03	0.61538E+02	-0.12284E+00	-0.10000E-10
5	0.13353E+02	0.76382E+02	0.44667E+02	0.48271E+03	0.61526E+02	-0.12195E+00	-0.10000E-10
6	0.13127E+02	0.77108E+02	0.45000E+02	0.48271E+03	0.61514E+02	-0.12107E+00	-0.10000E-10
7	0.12573E+02	0.77602E+02	0.45259E+02	0.48271E+03	0.61502E+02	-0.12022E+00	-0.10000E-10
8	0.11872E+02	0.78457E+02	0.45505E+02	0.48271E+03	0.61491E+02	-0.11941E+00	-0.10000E-10
9	0.11024E+02	0.79064E+02	0.45668E+02	0.48271E+03	0.61481E+02	-0.11865E+00	-0.10000E-10
1C	0.10063E+02	0.79616E+02	0.45821E+02	0.48271E+03	0.61472E+02	-0.11795E+00	-0.10000E-10
11	0.91017E+01	0.80115E+02	0.45925E+02	0.48271E+03	0.61464E+02	-0.11731E+00	-0.10000E-10
12	0.83102E+01	0.80569E+02	0.46081E+02	0.48271E+03	0.61456E+02	-0.11671E+00	-0.10000E-10
13	0.78580E+01	0.80597E+02	0.46261E+02	0.48271E+03	0.61449E+02	-0.11614E+00	-0.10000E-10
14	0.76658E+01	0.81414E+02	0.46484E+02	0.48271E+03	0.61442E+02	-0.11558E+00	-0.10000E-10
15	0.75527E+01	0.81624E+02	0.46680E+02	0.48271E+03	0.61435E+02	-0.11503E+00	-0.10000E-10
16	0.72527E+01	0.82218E+02	0.46830E+02	0.48271E+03	0.61429E+02	-0.11449E+00	-0.10000E-10
17	0.67450E+01	0.82583E+02	0.46930E+02	0.48271E+03	0.61422E+02	-0.11399E+00	-0.10000E-10
18	0.61055E+01	0.82912E+02	0.47000E+02	0.48271E+03	0.61417E+02	-0.11352E+00	-0.10000E-10
19	0.53140E+01	0.83196E+02	0.47008E+02	0.48271E+03	0.61412E+02	-0.11310E+00	-0.10000E-10
2C	0.44660E+01	0.83433E+02	0.47009E+02	0.48271E+03	0.61408E+02	-0.11273E+00	-0.10000E-10
21	0.41268E+01	0.83650E+02	0.47148E+02	0.48271E+03	0.61405E+02	-0.11237E+00	-0.10000E-10
22	0.48052E+01	0.83906E+02	0.47494E+02	0.48271E+03	0.61400E+02	-0.11198E+00	-0.10000E-10
23	0.64447E+01	0.84252E+02	0.48019E+02	0.48271E+03	0.61395E+02	-0.11150E+00	-0.10000E-10

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HSAT=151.6 BTU/LBM
81 T= 2.610   DT= 0.10567E-01   HAV= 0.79264E+02 GAV= 0.48270E+03 DAV= 0.61478E+02 TIN= 0.40005E+02 TOUT= 0.46795E+02

INCH	BTU/S/FT**2. QETAV	BTU/LBM H(I,J)	C C Th(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	hSAT=194.4 BTU/LBM CONB(I,J)
0	0.0	0.72050E+02	0.45198E+02	0.40677E+03	0.61598E+02	-0.12708E+00	-0.10000E-10
1	0.21186E+02	0.73447E+02	0.43908E+02	0.40677E+03	0.61575E+02	-0.12550E+00	-0.10000E-10
2	0.14426E+02	0.74396E+02	0.43823E+02	0.40677E+03	0.61555E+02	-0.12439E+00	-0.10000E-10
3	0.12722E+02	0.75230E+02	0.44218E+02	0.40677E+03	0.61545E+02	-0.12339E+00	-0.10000E-10
4	0.12584E+02	0.76055E+02	0.44678E+02	0.40677E+03	0.61531E+02	-0.12241E+00	-0.10000E-10
5	0.12573E+02	0.76879E+02	0.45116E+02	0.40677E+03	0.61518E+02	-0.12143E+00	-0.10000E-10
6	0.12340E+02	0.77685E+02	0.45488E+02	0.40677E+03	0.61504E+02	-0.12047E+00	-0.10000E-10
7	0.11839E+02	0.78456E+02	0.45780E+02	0.40677E+03	0.61491E+02	-0.11954E+00	-0.10000E-10
8	0.11179E+02	0.79183E+02	0.46056E+02	0.40677E+03	0.61479E+02	-0.11866E+00	-0.10000E-10
9	0.10388E+02	0.79956E+02	0.46242E+02	0.40677E+03	0.61468E+02	-0.11783E+00	-0.10000E-10
10	0.94752E+01	0.80468E+02	0.46416E+02	0.40677E+03	0.61458E+02	-0.11707E+00	-0.10000E-10
11	0.85703E+01	0.81020E+02	0.46537E+02	0.40677E+03	0.61449E+02	-0.11637E+00	-0.10000E-10
12	0.78251E+01	0.81521E+02	0.46712E+02	0.40677E+03	0.61440E+02	-0.11572E+00	-0.10000E-10
13	0.73992E+01	0.81994E+02	0.46911E+02	0.40677E+03	0.61432E+02	-0.11511E+00	-0.10000E-10
14	0.72192E+01	0.82453E+02	0.47157E+02	0.40677E+03	0.61425E+02	-0.11450E+00	-0.10000E-10
15	0.71118E+01	0.82906E+02	0.47374E+02	0.40677E+03	0.61417E+02	-0.11391E+00	-0.10000E-10
16	0.68350E+01	0.83239E+02	0.47540E+02	0.40677E+03	0.61410E+02	-0.11333E+00	-0.10000E-10
17	0.63559E+01	0.83740E+02	0.47653E+02	0.40677E+03	0.61403E+02	-0.11275E+00	-0.10000E-10
18	0.57450E+01	0.84100E+02	0.47731E+02	0.40677E+03	0.61397E+02	-0.11229E+00	-0.10000E-10
19	0.50038E+01	0.84410E+02	0.47743E+02	0.40677E+03	0.61392E+02	-0.11184E+00	-0.10000E-10
20	0.42053E+01	0.84667E+02	0.47745E+02	0.40677E+03	0.61388E+02	-0.11144E+00	-0.10000E-10
21	0.38859E+01	0.84903E+02	0.47895E+02	0.40677E+03	0.61384E+02	-0.11107E+00	-0.10000E-10
22	0.45247E+01	0.85181E+02	0.48268E+02	0.40677E+03	0.61379E+02	-0.11066E+00	-0.10000E-10
23	0.60684E+01	0.85560E+02	0.48836E+02	0.40677E+03	0.61373E+02	-0.11014E+00	-0.10000E-10

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hSAT=191.6 BTU/LBM

41   T=   3.178   DT= 0.12524E-01   HAV= 0.80062E+02 GAV= 0.40677E+03 DAV= 0.61464E+02 TIN= 0.40005E+02 TCUT= 0.47522E+02

INCH	BTU/S/FT**2. QFTAV	BTU/LPM H(I,J)	C C TH(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	PSAT=194.4 BTU/LBM CCAB(I,J)
0.	0.0	0.72C50E+C2	0.45904E+02	0.31945E+03	0.61598E+02	-0.127C8E+C0	-0.1CC00E-10
1	0.19869E+02	0.73713E+C2	0.44478E+C2	0.31945E+03	0.61571E+02	-0.12522E+C0	-0.1CC0CE-10
2	0.13529E+02	0.74641E+C2	0.444C8E+C2	0.31945E+C3	0.61552E+02	-0.12393E+C0	-0.1CC00E-10
3	0.11931E+02	0.75832E+C2	0.44879E+02	0.31945E+03	0.61535E+02	-0.12277E+00	-C.1CC0CE-1C
4	0.11801E+02	0.76810E+C2	0.45423E+02	0.31945E+03	0.61519E+02	-0.12163E+C0	-0.1C000E-10
5	0.11791E+02	C.77784E+C2	0.45941E+02	0.31945E+03	0.61503E+02	-0.12C49E+C0	-0.1CCCCE-10
6	0.11592E+02	C.78739E+C2	0.46384E+C2	0.31945E+03	0.61487E+02	-0.11937E+00	-0.1CC00E-10
7	0.11102E+02	0.79650E+C2	0.46734E+02	0.31945E+03	0.61471E+02	-0.11830E+C0	-0.1CCCCE-1C
8	0.10483E+02	C.805C8E+C2	0.47C64E+02	0.31945E+03	0.61457E+02	-0.11728E+C0	-0.1CC0CE-10
9	0.97346E+01	C.813C0E+C2	0.47291E+02	0.31945E+03	0.61444E+02	-0.11633E+C0	-C.1CC0CE-10
1C	0.88859E+01	C.82C19E+C2	0.47502E+02	0.31945E+03	0.61432E+02	-0.11546E+C0	-0.1CCCCE-10
11	0.80373E+01	C.82665E+C2	0.47651E+02	0.31945E+03	0.61421E+02	-0.11466E+C0	-C.1CCCCE-10
12	0.73364E+01	C.83251E+C2	0.47859E+02	0.31945E+03	0.61411E+02	-0.11393E+C0	-0.1CCCCE-10
13	0.69390E+01	C.83802E+C2	0.48093E+02	0.31945E+03	0.61402E+02	-0.11323E+C0	-C.1CCCCE-1C
14	0.67623E+01	0.84338E+C2	0.48379E+02	0.31945E+03	0.61393E+02	-0.11254E+C0	-0.1CC00E-10
15	C.66695E+01	0.84864E+C2	0.48632E+02	0.31945E+03	0.61384E+02	-0.11187E+C0	-C.1CCCCE-1C
16	0.64C99E+01	C.85366E+C2	0.48827C+02	0.31945E+03	0.61376E+C2	-0.11122E+C0	-C.1CC0CE-10
17	0.59606E+01	C.85830E+02	0.48960E+02	0.31945E+03	0.61368E+02	-0.11061E+C0	-0.1CCCCE-10
18	0.53915E+01	0.86246E+C2	0.49054E+02	0.31945E+03	0.61361E+02	-0.11C06E+C0	-0.1CC00E-10
19	0.46926E+01	C.86601E+C2	0.4907CE+02	0.31945E+03	0.61355E+02	-0.10956E+C0	-0.1CC0CE-10
2C	0.39438E+01	0.86893E+C2	0.49074E+02	0.31945E+03	0.6135CE+02	-0.1C913E+C0	-C.1CC00E-10
21	0.36442E+01	0.87160E+C2	0.49243E+02	0.31945E+03	0.61346E+02	-0.1C873E+C0	-C.1CCCCE-10
22	0.42433E+01	0.87476E+C2	0.49665C+02	0.31945E+03	0.61341E+02	-0.1C827E+C0	-C.1CCCCE-10
23	0.56910E+01	0.87513E+C2	0.5C31CE+02	0.31945E+03	0.61333E+02	-0.10769E+C0	-C.1CCCCE-1C

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HSAT=151.6 BTU/LBM

91 T= 3.882   DT= 0.159C6E-01   HAV= 0.815C8E+02 CAV= 0.31945E+03 DAV= 0.6144CE+02 TIN= 0.4CCC5E+02 TCUT= C.4883CE+02

NATURAL CCNVECTICN VALVE CPENS
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		51 T= 5.602C0		DT= 0.1CCC0E+00			

INCH	BTU/S/FT**2. QFTAV	BTU/LBM H(I,J)	C C TW(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCNB(I,J)
C	0.0	0.72111E+C2	0.68653E+02	0.78968E+01	0.61597E+02	-0.127C1E+C0	-C.1CCC0E-10
1	0.17505E+02	0.84604E+C2	0.57343E+02	0.78695E+01	0.61385E+C2	-0.11391E+C0	-0.1CCC0E-10
2	0.11919E+02	0.93273E+C2	0.6C949E+02	0.785C8E+01	0.61244E+C2	-0.1C478E+C0	-C.1CCC0E-10
3	0.10512E+02	0.10C98E+C3	0.65423E+02	0.78341E+01	0.61115E+02	-0.96651E-C1	-C.1CCC0E-10
4	0.10397E+02	0.10853E+C3	0.69750E+02	0.78176E+01	0.60989E+02	-0.88679E-01	-0.1CCC0E-10
5	0.10389E+02	0.11586E+C3	0.73875E+02	0.78017E+01	0.60867E+02	-0.80938E-C1	-C.1CCC0E-1C
6	0.10213E+02	0.12270E+C3	0.77551E+02	0.77869E+01	0.60753E+C2	-0.73716E-C1	-0.1CCC0E-10
7	0.97817E+01	0.12869E+C3	0.8C593E+02	0.77738E+01	0.60652E+02	-0.67361E-C1	-0.1CCC0E-1C
8	0.92363E+01	C.13366E+C3	0.83212E+02	0.77629E+01	0.60569E+02	-0.62075E-C1	-C.1CCC0E-10
9	0.85766E+01	0.13746E+C3	0.84914E+02	0.77546E+01	0.60506E+02	-0.59C03E-01	-0.1CCC0E-10
1C	0.782C9E+01	C.14C02E+C3	0.86C84E+02	0.7749CE+01	0.60463E+02	-0.55216E-01	-0.1CCC0E-10
11	0.70912E+01	0.14139E+C3	0.86456E+02	0.77459E+01	0.6C44CE+02	-0.53667E-C1	-0.1CCC0E-1C
12	0.64654E+01	0.14175E+C3	0.86634E+02	0.77450E+01	0.60434E+02	-0.53169E-C1	-C.1CCC0E-1C
13	0.61136E+01	0.14140E+C3	0.86485E+02	0.78587E+01	0.6C44CE+02	-0.53407E-C1	-0.1CCC0E-10
14	0.59640E+01	0.14C61E+C3	0.86246E+02	0.79740E+01	0.60453E+02	-0.5410CE-C1	-0.1CCC0E-1C
15	0.58761E+01	C.13955E+C3	0.85626E+02	0.80911E+01	0.60471E+C2	-0.55078E-C1	-0.1CCC0E-1C
16	0.56474E+01	0.13822E+C3	0.84626E+02	0.82098E+01	0.60493E+02	-0.56322E-C1	-0.1CCC0E-1C
17	0.52515E+01	0.13662E+C3	0.83276E+02	0.833C2E+01	0.6C52CE+02	-0.5785RE-C1	-0.1CCC0E-10
18	0.475C1E+01	C.13474E+C3	0.81702E+02	0.84523E+01	0.60551E+02	-0.59685C-C1	-0.1CCC0E-1C
19	0.41344E+01	0.13256E+C3	0.79743E+02	0.85762E+C1	0.60588C+02	-0.61829E-01	-0.1CC00E-10
2C	0.34746E+D1	C.13C07E+C3	0.77731E+02	0.87C18E+01	0.60629E+02	-0.64284E-C1	-C.1CCC0E-1C
21	C.32107E+01	C.12755E+C3	0.76475E+02	0.88292E+01	0.60671E+C2	-0.66734E-C1	-0.1CCC0E-10
22	C.37385E+01	C.12565E+C3	0.76375E+C2	0.89584E+01	0.60702E+02	-0.68579E-C1	-C.1CCC0E-1C
23	C.50140E+01	C.12492E+C3	0.77404E+02	0.9C893E+01	0.60715E+02	-0.69251E-C1	-0.1CCC0E-1C

=== HSAT=191.6 BTU/LBM

51 T= 5.602   CT= 0.1C000E+0C   MAV= 0.12261E+03 GAV= 0.80898E+01 DAV= 0.6C754E+02 TIN= 0.4C039E+02 TCUT= C.69365E+C2

INCH	BTU/S/FT**2. QFTAV	BTU/LBM h(I,J)	C C TW(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	FSAT=194.4 BTU/LBM CONB(I,J)
C	C.0	C.72955E+C2	0.63473E+02	0.11237E+02	0.61583E+02	-0.12614E+C0	-0.1CCCCE-10
1	0.13876E+02	C.81576E+C2	0.54225E+02	0.11209E+02	0.61433E+02	-0.11664E+C0	-0.1CC00E-10
2	0.94484E+01	C.88197E+C2	0.56593E+02	0.11190E+02	0.61329E+02	-0.11CC5E+C0	-0.1CCCCE-10
3	0.93327E+01	C.93758E+C2	0.59779E+02	0.11173E+02	0.61236E+02	-0.1C415E+C0	-0.1CCC0E-10
4	0.82421E+01	C.99313E+C2	0.62907E+02	0.11155E+02	0.61143E+02	-0.98255E-01	-0.1CCCCE-10
5	0.82351E+01	0.10430E+C3	0.65938E+02	0.11138E+02	0.61C50E+02	-0.92325E-01	-0.1CCCGE-10
6	0.80957E+01	C.11C43E+C3	0.68731E+02	0.11121E+02	0.60957E+02	-0.86460E-C1	-0.1CCCCE-1C
7	C.77540E+01	C.11575E+C3	0.71213E+02	0.11105E+02	0.60869E+02	-0.80806E-01	-0.1CC0CE-10
8	0.73216E+01	0.12C80E+C3	0.73617E+02	0.11C89E+02	0.60784E+02	-0.75432E-01	-C.1CCCCE-1C
9	0.67987E+01	0.12552E+C3	0.75591E+02	0.11075E+02	0.60705E+02	-0.7C403E-C1	-0.1CCCCE-10
1C	0.62C60E+01	0.12586E+C3	0.77467E+02	0.11061E+02	0.60633E+02	-0.65770E-01	-C.1CCCCE-1C
11	0.56133E+01	C.13381E+C3	0.79039E+02	0.11C49E+02	0.60567E+C2	-0.61536E-C1	-0.1CCCCE-10
12	0.51252E+01	0.13745E+C3	0.8C762E+02	0.11038E+02	0.605C6E+02	-0.57628E-C1	-0.1CCCCE-1C
13	0.43462E+01	C.14C92E+C3	0.82494E+02	0.11027E+02	0.60448E+02	-0.53899E-C1	-C.1CCCCE-1C
14	0.47277E+01	C.14433E+C3	0.84368E+02	0.11017E+02	0.60391E+02	-0.50236E-C1	-C.1CCCCE-10
15	0.46580E+01	C.14771E+C3	0.86096E+02	0.11CC6E+02	0.60335E+02	-0.46602E-C1	-0.1CCCCE-10
16	0.44767E+01	0.15C98E+C3	0.87623E+02	0.10996E+02	0.602BCE+02	-0.43076E-C1	-0.1CCCCE-10
17	0.41629E+01	C.15406E+C3	0.88928E+02	0.10987E+02	0.60229E+02	-0.39752E-C1	-0.1CCCCE-10
18	0.37654E+01	0.15689E+C3	0.9CC7CE+02	0.10978E+02	0.60182E+02	-0.36688E-C1	-C.1CCCCE-1C
19	0.32773E+01	C.15940E+C3	0.9C891E+C2	0.10970E+02	0.6014CE+02	-0.33949E-C1	-C.1CCCGE-10
20	0.27543E+01	0.16158E+C3	0.91631E+02	0.1C964E+02	0.60103E+02	-0.31560E-C1	-0.1CCCCE-10
21	0.25451E+01	C.16363E+C3	0.92917E+02	0.10957E+02	0.6C069E+02	-0.29299E-01	-0.1CCCCE-1C
22	0.29635E+01	0.166CCE+C3	0.95C49E+02	0.10950E+02	0.6CC29E+02	-0.26719E-C1	-0.1CCCCE-1C
23	0.39746E+01	0.16907E+C3	0.97989E+02	0.10941E+02	0.59978E+C2	-0.23355E-C1	-0.1CCCCE-1C

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FSAT=191.6 BTU/LBM

11 T= 10.435   DT= 0.1CCCOE+CC   HAV= 0.12811E+C3 GAV= C.11C55E+02 DAV= 0.6C662E+02 TIN= C.4C509E+02 TOUT= C.9362SE+02

INCH	BTU/S/FT**2. QETAV	BTL/LBM H(I,J)	C C TX(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTL/LBM CCNR(I,J)
0	0.0	0.74570E+C2	0.58199E+02	0.89114E+01	0.61556E+02	-0.12446E+C0	-0.1CCOCE-10
1	0.10271E+02	C.81E85E+C2	0.51561E+02	0.88939E+01	0.61437E+02	-0.11694E+C0	-0.1CCCCE-1C
2	0.69937E+01	C.86545E+C2	0.53557E+02	0.88820E+01	0.61356E+02	-0.11177E+C0	-0.1CCOCE-10
3	0.61679E+01	0.9CE46E+C2	0.56057E+02	0.88715E+01	0.61284E+02	-0.10718E+00	-0.1CCOCE-10
4	0.61CC8E+01	0.95111E+C2	0.58475E+02	0.88610E+01	0.61213E+02	-0.1C262E+C0	-0.1CCCCE-10
5	0.60956E+01	0.99384E+C2	0.6C805E+02	0.88506E+01	0.61142E+02	-0.98C55E-01	-0.1CCCCE-10
6	0.59924E+01	C.1C360E+C3	0.62949E+02	0.88402E+01	0.61072E+02	-0.93554E-C1	-0.1CCCCE-10
7	0.57395E+01	0.1C764E+C3	0.64855E+02	0.88303E+C1	0.61C04E+02	-0.89224E-01	-0.1CCCCE-10
8	0.54195E+01	C.11148E+C3	0.66696E+02	0.88209E+01	0.6094CE+02	-0.85117E-C1	-C.1CCCCE-10
9	0.50324E+01	0.11505E+C3	0.68214E+02	0.88122E+01	0.60E8CE+02	-0.81281E-C1	-0.1CCOCE-10
1C	0.45937E+01	0.11832E+C3	0.69654E+02	0.88042E+01	0.60826E+02	-0.77754E-C1	-0.1CCCCE-1C
11	0.41549E+01	C.12129E+C3	0.7C860E+02	0.87969E+01	0.60776E+02	-0.74539E-C1	-0.1CCCCE-1C
12	0.37936E+01	0.12402E+C3	0.72166E+02	0.87902E+01	C.6073CE+02	-0.71580E-C1	-0.1CCCCE-10
13	0.35872E+01	0.12661E+C3	0.7347CE+02	0.87838E+01	0.60687E+02	-0.68764E-01	-0.1CCCCE-1C
14	C.34994E+01	C.12515E+C3	0.74873E+02	0.87776E+01	0.60645E+02	-0.66005E-C1	-C.1CCCCE-10
15	0.34478E+C1	0.13165E+C3	0.76163E+02	0.87715E+C1	0.6C603E+C2	-0.63276E-C1	-0.1CCCCE-1C
16	0.33136E+01	C.13407E+C3	0.7730E+02	0.87656E+01	0.60563E+02	-0.6C639E-C1	-0.1CCCCE-1C
17	0.30814E+01	0.13633E+C3	0.78249E+02	0.876CCE+01	0.60525E+02	-0.58165E-C1	-C.1CCCCE-1C
18	0.27872E+01	C.13E39E+C3	0.791C8E+02	0.87550E+01	0.60491E+02	-0.55900E-C1	-C.1CCCCE-1C
19	0.24259E+01	0.14C20E+C3	0.79701E+02	0.87506E+01	0.6C46CE+02	-0.53855E-01	-0.1CCCCE-10
2C	0.20388E+01	C.14174E+C3	0.8C223E+02	0.87468E+01	0.6C435E+02	-0.52168E-C1	-0.1CCCCE-10
21	0.18839E+01	C.14317E+C3	0.81139E+02	0.87433E+01	0.60411E+02	-0.50551E-C1	-0.1CCCCE-10
22	0.21936E+01	C.14483E+C3	0.82673E+02	0.87392E+01	0.60383E+02	-0.48703E-01	-0.1CCCCE-1C
23	0.20420E+01	0.14702E+C3	0.84803E+02	0.87338E+01	0.6C346E+02	-0.46302E-01	-0.1CCCCE-10

===

HSAT=151.6 BTL/LBM

21 T= 20.435 CT= 0.1CCCCE+CC HAV= 0.11669E+03 GAV= 0.88012E+01 DAV= 0.60853E+02 TIN= 0.41408E+02 TOUT= C.8154lE+C2

```
71   T= 25.43422        CT= 0.1CCC0E+00
```

INCH	BTU/S/FT**2. QETAV	BTL/LBM H(I,J)	C C TH(I,J)	LBM/S/FT**2 G(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCHB(I,J)
C	0.0	0.75C59E+C2	0.56995E+02	0.837C6E+01	0.61549E+02	-0.12395E+C0	-0.1CCCCE-10
1	0.93681E+01	0.81605E+C2	0.5C94CE+C2	0.83555E+01	0.61439E+02	-0.11703E+00	-0.1CCCCE-10
2	0.63788E+01	0.86C75E+C2	C.52792E+02	0.83452E+01	0.61364E+02	-0.11226E+C0	-0.1CCCCE-1C
3	0.56256E+01	0.9CC2PE+C2	0.55093E+02	0.83361E+01	0.6129EE+02	-0.1C803E+C0	-0.1CCCCE-1C
4	0.55644E+01	0.93547E+C2	C.57316E+02	0.83271E+01	0.61233E+02	-0.1C383E+C0	-0.1CCCCE-1C
5	0.55597E+01	0.97872E+C2	0.55457E+02	0.83180E+01	0.61167E+02	-0.99625E-01	-C.1CCC0E-1C
6	0.54655E+01	C.1C174E+C3	0.6142EE+02	0.83091E+01	0.61103E+02	-0.95481E-C1	-0.1CCC0E-10
7	0.52348E+01	0.1C546E+C3	0.63182E+02	0.83CC6E+01	0.61C40E+02	-0.91496E-01	-0.1CCC00E-10
8	0.49430E+01	C.1C897E+C3	0.64874E+02	0.82925E+01	0.60982E+02	-0.87716E-C1	-0.1CCCCE-1C
9	0.45899E+01	0.11225E+C3	0.66271E+02	0.82849E+01	0.60927E+02	-0.84187E-C1	-0.1CCC0E-10
10	C.41858E+01	C.11525E+C3	0.67599E+02	0.82780E+01	0.60877E+02	-0.8C943E-01	-0.1CCCCE-1C
11	0.37896E+01	C.11797E+C3	0.68706E+02	0.82717E+01	0.60831C+02	-0.77987E-C1	-0.1CCC0E-10
12	0.346C1E+01	C.12C47E+C3	0.65908E+02	0.82660E+01	0.6079CE+02	-0.75267E-C1	-0.1CCCCE-1C
13	0.32718E+01	C.12294E+C3	0.71103E+02	0.82605E+01	0.6075CE+C2	-0.72680E-C1	-0.1CCCCE-10
14	0.31917E+01	C.12516E+C3	0.72388E+02	0.82552E+01	0.60711E+02	-0.70147E-01	-0.1CCCCE-1C
15	0.31447E+01	0.12745E+C3	0.73569E+02	0.82499E+01	0.60673E+02	-0.67644E-C1	-0.1CCCCE-10
16	0.30223C+01	C.12965E+C3	0.7461CE+C2	0.82448E+01	0.60636E+02	-0.65226E-01	-0.1CCCCE-10
17	0.28104E+01	C.13171E+C3	0.75494E+02	0.82401E+01	C.60602E+C2	-0.62960E-C1	-C.1CCCCE-10
18	0.25421E+C1	0.13359E+C3	0.7626CE+02	0.8237CE+01	0.60571E+02	-0.6C88E-C1	-C.1CCCCE-1C
19	0.22126E+01	0.13523E+C3	0.76799E+02	0.82320E+01	0.6C543E+02	-0.59055E-C1	-0.1CCCCE-1C
20	0.18595E+01	0.13662C+C3	0.77272E+02	0.82287E+01	0.6052CE+02	-0.57480E-C1	-0.1CCCCE-1C
21	0.17183E+01	0.13792E+C3	0.78103E+02	0.82258E+01	0.60498E+02	-0.56CC6E-C1	-0.1CCCCE-1C
22	0.20007E+01	0.13942E+C3	0.75498E+02	0.82223E+01	0.60473E+02	-0.54321E-C1	-0.1CCCCE-1C
23	0.26933E+01	0.14141E+C3	0.81434E+02	0.82177E+01	0.6C44CE+02	-0.52128E-01	-C.1CCCCE-10

```
                        ========================================================          HSAT=191.6 BTU/LBM
71  T= 25.434   CT= 0.1CCC0E+CC       HAV= 0.11371E+03 GAV= 0.82756E+01 DAV= 0.6C9C2E+02 TIN= 0.4168CE+C2 TCUT= C.78455E+02
```

```
31   T=  30.43376          CT= 0.1CCCOE+00
```

INCH	BTU/S/FT**2. OFTAV	BTU/LBM H(I,J)	C C TH(I,J)	LBM/S/FT**2 GL(I,J)	LBM/FT**3 DEN(I,J)	X(I,J)	HSAT=194.4 BTU/LBM CCNB(I,J)
0	0.0	0.75523E+C2	0.56136E+02	0.79585E+01	0.6154CE+02	-0.12347E+00	-0.1CCCOE-10
1	C.86945E+01	0.81633E+02	0.50523E+02	0.79451E+01	0.61438E+02	-0.117COE+C0	-0.1CCCCE-10
2	0.59133E+01	0.85804E+C2	0.52263E+02	0.7936CE+01	0.61369E+02	-0.11254E+C0	-0.1CCCCE-10
3	0.52151E+01	0.89491E+C2	0.54411E+02	0.79279E+01	0.61307E+02	-0.1C858E+C0	-0.1CCCCE-10
4	0.51584E+01	0.93145E+C2	0.56484E+C2	0.791S9E+01	0.61246E+02	-0.1C466E+C0	-0.1CCCOE-1C
5	0.51540E+01	0.96804E+C2	0.58481E+02	0.79118E+01	0.61185E+02	-0.1C073E+C0	-0.1CCCCE-10
6	0.50667E+01	0.1CC41E+C3	C.6C319E+02	0.79039E+01	0.61125E+02	-0.96864E-C1	-0.1CCCCE-10
7	0.48529E+01	C.1C387E+C3	0.61956E+02	0.78963E+01	0.61067E+02	-0.93143E-01	-0.1CCCCE-1C
8	0.45823E+01	0.1C715E+C3	0.63534E+02	0.78892E+01	0.61012E+02	-0.89614E-01	-0.1CCCCE-1C
9	0.42550E+01	C.11C20E+C3	0.64838E+02	0.78825E+01	0.60961E+02	-0.86320E-01	-0.1CCCCE-10
10	0.38840E+01	0.11299E+C3	0.66073E+02	0.78764E+01	0.60915E+02	-0.83293E-C1	-0.1CCCCE-10
11	0.35131E+01	C.11552E+C3	0.671C8E+02	0.787C8E+01	0.60872E+02	-0.8C536E-C1	-C.1CCCCE-1C
12	0.32076E+01	C.11784E+C3	0.68227E+02	0.78657E+01	0.60834E+02	-0.77S99E-C1	-0.1CCCOE-10
13	0.30330E+01	0.12CO4E+C3	0.69343E+02	0.78609E+01	0.60797E+02	-0.75588E-C1	-C.1CCCCE-1C
14	0.29589E+01	0.12219E+C3	0.7C536E+02	0.78562E+01	0.60761E+C2	-0.73228E-C1	-0.1CCCOE-10
15	0.29152E+01	C.12431E+C3	0.71633E+02	0.78515E+01	C.6C726E+02	-0.70896E-C1	-0.1CCCCE-10
16	0.28017E+01	C.12636E+C3	0.726CCE+02	0.7847CE+01	0.60691E+02	-0.68646E-C1	-C.1CCCCE-10
17	0.26CS4E+01	C.12827E+C3	0.7342CE+02	0.78429E+01	0.6066CE+02	-0.66537E-C1	-C.1CCCCE-10
18	0.23566E+01	0.13CCOE+C3	0.7413CE+02	0.78391E+01	0.60631E+02	-0.64610E-C1	-0.1CCCCE-10
19	0.20511E+01	C.13152E+C3	0.74629E+02	0.78357E+01	0.60605E+02	-0.62907E-01	-C.1CCCCE-1C
20	0.17238E+01	0.132P1E+C3	0.75065E+02	0.78329E+01	0.60584E+02	-0.61445E-C1	-0.1CCCCE-10
21	0.15929E+01	C.124COE+C3	0.75832E+02	0.78303E+01	0.60564E+02	-0.60078E-01	-0.1CCCCE-1C
22	0.18547E+01	C.13538E+C3	0.7712CE+02	0.78273E+01	0.60541E+02	-0.58515E-C1	-0.1CCCOE-10
23	0.24825E+01	C.13722E+C3	0.7E912E+02	0.78232E+01	0.60510E+02	-C.56478E-C1	-C.1CCCCE-1C

```
=====================================================================              HSAT=191.6 BTU/LBM
31  T= 30.434   DT= 0.100COE+CC      HAV= 0.11152E+03 GAV= 0.78743E+01 DAV= 0.60939E+02 TIN= 0.41938E+02 TCUT= 0.76148E+02
```

APPENDIX D

TWO PHASE FLOW ANALYSIS

D.1   Friction Coefficient

D.2   Void Fraction

D.3   Boiling Criteria

APPENDIX D

TWO PHASE FLOW

D.1 Friction Coefficient

Due to small dimensions of flow channels, one dimensional uniform velocity can be assumed for the coolant in upward motion. Mesh point calculation showed that considering the density variation along the fuel plate, the variation in fluid velocity is negligibly small. Therefore, one can consider constant but not equal velocities for vapour and liquid.

The maximum pressure in the lower plenum in the case of pump coast-down and natural convection, which is the probable case for boiling to occur, is about 19.5 psia. This means that in the case of boiling, steam bubbles are free to have relative velocity with respect to the liquid, therefore, the Separated Flow Model could be applied, whereas at high pressures that vapour and liquid could not have any relative velocity, the Homogeneous Model is a better assumption.

With these assumptions, Lockhart-Martinelle Correlation (Ref, D,1) could be used as the first step:

$$\frac{dP}{dz} \Big|_{friction} = [(2f_f G \ (1-x)v_f)/D]\phi_f^2 \tag{D.1}$$

where
$$\phi_f = 1 + C/X + 1/X^2 \tag{D.2}$$

and C is a constant of fluid conditions (turbulent or viscous) and

$X = dP/dz)_f/dP/dz)_g$ is the ratio of liquid phase to vapour phase

friction pressure gradient assuming each one

is flowing alone in the channel

G total mass flow rate per unit area

x mass quality

D hydraulic diameter

ν_f liquid volume density, and

f_f liquid friction coefficient

For laminar flow in rectangular channels $\quad f = C(GD/\mu)^{-n}$

therefore

$$X = [f_f G^2(1-x)^2 \nu_f/D]/[f_g G^2 x^2 \nu_g/D] = (1-x)^2 \nu_f/x^2 \nu_g \quad f_f/f_g$$

Since

$$f_f/f_g = C(GD(1-x)/\mu_f)^{-n}/C(GDx/\mu_g)^{-n} = (\mu_f/\mu_g)^n (x/(1-x))^n$$

$$X = (\nu_f/\nu_g)(\mu_f/\mu_g)^n ((1-x)/x)^{2-n} \tag{D.3}$$

Because of the relative velocity between vapour and liquid, Chisholm (Ref. .2) corrected the L.M. method by allowing for the interfacial shear force between the phases. He also used Equation D.2 to introduce the influence of mass velocity on ϕ_f (Ref. D.3). A most convenient general expression (Ref D.4) for the coefficient C, used by Collier (Ref. D.5) is:

$$C = [\lambda + (C_2 - \lambda)(\nu_{fg}/\nu_f)^{0.5}][(\nu_g/\nu_f)^{0.5} + (\nu_f/\nu_g)^{0.5}]$$

$$\tag{D.4}$$

where $\lambda = (2^{2-n} - 2)/2$

and for smooth tube of $G \leq 1.47 \times 10^6$ lb$_m$/hr ft^2 $C_2 = 1.47 \times 10^6/G$

$n = 1$ for laminar flow

$n = 0.25$ for transition region

D.2 Void Fraction

Lockhart and Martinelli suggested the following correlation for void fraction as a function of pressure for separated flow model:

$$\alpha = (1 + X^{0.8})^{-0.378} \tag{D.5}$$

The the slip ratio can be found from the general equation:

$$S = (x/(1-x))((1-\alpha/\alpha)(\nu_g/\nu_f) \tag{D.6}$$

where as defined before

$$X = (\nu_f/\nu_g)(\mu_f/\mu_g)^n((1-x)/x)^{2-n}$$

D.3 Boiling Criteria

Following a pump coast down, the decay energy released into the coolant will increase the enthalpy to a point that may exceed the saturation enthalpy, and therefore Saturated Pool Boiling occurs. If the heat flux is large enough, Subcooled Pool Boiling may occur, even though the enthalpy is below saturation. These can be shown on the characteristic curve of pool boiling; surface heat flux versus wall temperature.

AB   natural convection

B'C nucleate boiling

CD   transition boiling

DE   film boiling

ONB onset of nucleate
     boiling

CHF critical heat flux
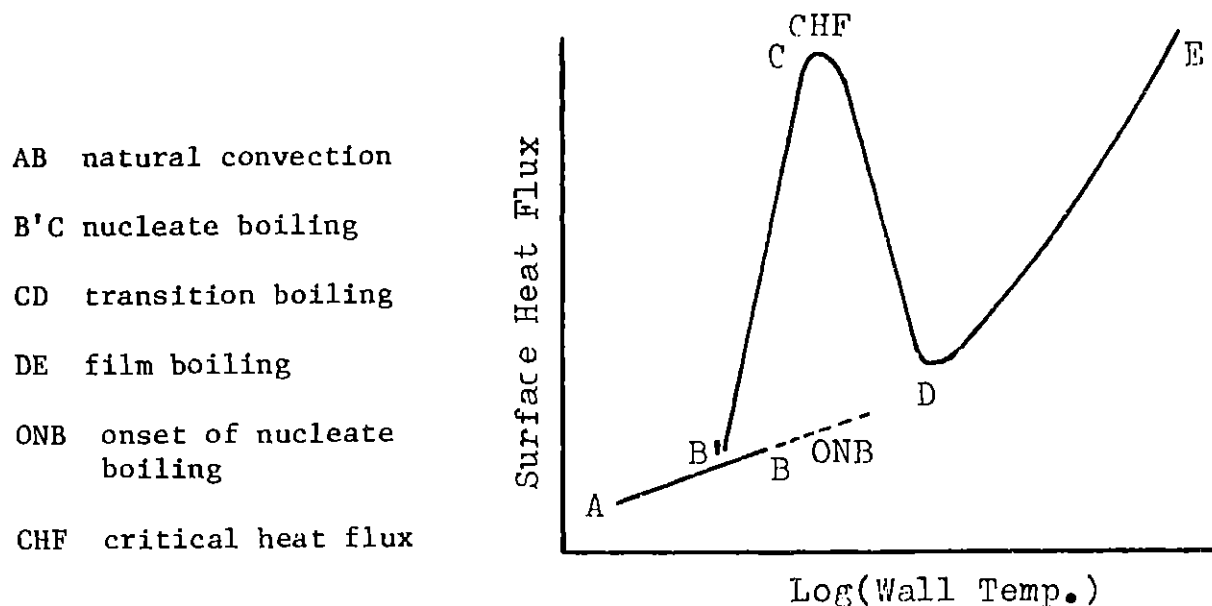
In the natural convection region, the liquid is at or below the saturation temperature, therefore, in this region fluid can be treated as a single phase liquid and in the case of convection, natural convection formulas can be applied correctly.

In the nucleate boiling region, the surface temperature increases slowly for a large increase in surface heat flux. Several equations are known for this condition, but the Rohsenow Correlation (Ref. D.6) gives a conservative results for pressures around atmospheric:

$$T_w = T_{sat} + C_{sf}(\mu_f H_{fg}/k)\,[(q''/\mu_f H_{fg})\ \sqrt{(\sigma/g(\rho_f - \rho_g))}\ ]^{0.33} \qquad (D.7)$$

where

σ is surface tension, lb/ft

H_{fg} is the latent enthalpy, Btu/lbm

q'' surface heat flux, Btu/ft^{2}hr

μ dyn. viscosity, lb/ft hr

k   thermal conductivity, Btu/hr ft °F   and

C_{sf} surface fluid constant, conservatively taken to be 0.013

Critical Heat Flux

High increase in surface heat flux will result in a sudden drop in
heat transfer coefficient which causes a surface termperature surge, that
usually ends up to melt the heating surface.

Several equations are offerred for pool boiling crisis, but only two of
them are taken here and the most conservative result should be used.

Rohsenow and Griffith (Ref. D.7) obtained the following correlation for
the critical heat flox

$$q_c'' = 143 \ H_{fg} \ \rho_v ((\rho_f - \rho_v)/\rho_v)^{0.6} \ (g/g_0)^{0.25} \quad\quad (D.8)$$

where

ρ is the mass density lbm/ft^3

H_{fg} latent enthalpy Btu/lbm, and

q_c'' Btu/hr ft^2

The other equation is for low velocity convection, obtained by Mcbeth
(Ref. D.8):

$$q_c''/10^6 = 0.00633 \ H_{fg} \ De^{-0.1} \ (G/10^6)^{0.51}(1 - x_{exit}) \quad\quad (D.9)$$

which is valid over the range of

P = 15 to 2000 psia

$G/10^6$ = 0,1 to 7.7 lb/hr ft^2

De = 0.1 to 0.94 in   ;   equivalent wetted diameter

L = 6 to 123 in   ;   length of heated chamber

and x_{exit} = negative to positive ; quality.

APPENDIX E

STARTUP INCORE TEMPERATURE MEASUREMENTS

NOTE : Thermocouple Positions are Desoribe in Table 4.1

Table   E-1

STARTUP INCORE TEMPERATURE MEASUREMENTS ($^{\circ}$ C)

STEADY STATE POWER OF 2.5   MWth FOR 3 hrs.

Time	15	19	8 ※	10	11	12	13	14
S. 0.0	44.8	54.4	52.0	53.0	45.8	48.0	44.8	44.0
3.0			48.2					
43.0			61.8					
60.0			66.7					
80.0			68.2					
110.0			65.2					
120.0				49.0				
130.0					41.2			
150.0						42.2		
160.0							38.7	
190.0								38.5
235.0		50.8						
265.0			61.8					
346.0				54.4				
347.0					43.5			
348.0						41.0		
348.5							38.5	
349.5								38.4
350.0	38.4							
352.0			60.2					

※ Thermocouple no. 8 is the same as 9 for the other Tables

Table E-2

STARTUP INCORE TEMPERATURE MEASUREMENTS ($^\circ$C)

STEADY STATE POWER OF 3.0 MWth FOR 3hrs. (run#3)

T/C no. Time	6	7	9	10	11	12	13	16
s.								
0.0		38.8	40.8		33.3	39.5		
11.0						49.3		
20.0		52.0						
27.0						43.3		
32.0					35.8			
50.0						40.5		
56.0					36.0			
68.0			62.4					
75.0		58.8						
83.0						38.5		
90.0					36.4			
95.0						38.3		
115.0			57.5					
122.0		53.5						
min.								
2.5						36.8		
3.5					36.0			
4.0			54.0					
4.5		50.8						
5.5					36.2			
7.8			53.8					

Table E-2 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 3.0 MWth FOR 3hrs. (run #3)

Time min. \ T/C no.	6	7	9	10	11	12	13	16
8.5		50.5						
9.5						36.8		
12.0					36.8			
12.1			53.2					
12.5		50.7						
13.5						37.3		
15.5					37.3			
16.5			53.3					
17.0		50.8						

Table E-3

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 3.5 MWth FOR 6.0 hrs.37 min.

Time \ T/C no.	6	7	9	10	11	12	13	16
S.								
0.0	40.2	39.3	41.3	132.3	32.6	41.9	35.4	
25.0						45.0		
30.0						44.0		
33.0			69.0					
42.0					35.8			
48.0						45.5		
55.0						40.5		
70.0		60.5						
75.0			63.3					
93.0					38.5			
105.0						38.5		
133.0			58.5					
142.0		54.6						
150.0					36.6			
min. 165.0						37.5		
3.5						37.3		
4.0					35.8			
4.5			55.8					
5.0		52.5						
7.5						36.8		

Table E-3 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 3.5 MWth FOR 6.0 hrs., 37 min.

Time min.	6	7	9	10	11	12	13	16
10.0						37.3		
12.0						37.5		
12.5					37.3			
14.0		52.0						
15.0			54.4					
16.5		52.0						
17.5						37.8		
18.0					38.5			
20.0						38.0		
21.0					38.5			
21.5				119.3				
22.0			54.8					
22.5		53.0						
25.0	53.0							
26.0							35.5	
27.0						38.5		
40.0						38.6		
40.5							35.9	
42.0					40.9			
43.0				112.5				

Table E-4

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF   4.0   MWth FOR   10.0   mins.

Time \ T/C no.	6	7	9	10	11	12	13	16
S.								
0.0	45.3	44.4	46.6	85.8	36.8	45.8	39.0	51.8
25.0						46.3		
30.0			71.3					
40.0					42.3			
45.0					40.0			
50.0						43.1		
60.0		62.4						
75.0			64.3					
85.0					40.8			
95.0						40.5		
110.0		57.8						
115.0			60.0					
125.0					40.8			
130.0						39.5		
150.0	55.5							
155.0		55.5						
160.0			56.8					
170.0					39.8			
180.0						38.5		
190.0								35.8

Table E-4 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.0 MWth FOR 10.0 min.

T/C no. Time	6	7	9	10	11	12	13	16
mins.								
3.4						38.1		
5.0	53.3							
5.6		52.8						
6.0			55.0					
7.4					38.9			
8.5						37.5		
9.5							34.8	
14.5						37.4		
14.8	52.0							
15.2		52.5						
15.5			54.0					
15.9					38.5			
16.7						37.0		
17.2							33.9	
17.7				82.3				
19.7	51.8							
20.0		52.0						
20.4			54.0					
21.0					38.6			
21.3						36.6		

Table E-5

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.0 MWth FOR 11.5 hrs.

Time (S.) \ T/C no.	6	7	9	10	11	12	13	16
0.0	50.8	49.8	52.3	152.8	42.5	49.0	43.0	83.0
13.0						50.5		
17.0					44.3			
20.0			73.3					
25.0						53.3		
28.0					55.5			
34.0			78.3					
38.0						49.0		
43.0					45.5			
47.0			73.8					
50.0						48.0		
65.0					46.8			
75.0			70.5					
82.0		66.0						
90.0					47.3			
100.0						46.3		
105.0			68.5					
112.0		64.8						
120.0						45.8		
125.0					46.3			

Table E-5 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.0 MWth FOR 11.5 hrs.

Time \ T/C no.	6	7	9	10	11	12	13	16
S. 160.0					46.5			
170.0						45.5		
190.0			65.8					
200.0		62.8						
210.0	63.0							
230.0						45.5		
250.0							41.5	
280.0				148.5				
290.0								78.3
310.0						45.5		
360.0			65.3					
370.0		62.3						
380.0					47.0			
390.0						45.8		
510.0						46.3		
530.0	62.5							
550.0		62.5						
570.0			65.3					
585.0				143.3				
610.0					48.8			

Table E-5   Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.0   MWth FOR   11.5 hrs.

Time	6	7	9	10	11	12	13	16
S.								
610.0					48.8			
640.0						46.6		
660.0							43.3	
680.0								72.8
700.0	63.0							
730.0		63.3						
760.0			66.0					
790.0				140.0				
820.0					50.0			
850.0						47.3		
870.0							44.3	
900.0								70.5
910.0	63.5							
930.0						47.5		

Table E-6

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.5 MWth FOR 3.25 hrs.

T/C no. / Time	6	7	9	10	11	12	13	16
3. 0.0	44.8	43.5	46.3	152.5	35.0	45.8	38.3	83.8
12.0						44.3		
14.0						46.6		
18.0						47.8		
22.0						48.8		
30.0			75.4					
40.0					38.3			
45.0						45.5		
50.0						44.5		
60.0					3E.8			
70.0			68.0					
80.0						42.8		
90.0		61.0						
100.0			65.3					
105.0					39.3			
110.0						42.0		
150.0		58.3						
160.0			63.0					
170.0					38.3			
190.0						40.3		

Table   E-6 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.5   MWth FOR 3.25 hrs.

Time (S.)	6	7	9	10	11	12	13	16
210.0							36.0	
225.0	57.3							
230.0		56.5						
240.0			60.5					
250.0				149.0				
270.0					39.0			
285.0						40.3		
300.0							36.4	
320.0								78.2
350.0	56.8							
360.0		56.3						
365.0			59.8					
375.0				146.9				
380.0					40.5			
385.0						41.2		
400.0							37.3	
410.0								76.0
425.0	57.5							
430.0		57.2						
450.0			60.5					

Table E-6 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF   4.5   MWth FOR   3.25   hrs.

Time S. / T/C no.	6	7	9	10	11	12	13	16
455.0				142.5				
460.0					42.0			
470.0						42.0		
480.0							38.3	
490.0								72.3
515.0	57.5							
525.0		57.5						
530.0			60.3					
540.0				139.8				
545.0					43.3			
555.0						42.8		
560.0							39.0	
570.0								70.0
580.0						42.5		

Table E-7

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF   4.9   MWth FOR   10.0 mins.

T/C no. / Time	6	7	9	10	11	12	13	16
S. 0.0	50.3	49.0	51.8		40.0	51.5	43.0	55.5
9.0						46.8		
11.0						47.5		
14.0						49.3		
20.0						52.3		
26.0					42.8			
35.0					43.8			
43.0			76.8					
51.0						47.8		
56.0						47.3		
60.0					43.8			
70.0			70.3					
75.0			64.5					
85.0						45.5		
90.0		63.5						
95.0			66.5					
100.0					45.0			
104.0						44.8		
128.0		62.0						
131.0			63.0					

Table E-7 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF   4.9   MWth FOR   10.0   mins.

T/C no. Time mins.	6	7	9	10	11	12	13	16
5.7							39.0	
6.0								57.3
8.6	58.0							
8.65		58.0						
8.7			60.5					
8.8				99.3				
8.9					43.3			
9.0						42.5		
9.2							39.8	
9.3								56.0
10.5	58.3							
10.6		58.3						
10.75			60.5					
10.95				97.8				
11.1					44.8			
11.3						43.5		
11.5							40.0	
12.0								55.3
12.5						43.3		
13.5					44.5			

Table E-7 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.9 MWth FOR 10.0 mins.

Time \ T/C no.	6	7	9	10	11	12	13	16
S. 134.0					44.3			
135.0					44.0			
137.0						42.8		
140.0							39.5	
146.0								59.5
150.0				103.0				
152.0	58.8							
154.0		58.8						
156.0			60.8					
158.0				102.8				
160.0					44.0			
163.0						42.5		
164.0							39.0	
170.0								58.8
270.0	57.8							
mins. 4.8		58.0						
5.0			60.3					
5.2				101.0				
5.4					43.8			
5.5						42.8		

Table E-8

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.83 MWth FOR 18 hrs.

Time \ T/C no.	6	7	9	10	11	12	13	16
S. 0.0	51.8	51.3	53.5	179.0	41.3	51.3	43.5	95.8
6.0						48.0		
9.0						49.0		
11.0						50.5		
15.0					43.0			
23.0			78.0					
27.0						54.4		
32.0					44.8			
37.0			81.6					
43.0						51.0		
50.0					46.3			
55.0			76.5					
60.0		71.3						
65.0	70.8							
70.0						49.0		
77.0					47.5			
90.0			72.3					
98.0		68.5						
103.0	68.5							
108							42.0	

Table E-8 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF 4.83   MWth FOR 18 hrs.

T/C no. \ Time	6	7	9	10	11	12	13	16
S. 115.0						47.0		
120.0					46.8	46.8		
122.0					45.8			
130.0					46.2			
140.0			68.8					
145.0		66.3						
180.0								92.0
188.0							41.5	
200.0						46.0		
210.0					46.5			
230.0				125.0				
235.0			67.3					
250.0		65.5						
255.0	65.3							
265.0								90.0
270.0							40.3	
270.0						46.3		
300.0					46.8			
310.0				173.5				
315.0			67.5					

Table E-8 Cont.

STARTUP INCORE TEMPERATURE MEASUREMENTS (°C)

STEADY STATE POWER OF   4.83   MWth FOR   18   hrs.

T/C no. / Time	6	7	9	10	11	12	13	16
S. 330.0		64.8						
335.0	64.5							
340.0						46.8		
400.0								86.3
405.0							36.6	
415.0						47.8		
430.0					49.3			
450.0				169.5				
455.0			68.0					
465.0		65.3						
475.0	65.5							
min. 15.2								81.8
15.3							45.8	
15.5						49.0		
15.75					52.0			
15.8				164.8				
16.0			69.0					
16.2		66.5						
16.3	66.5							
16.5						49.3		

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