The following material is to be
inserted in Volume II of
NEDO-0084-2, "IF-300 Consolidated
Safety Analysis Report"

8006060078

NEDO-10084-2
April 1980

Consolidated Safety Analysis Report
for
IF 300 Shipping Cask

REVISION INDEX for Revision 2A, April 1980

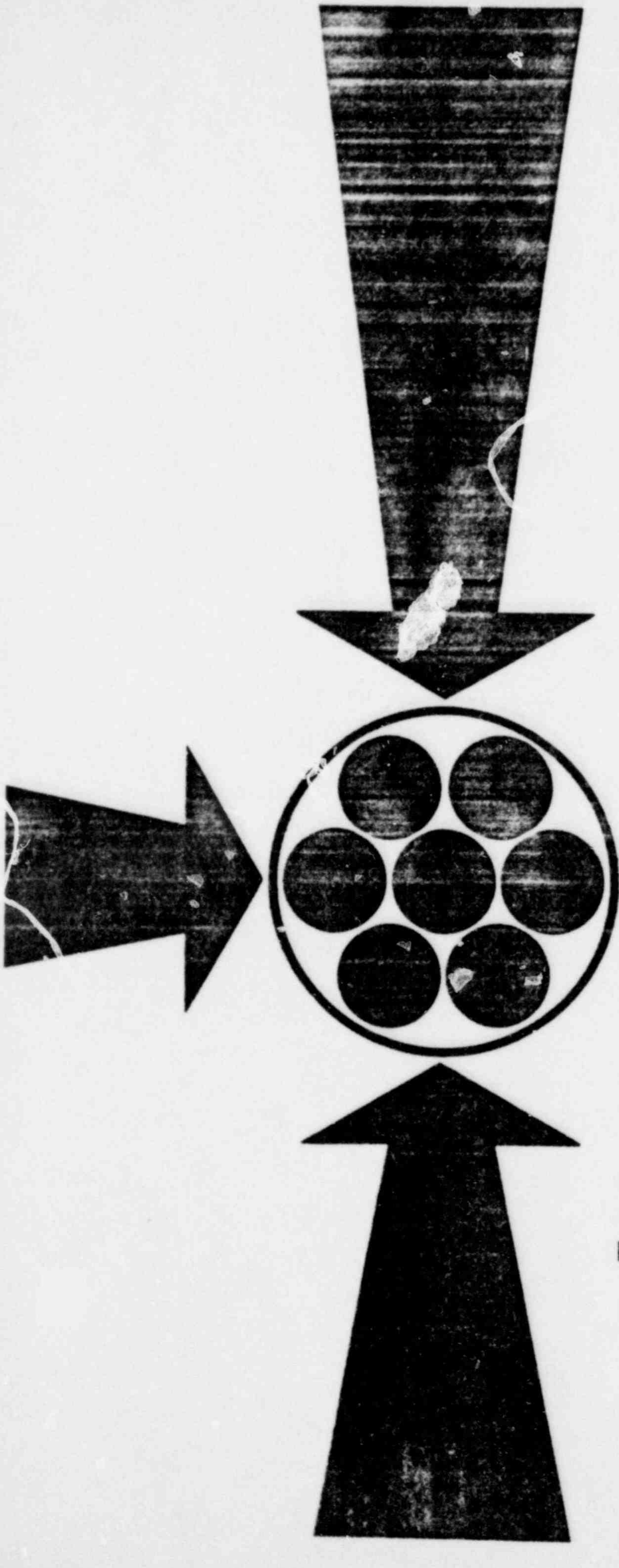
Revision 2A incorporates high pressure fuel rod accident analysis for dry cask shipping mode.

Pages to be Removed			Pages to be Inserted		
Chapter	Page No.	Date	Chapter	Page No.	Date
			Volume I		
			Title page		10/79
			Legal Notice		10/79
			Revision Summary		4/80
			Table of Contents	iii,iv, v/vi	4/80
Volume II			Volume II		
			Title page		10/79
			Legal Notice		10/79
			Revision Summary		4/80
			Table of Contents	iii,iv, v/vi	4/80
Table of Contents	6-i,6-ii	10/79	Table of Contents	6-i,6-ii	4/80
List of Illustrations	6-iii,6-iv	10/79	List of Illustrations	6-iii,6-iv	4/80
List of Tables	6-v,6-vi	10/79	List of Tables	6-v,6-vi	4/80
Chapter 6	6-13,6-14, 6-15,6-16	10/79	Chapter 6	6-13,6-14, 6-15,6-16	4/80
	6-19,6-20	10/79		6-19,6-20	4/80
	6-85,6-86	10/79		6-85,6-86	4/80
	6-91,6-92	10/79		6-91,6-91a through 6-91j,6-92	4/80
	6-113 through 6-118	10/79		6-113 through 6-118b	4/80

REVISION 2A (CONTINUED)

Pages to be Removed			Pages to be Inserted		
Chapter	Page No.	Date	Chapter	Page No.	Date
Volume II			Volume II		
Chapter 6			Chapter 6		
	6-123, 6-124, 6-125, 6-126	10/79		6-123, 6-124, 6-125, 6-126	4/80
	6-169, 6-170	10/79		6-169, 6-170	4/80
Chapter 11			Chapter 11		
	11-5,11-6	10/79		11-5,11-6	4/80

NEDO-10084-2
OCTOBER 1979



IF 300
SHIPPING CASK

CONSOLIDATED SAFETY ANALYSIS REPORT

VOLUME II

NUCLEAR FUEL & SERVICES DIVISION

GENERAL ELECTRIC

DISCLAIMER OF RESPONSIBILITY

This document was prepared by or for the General Electric Company. Neither the General Electric Company nor any of the contributors to this document:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information disclosed in this document may not infringe privately owned rights; or

B. Assumes any responsibility for liability or damage of any kind which may result from the use of any information disclosed in this document.

CONSOLIDATED SAFETY ANALYSIS REPORT
FOR
IF 300 SHIPPING CASK

Revision and Amendment	Date	Summary
NEDO-10084-2	10/79	Consolidation of previous licensing documentation.
NEDO-10084-2A	4/80	Incorporation of high pressure fuel rod accident analysis for dry cask shipping mode.

REVISION CODING KEY: New or changed information is indicated by vertical bars in the right margin opposite the new or changed information: "N" indicates new information; "E" indicates editorial changes or corrections.

DOCUMENT NUMBER KEY:

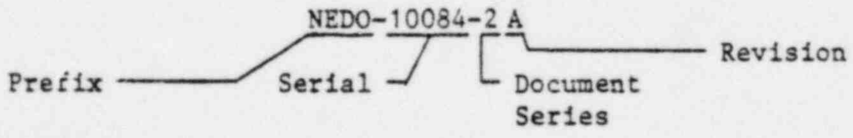


TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS

VI THERMAL ANALYSIS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

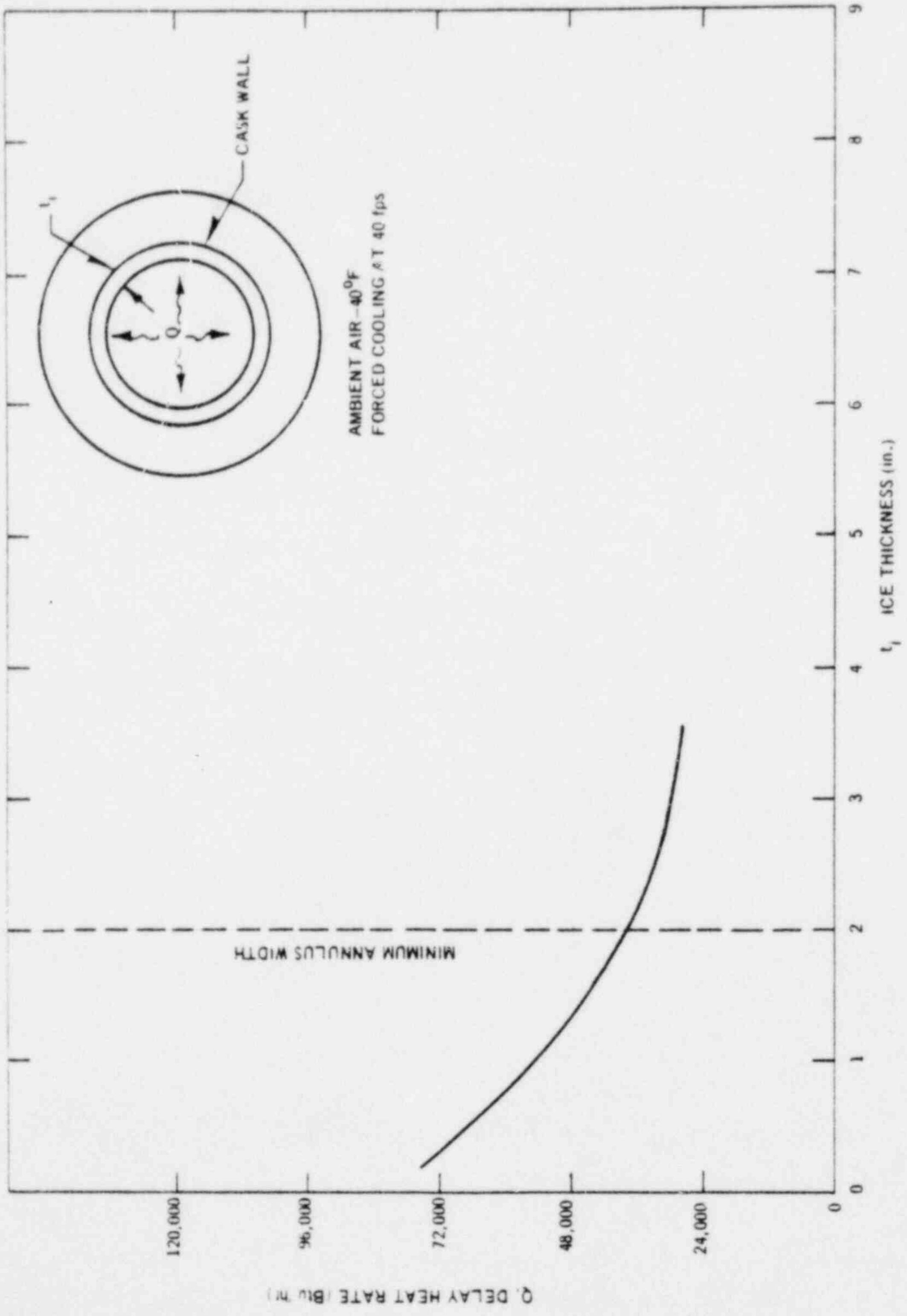


Figure VI-4. Heat Rate vs. Ice Thickness to Yield 32° F at the Ice Annulus Inner Surface a "zero release" unit under accident conditions. On this basis the air is considered to be "contents" not "coolant" and is not required to be sampled before and after shipment. This is discussed in Chapter IX.

The heat load for dry shipping is 40,000 Btu/hr (12 kW). This value was somewhat arbitrarily chosen based on providing an overlap on the wet low temperature heat load of 36,400 Btu/hr (6.2.6). The important parameter in the analysis of dry shipping is maximum fuel cladding temperature. Table VI-7 shows the maximum fuel cladding temperatures for both BWR and PWR fuel assemblies under the regulatory high and low ambient air temperature conditions. For each condition and fuel type, the maximum cladding temperatures are computed for both the system conditions of operation and inoperation.

Table VI-7
MAXIMUM FUEL CLADDING TEMPERATURES
UNDER DRY CASK CONDITIONS

		Maximum Fuel Cladding Temperature, °F	
Fuel Type	Cooling System	@ T_{amb} = 130°F	@ T_{amb} = -40°F
BWR (7 x 7)	On	480	315
	Off	510	370
PWR (15 x 15)	On	635	520
	Off	650	535

The average fuel cladding temperature considering all rods contained in the cask will be much lower than those in Table VI-7. The maximum cladding temperatures shown above are significantly below the cladding failure values (see: Chapter IX).

6.2.8 Accident Conditions - Air-Filled Cavity

For an air-filled cavity under accident conditions at 130°F ambient air with a 40,000 Btu/hr heat load, the maximum cavity wall and fuel cladding temperatures may reach 377°F and 658°F, respectively. Even under these severe conditions, none of the cavity contents will be released from the cask. N

6.2.9 Miscellaneous Thermal Considerations

6.2.9.1 Effects of Ethylene Glycol (Antifreeze) on Neutron Shielding Liquid Heat Transfer

To preclude the freezing of the neutron shielding water under low temperature conditions ethylene glycol will be added to form a fifty-fifty volume percent mixture. This mixture has a freezing point below the regulatory -40°F low temperature limit.

Thermal tests of the IF-300 casks show that the effective conductivity of the water-antifreeze mixture was less than that of water alone. As a consequence it is necessary to place heat load-related restrictions on the cask on a seasonal basis. If the total package decay heat is greater than 183,400 Btu/hr then the following may be used as the neutron shielding medium:

- Water only - May through October
- 50/50 volume percent mixture of ethylene glycol and water - October through May

If the decay heat is less than 183,400 Btu/hr the ethylene glycol-water mixture may remain in place all year.

6.2.9.2 Fuel Cladding Temperatures in Cavity Expansion Void - Water-Filled Cavity E

When the cask is horizontal and the cavity water is relatively cool (i.e. early stages of heat-up transient) a few rows of fuel rods are temporarily uncovered. Once the cavity water heats and expands then all the fuel becomes covered.

To place an upper value on fuel cladding temperature, it was assumed that only free convection cooling of the exposed fuel rods occurred (no radiation). Furthermore, the maximum cavity temperature under LOMC conditions was also assumed. The resultant cladding temperature is 567°F. This is significantly below the cladding failure temperature (see Chapter IX).

6.2.9.3 Thermal Expansion of Liquids - Effects on Pressure

The IF-300 cask has two regions which may contain liquids, the cask inner cavity and the neutron shielding barrel. This latter structure is in two sections each of which is pressure-retaining.

The inner cavity is water-filled for heat loads in excess of 40,000 Btu/hr and may be air-filled at lesser loads. The neutron shielding barrels always remain liquid-filled, sometimes with water and at other times with a mixture of water and ethylene glycol (see 6.2.9.1).

a. Neutron Shielding Barrels

Each shielding barrel section has an associated liquid expansion space. This space comes from both the small voids of trapped air in the upper sections of the corrugations (cask horizontal) and the expansion tanks mounted external to the neutron shielding structure. The expansion tanks are sized such that at minimum water volume (4°C) there is at least 4-1/2 inches of shielding liquid, the minimum analyzed. As the temperature rises the liquid expands first into the remaining barrel voids and then into the external tanks. The neutron shielding system is rated at 200 psig and has safety relief valves set at that pressure. Thermal tests on Cask #301 confirmed that under LOMC conditions the neutron shielding barrels remain below 200 psig.

6.2.9.6 Effect of Residual Water on Cavity Pressure - Air Filled Cavity

As discussed in Section 6.2.7 the cask cavity may be air-filled instead of water-filled if the fuel decay heat is 40,000 Btu/hr or less. The IF-300 cask cavity design does not permit complete draining; a small volume of water remains. The presence of this residual water and the temperature of the cavity wall and contents act to pressurize the cavity under certain circumstances.

The calculations show that the residual water is less than one cubic
foot for both the BWR and PWR configurations (0.605 ft^3 and 0.420 ft^3,
respectively). At an average cavity wall temperature of 210°F (LOMC,
130°F ambient air conditions), the cavity pressure is less than 78 psia.
For the accident case at 130°F ambient, the cavity wall temperature N
may reach 377°F and the cavity pressure may reach 254 psia. The
cavity relief pressure is 375 psig, providing a substantial relief
margin. N

6.2.10 Summary of Cask Thermal Tests

Section 6.6 discusses the details of the thermal test procedures, cask thermal acceptance criterion and the results of tests on casks 301 through 304.

The maximum permitted heat load for the IF-300 cask is 210,000 Btu/hr, however, based on the thermal tests and the acceptance criterion, each cask is assigned a specific maximum heat load which will be equal to or less than 210,000 Btu/hr. Each cask fabricated will undergo a thermal test to determine maximum heat load prior to being accepted for use.

The following table shows the heat load limits for casks 301 through 304.

Cask No.	Maximum Heat Load
301	210,000 Btu/hr
302	202,000 Btu/hr
303	206,000 Btu/hr
304	194,000 Btu/hr

The thermal tests suggested that the computer model slightly under predicted cask temperatures. As a result, the reduction in design-basis heat load was necessary. Also contributing to this decrease was the NRC requirement of cavity pressure/temperature limitations without giving credit for the effects of the mechanical cooling system.

The thermal test results formed the basis for the conclusions on the thermal effects of ethylene glycol in the neutron shielding barrel.

In addition to determining cask heat loads thermal test data are used in conjunction with the computer model and the temperature measurements taken while in use, to perform an annual evaluation of cask thermal performance. This is to determine if there has been any degradation of the cask's ability to dissipate heat.

6.3 PROCEDURES AND CALCULATIONS

6.3.1 Introduction

The thermal analyses of the various conditions summarized in Section 6.2 have been, with minor exceptions, calculated by computer. These calculations are based on parameters specified in Table VI-1 (Section 6.1). This section of the report describes the calculation/methodology incorporated in the various computer codes, discusses the bases for the procedures used, and details the calculations performed.

It should be reemphasized that the thermal analysis is not based on specific fuels but rather on a "design basis" configuration that sets an analyzed upper limit on the cask thermal capacity. The cask is intended as a general purpose container and, as long as the design basis conditions are not exceeded, will function adequately and safely for any light water moderated reactor fuel that may be placed in the cavity fuel baskets. See Section III for a detailed fuels description.

"squared" by dividing the circumference by four as shown in Figure VI-16. The number of fuel rod rows was taken as the square root of the total number of rods (225 X 7 = 1575).

The resulting maximum fuel cladding temperature at a wall temper- | E
ature of 740°F is 1555°F. This value is approximately one percent
lower than the "two-step" method results of 1576°F.

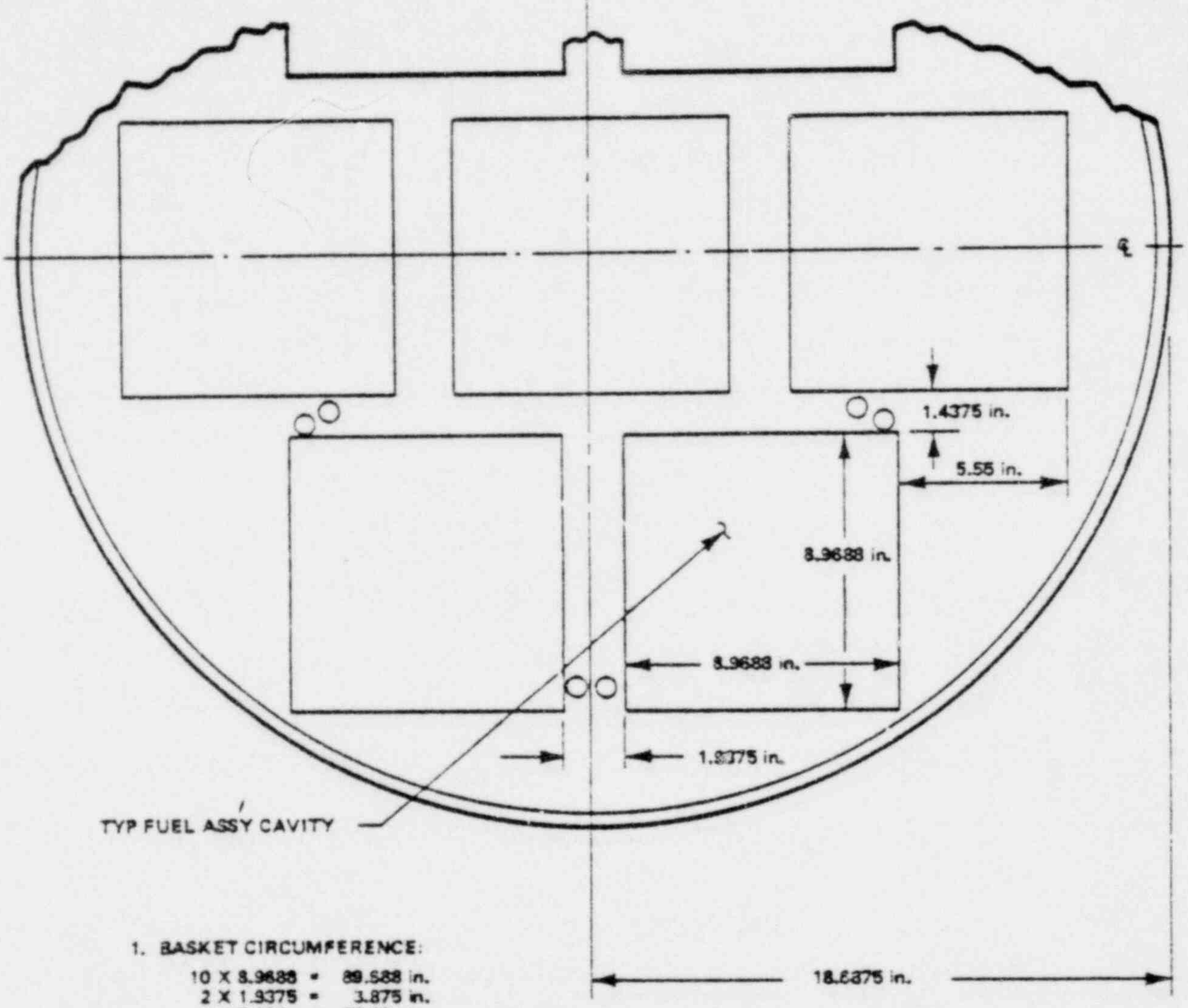
6.3.14.5.A Dry Shipping Low Heat Load Fuel in the IF-300 Cask

The Wooton-Epstein correlation was applied to the evaluation of
post-accident fuel cladding temperatures. This same methodology | E
is used to estimate fuel cladding temperatures for the air-filled | E
cavity at a total cask decay heat rate of 40,000 Btu/hr. Both
normal cooling and LOMC casts are considered. Only the hottest
fuel cladding temperature in the fuel matrix is identified.

A time-sharing program was written to solve equation 6.30 directly
for a load of BWR fuel and indirectly via the "two-step" method of
PWR fuel. The program takes heat generation and cavity wall temp-
erature as input and computes the hottest fuel cladding temperature. | E

Combining the time-sharing input/output with the thermal test results
of cask #301, yields a plot of ambient air temperature vs. maximum | E
fuel cladding temperature for a series of heat loads with and without
the cooling system in operation. These relationships are shown as
Figures VI-17 and VI-18 for the BWR and PWR configurations respectively.

By cross-plotting the data from Figures VI-17 and VI-18, the relation-
ship between heat load and maximum fuel cladding temperature can be | E
obtained for any given ambient temperature. To comply with the
requirements contained in the federal regulations pertaining to
shipping casks, ambient temperatures of +130°F and -40°F were selected
for the maximum fuel cladding evaluation. Figures VI-19 and VI-20 | E
show heat load vs. maximum fuel cladding temperature for the two | E
ambient conditions with and without the cooling system in operation.



1. BASKET CIRCUMFERENCE:

10 X 8.9688 = 89.588 in.
2 X 1.9375 = 3.875 in.
4 X 5.550 = 22.20 in.
4 X 1.4375 = 5.75 in.
C = 121.513 in.

2. EFFECTIVE HEIGHT:

$$H = \frac{C}{4}$$

$$= \frac{121.513 \text{ in.}}{4}$$

$$= 30.378 \text{ in.}$$

Figure VI-16. PWR Basket

Table VI-28 shows the maximum temperature under these conditions at the proposed maximum dry shipment heat load of 40,000 Btu/hr. The average fuel cladding temperature considering all the rods contained in the cask will be much lower than the values shown in Table VI-28.

Table VI-28

MAXIMUM FUEL CLADDING TEMPERATURES

UNDER DRY CASK CONDITIONS

Fuel Type	Cooling System	Tamb = +130°F	Tamb = -40°F
BWR (40,000 Btu/hr)	ON	480°F	315°F
	OFF	510	370
PWR (40,000 Btu/hr)	ON	635	520
	OFF	650	535

6.3.14.5.B Accident Conditions

The methodology employed in this thermal analysis uses the previous THTD thermal model to obtain the cask cavity temperature and some recently developed models to obtain the fuel cladding temperature. The focus of the analysis is on the cask and fuel behavior under post-fire accident conditions since this has been analyzed (Section 6.2.5) to be the worst-case environment. This thermal analysis is an intermediate step in the evaluation of the maximum cavity pressure in the cask under accident conditions. The determination of the cavity and fuel cladding temperatures will permit the calculation of the partial pressures of the cavity air, fuel rod residual gas, and water vapor which together make up the total pressure in the cask cavity. The cavity pressure analysis is described in Section 6.3.14.6.2 for accident conditions.

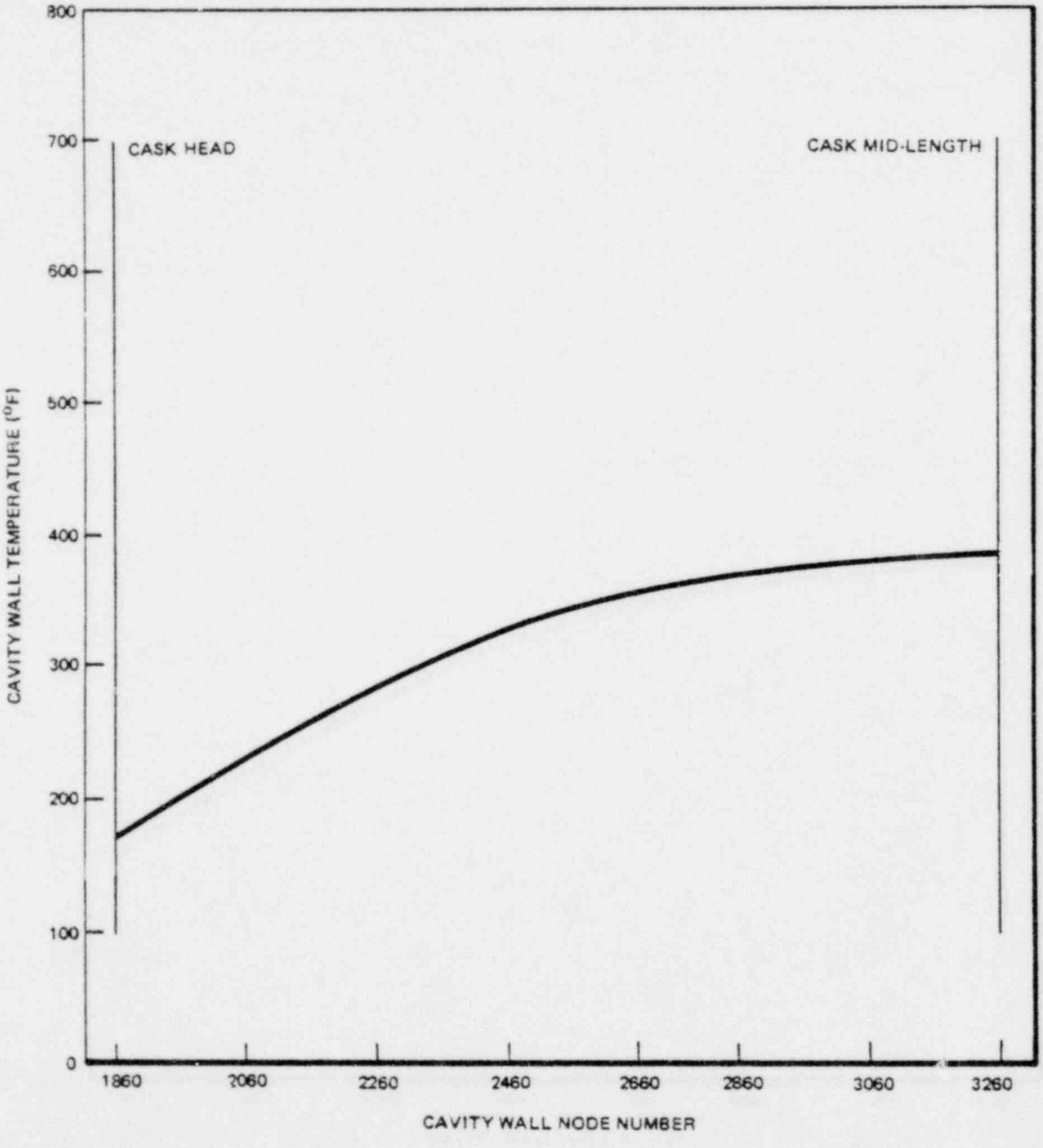
1. Cask Cavity Wall Temperature

   The THTD heat transfer code described in Section 6.3.2 was used to calculate the cask cavity wall temperature distribution under fire-accident conditions. The cask heat load used was 40,000 Btu/hr with the cask in the dry operating mode.

The IF-300 cask temperature distribution at the start of the fire-accident analysis is the no-mechanical cooling condition at 130°F ambient air temperature. The cask model assumes that the neutron shielding liquid has been vented due to mechanical damage of its containment structure from the 30-foot drop. The neutron shielding containment structure acts as a thermal radiation barrier during the 1475°F/30 minute fire condition, thus limiting heat input to the cask. However, following the termination of the fire the cask body continues to heat because the void left by the vented neutron shielding liquid presents a large resistance to the outward flow of the content's decay heat. At equilibrium the principal heat transfer mode across the neutron shielding void space is radiation.

The general boundary conditions and material properties, including a 0.6 emissivity for the cask outer shell, discussed in Sections 6.3.3, 6.3.4 and 6.3.5 were used as input to THTD with the 40,000-Btu/hr heat rate to calculate the cavity equilibrium temperature. The results are plotted in Figure VI-20A. A maximum temperature of 377°F occurs at the cask cavity mid-length as compared to the minimum of 170°F at the cask ends. The IF-300 cask cavity temperature distribution is not affected by the contained fuel configuration or array size as long as the active length of the heat source is approximately 12 feet. The fuel configuration and array size are only important in the determination of the fuel cladding temperature. The maximum temperature of the cavity wall was used to calculate the fuel basket channel and fuel cladding temperatures.

N



N

Figure VI-20A. THTD Results - Dry Cavity Temperature Profile for Low Heat Load

N

2. Fuel Basket Channel Temperature

A program entitled SCRHT (Sparrow and Cess Radiative Heat Transfer) was written to calculate basket channel temperatures for both BWR and PWR fuel. The input boundary condition used for SCRHT was the maximum cask cavity wall temperature obtained from the THTD cask model. SCRHT is a radiation-only code and thus it tends to conservatively predict channel temperatures.

The SCRHT computer code calculates the channel surface temperatures given the fuel bundle heat flux and the cavity wall temperature. The method used to calculate the temperatures is described in Reference 6.26. The method involves the solution of two equations, one for the surface for which the temperature is prescribed, and the other for surfaces with prescribed heat flux. For the prescribed temperature case the equation is given by:

$$\frac{Q_i}{A_i} = \sum_{j=1}^{N_1} \Lambda_{ij}\, \sigma\, T_j^{\,4} - \frac{\varepsilon_i}{1-\varepsilon_i} \sum_{j=(N_1+1)}^{N} \Psi_{ij} \frac{Q_j}{A_j} \; ; \; 1 \le i \le N_1$$

where

N_1 = Number of surfaces with prescribed temperatures

N = Total number of surfaces

σ = Stefan-Boltzmann constant

ε_i = Emittance of ith surface

Q_i/A_i = Heat flux of ith surface

T_j = Temperature of jth surface N

$$\Lambda_{ij} = \frac{\varepsilon_i}{1 - \varepsilon_i} (\delta_{ij} - \Psi_{ij})$$

δ_{ij} = Kronecker Delta = 1 for $i = j$
= 0 for $i \neq j$

$$\Psi = X^{-1}$$

$$X_{ij} = \frac{\delta_{ij} - (i-\varepsilon_i) F_{ij}}{\varepsilon_i}$$

F_{ij} = Geometric shape factor from surface i to j, found by the crossed string method of Hottel.

For the surfaces in which the heat flux is prescribed, the temperature of the surface is given by: N

$$\sigma T_i^{\,4} = \sum_{j=1}^{N_i} \Psi_{ij}\, \sigma T_j^{\,4} + \sum_{j=(N_1+1)}^{N} \Phi_{ij} \frac{Q_i}{A_i}\,; \quad (N_1+1) \le i \le N$$

where:

$$\Phi_{ij} = \frac{1 - \varepsilon_i}{\varepsilon_i} \delta_{ij} + \Psi_{ij}$$

The other variables are as previously defined.

Thus, by applying the above equation to each of the fuel channels in the cask, the channel surface temperatures can be calculated. Also, applying the previous equation to the cask cavity surface allows the calculation of the cask heat flux, since its temperature is known. N

The BWR and PWR configurations modeled using the SCRHT code-calculated wall temperature are shown in Figure VI-13. Based on a uniform cask wall temperature of 377°F and an emissivity of 0.67 for all surfaces, a maximum temperature of 538°F was calculated for the central channel of the BWR basket. The maximum central channel temperature of the PWR basket was 530°F. These maximum channel temperatures were used to calculate the maximum cladding temperatures for the BWR and PWR fuels.

3. Fuel Cladding Temperature

The fuel cladding temperatures were calculated using the R.L. Cox radiative heat transfer array method described in Reference 6.27. The Cox method was developed for calculating cladding temperatures in spent nuclear fuel assemblies. The Cox method was conservatively applied to the IF-300 cask for BWR and PWR fuel assemblies by assuming that the maximum basket channel wall temperatures of 538°F and 530°F, respectively, were uniformly distributed over the entire length of every channel.

Using the Cox correlation, the hottest fuel cladding temperature was calculated from:

$$T_1 = \left\{ \left[Z + \left(\frac{1-\varepsilon}{\varepsilon}\right)\left(1 + \frac{mA_1}{A_n}\right)\right] \frac{Q_1}{A_1\sigma} + T_n{}^4 \right\}^{\frac{1}{4}}$$

where:

σ = Stefan-Boltzmann constant

T_1 = Maximum fuel cladding temperature, °R

T_n = Channel temperature, °R

ε = Emissivity N

m = No. pins in array

A_1 = Pin heat transfer area, ft^2/ft

A_n = Channel heat transfer area, ft^2/ft

Q_1/A_1 = Pin surface heat flux, Btu/hr ft^2

Z = Geometry factor

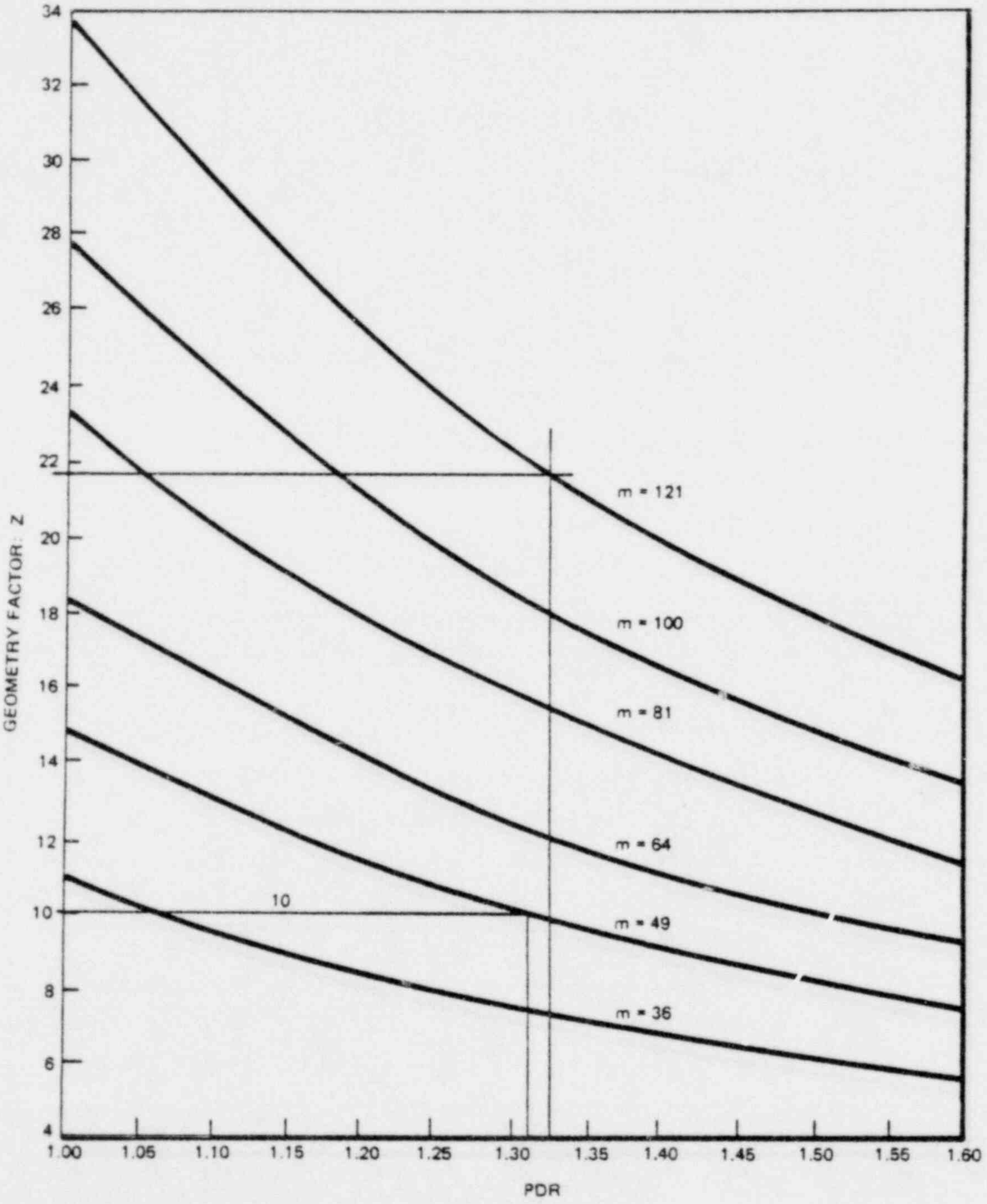
The geometry factor Z from Reference 6.27 is plotted in Figures VI-20B and VI-20C as a function of the rod pitch to diameter ratio (PDR). The bounding BWR and PWR input parameters with their resultant fuel cladding temperatures are tabulated in Table VI-28A. The highest cladding temperature calculated was 675°F for a 14x14 PWR fuel assembly. N

4. Emissivity Sensitivity

The sensitivity of cask temperatures to changes in emissivity of the cask outer shell and the neutron shielding barrel was examined. Under accident conditions the decay heat is radiated across the void created by the loss of the neutron shielding liquid. It is important to determine the effect on cask temperatures of a reduction in the emissivity of the two shells bounding the void.

The THTD code and the subsequent fuel cladding temperature correlations were utilized with an emissivity of 0.4 rather than the 0.6 value for the cask outer shell. As expected, there was a subsequent elevation of cavity surface temperatures as well as fuel clad temperatures. As a result, the cask internal pressure increased but remained well below the relief valve setting of 375 psig. Table VI-28B compares the two emissivity cases. N

N

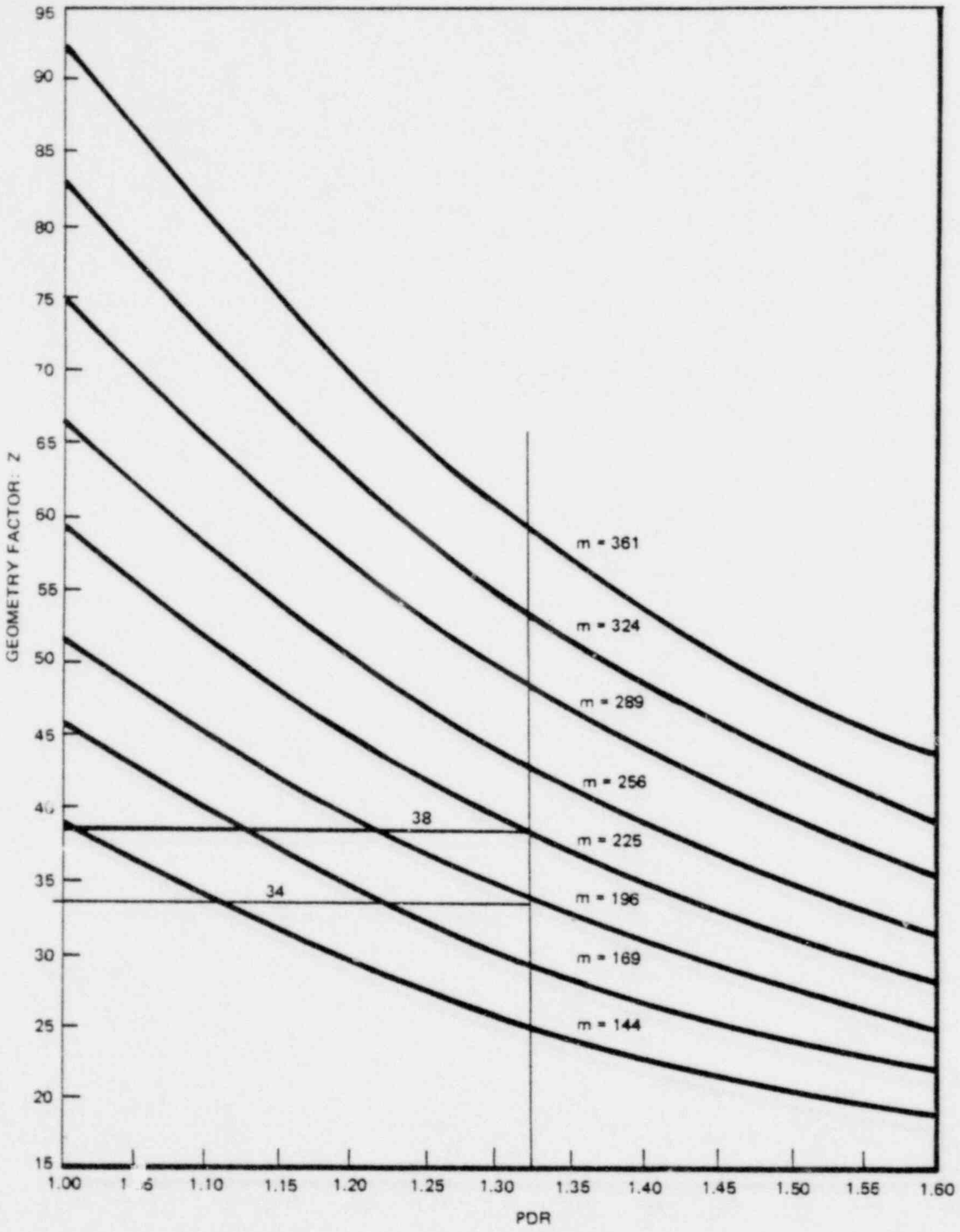


N

Figure VI-20B. Center-Rod Temperatures for Square Arrays of 36, 49, 64, 81, 100, and 121 Fuel Cladding

N

N



N

Figure VI-20C. Center-Rod Temperatures for Square Arrays of 144, 169, 196, 225, 256, 289, 324, and 361 Fuel Cladding

N

Table VI-28A

COX CORRELATION INPUTS AND RESULTS FOR THE ACCIDENT CONDITIONS

Type	BWR	PWR	PWR
Array	7x7	14x14	15x15
Active rods	49	176*	200*
Rod OD, in.	0.562	0.413	0.422
Rod pitch, in.	0.738	0.553	0.563
PDR	1.32	1.34	1.33
A_1, ft^2/ft	0.147	0.108	0.110
Q_1, Btu/hr ft^2	3.78	2.95	2.38
A_n, ft^2/ft	1.92	2.92	2.92
m	49	196	225
ε	0.67	0.67	0.67
T_n, °F**	538	529	529
T_i, °F**	582	658	646

*Approximately 10% of rod positions are used for instrumentation and control applications.
**Shown in °R in equation.

Table VI-28B

EMISSIVITY COMPARISON

	Case I	Case II
Emissivity, ε	0.6	0.4
Peak bbl surface temperature, °F	160	165
Peak outer shell temperature, °F	330	370
Peak cavity surface temperature, °F	377	415
Peak channel wall temperature, °F	529	533
Peak fuel cladding temperature, °F	658	675
Peak cavity pressure,* psia	254	358

*Relief valve lifting pressure is 375 psig.

6.3.14.6 Summary and Conclusions

A. Wet Shipping Mode - Accident Conditions

The Wooton-Epstein correlation was used to calculate the fuel cladding temperature for wet shipment under accident conditions. N This correlation was slightly modified to more accurately describe the PWR fuel configuration. As a double check on the modification the correlation was applied directly and found to predict the maximum fuel cladding temperature E within one percent. Furthermore, the temperature error was in the conservative direction (e.g., modified version produced a higher temperature). The BWR configuration geometry permitted a direct application of the correlation. Since the PWR is the more severe case, the temperature profile of Figure VI-15 will form the basis for the fission gas release analysis of Section IX.

B. Dry Shipping Mode - Accident Conditions

The Cox method which was recently developed was used to calculate the fuel cladding temperature for dry shipment under accident N conditions. The PWR fuel cladding temperature was the highest and will be used in calculating the cask cavity pressure in Subsection 6.3.20.

6.3.15 Cold Condition - Water Filled Cavity

Figure VI-4 summarizes the results of the "cold conditions" calculation. Note that calculations have been made only for the forced cooling case since it represents the maximum heat dissipation condition. The procedures used to perform these calculations are summarized below.

The calculation procedure consists of the following steps:

1. Compute the equivalent conductivity (k_e) of the cask wall, including exterior water. This equivalent value is a function of the position and conductivity of each cask wall component.

$$1/k_e = \frac{1}{\ln(D_o/D_i)} \left[\frac{\ln(D_o/D_i)_1}{k_1} + \frac{\ln(D_o/D_i)_2}{k_2} + \frac{\ln(D_o/D_i)_3}{k_3} \right] \qquad (6.32)$$

| E

where:

k = conductivity (Btu/hr-ft-°F)

D_o = outside diameter, ft

D_i = inside diameter, ft

Numbered subscripts denote various shells.

2. Set up the ΔT across the cask wall using the equivalent conductivity and the following:

$$\Delta T_W = \frac{Q}{2\pi k_e} \ln(D_o/D_i) \qquad (6.33)$$

where:

Q = linear heat rate, Btu/hr-ft

Table VI-35

VOLUME SUMMARY

Item	BWR	PWR
ΔV_{cavity}, ft^3	0.68	0.66
$\Delta V_{hard.}$, ft^3	.096	.082
ΔV_{net}, ft^3	.584 (increase)	.588 (increase)
% of free volume	0.7	0.72

3. Water level - cask horizontal

The water level in the cask forms a segment with the cavity wall. The volume of this segment is given by

$$V = \ell \left\{ R^2 \left[\text{Cos}^{-1} \frac{R - h}{R} \right] - (R - h) \sqrt{2Rh - h^2} \right\}$$

where: ℓ = effective cavity length
R = cavity radius
h = void volume height, max.

This relationship is valid until the fuel bundles are reached. Thereafter, the segment volume must be corrected for bundle volume. Figure VI-23 shows the void height vs. void volume for both cask configurations. From this a $\Delta V = 0.584\ ft^3$ produces a water level change of only 0.24 inches, an insignificant amount. This has no effect on cask operating conditions.

6.3.20 Effects of Residual Water on Cavity Pressure for Air-Filled Cavity N

The IF 300 cask cavity cannot be totally drained so that less than one cubic foot of water will remain in the cask when drained for N

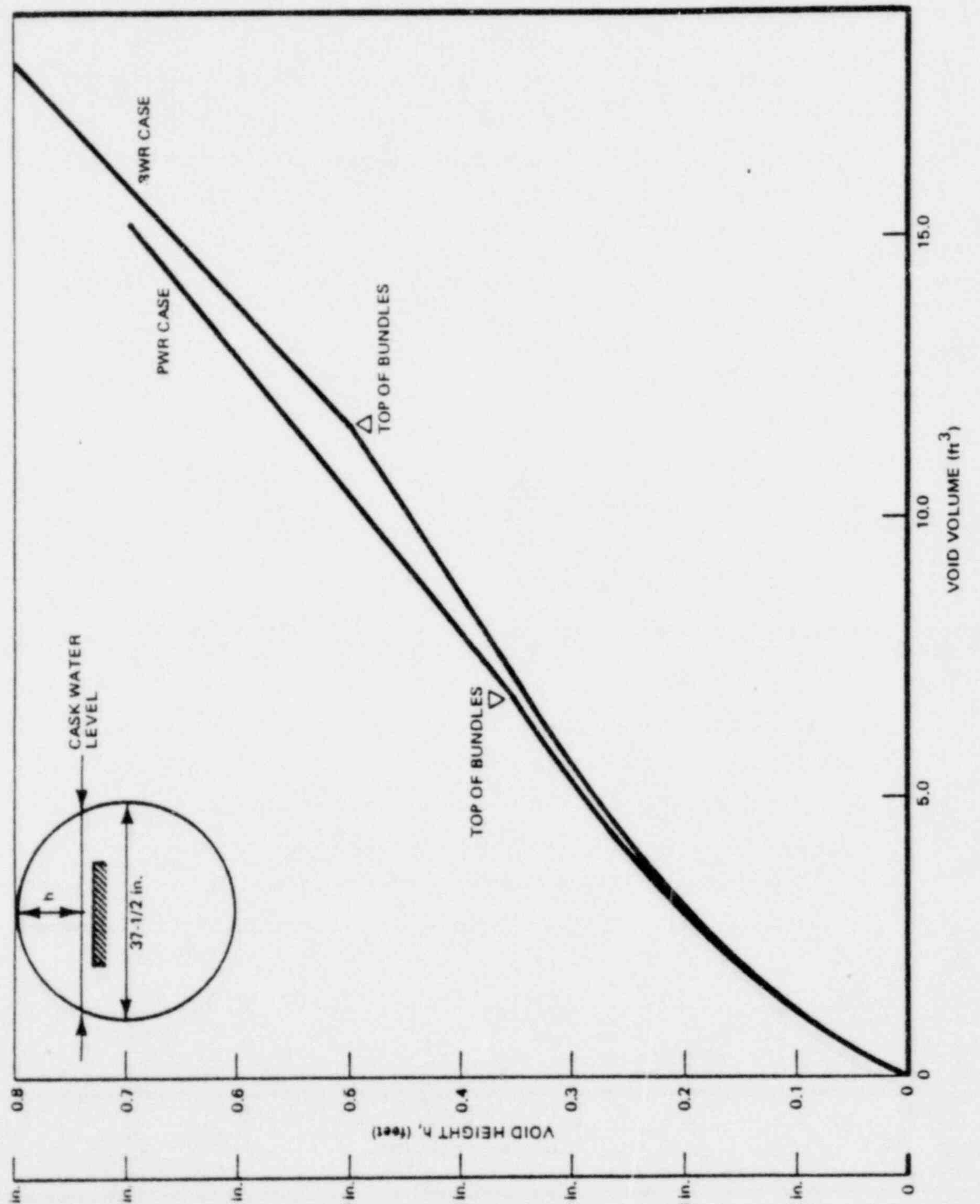


Figure VI-23. Void Height Vs. Void Volume dry shipment. The following analysis examines the effects of this residual water on cask cavity pressure. N

1. Amount of water remaining in cavity

   The cavity can be drained down to the 1-in. drain pipe diameter. A depth of 1.182 in. of water remains in the cask when it is vertical. Cask basket components displace some of this water and the net residual water for each of the two basket types are as follows:

Fuel Basket	Water Vol., ft^3	Water Wt., lb
BWR	0.605	37.8
PWR	0.420	26.2

   When the cask is horizontal, this water will form a segment with the cylindrical cask cavity. This segment will have a maximum depth of 0.8 inches and a chord length of 11.0 inches. It covers a maximum of 9.3% of the total cavity wall area. N

2. Cavity free volume

   Cavity volume calculations in Section 6.3.19 resulted in values as follows:

Fuel Loading	Free Vol, ft^3
BWR	83.67
PWR	82.22

3. Cask cavity pressure - normal/LOMC conditions

   The cask cavity pressure is the summation of (a) the cask air pressure, (b) the residual water vapor pressure, and (c) the pressure from the residual gas released from the fuel rods.

   a. Air pressure - The cavity air pressure is assumed to follow the ideal gas-temperature-pressure relationship. For this N calculation, it is conservatively assumed that the air is at the maximum fuel cladding temperature of 650°F for LOMC conditions as tabulated in Table VI-28. Then the air pressure is given by N

$$P_{air} = P_1 \frac{T_2}{T_1} = \frac{14.7 \times (650+460)}{(460+70)} = 30.2 \text{ psia}$$

b. <u>Water vapor pressure</u> - The residual water vapor pressure is determined by the cask cavity wall temperature. For this evaluation, it is conservatively assumed that the water temperature is at the maximum cavity wall temperature of 210°F derived from Figure VI-24 for LOMC conditions and a 130°F ambient temperature. Then the water vapor pressure is found in the steam tables to be

$$P_{vapor} = 14.1 \text{ psia}$$

N

c. <u>Residual gas pressure</u> - In the dry shipping mode ($\leq$ 40,000 Btu/hr), it is expected that no fuel rods will rupture. If in the extreme case it is assumed that all of the fuel rods rupture, then the residual gases in the fuel rods will increase the cavity pressure.

The number of moles, n, of residual gas that could be released into the cask cavity is estimated by

$$n = \frac{P_r V_g}{RT_r} = \frac{2200 \times 1.5}{(900 + 460) \times 10.73} = 0.226 \sim 0.23$$

where typically

P_r = 2200 psia, end-of-life rod pressure

T_r = 900°F, rod gas temperature at reactor conditions N

V_g = 1.5 ft^3 total gas volume in all rods available for release N

It is conservatively assumed that the residual gas released is at the maximum fuel cladding temperature of 650°F. Then the maximum residual gas pressure is

$$P_{gas} = \frac{nRT}{V_c} = \frac{0.23 \times 10.73 \times (650 + 460)}{82.2} = 33.3 \text{ psia}$$

where

T = 650°F, maximum fuel rod cladding temperature

V_c = 82.2, cask free volume, ft^3

The total pressure in the cask is the sum of the partial pressures or N

$$P_{total} = P_{air} + P_{vapor} + P_{gas}$$

$$= 30.2 + 14.1 + 33.3 = 77.6 \text{ psia}$$

For normal or LOMC conditions, the cask maximum cavity pressure of 77.6 psia is significantly lower than 375 psig, the lifting pressure of the pressure relief valve.

4. <u>Cask cavity pressure - accident conditions</u>

The cask cavity pressure is calculated by the same methods used for the normal/LOMC conditions.

a. Air pressure - It is conservatively assumed that the air is at the maximum fuel cladding temperature of 658°F, as N tabulated in Table VI-28A for accident conditions. Then the air pressure is given by N

$$P_{air} = P_1 \frac{T_2}{T_1} = \frac{14.7 \times (658 + 460)}{530} = 31.0 \text{ psia}$$

b. Water vapor pressure - It is conservatively assumed that the water is at the middle of the cask and has a temperature of 377°F as shown in Figure VI-20A. Then the water vapor pressure from the steam tables is

$$P_{vapor} = 189 \text{ psia}$$

c. Residual gas pressure - It is conservatively assumed that all of the fuel rods fail and release the total moles of residual gas which are at the maximum fuel cladding temperature of 658°F. N

Then the residual gas pressure is given by

$$P_{gas} = \frac{nRT}{V_c} = \frac{0.23 \times 10.73 \times (658 + 460)}{82.2} = 33.6 \text{ psia}$$

The total pressure in the cask cavity is the sum of the partial pressures, or

$$P_{total} = P_{air} + P_{vapor} + P_{gas}$$

$$= 31 + 189 + 33.6 = 253.6 \text{ psia}$$

For accident conditions, the maximum cask cavity pressure of 253.6 psia is significantly less than the 375 psig lifting pressure of the relief valve. N

5. Conclusions

N

The calculations show that at a maximum "dry" shipping heat load of 40,000 Btu/hr under loss-of-mechanical cooling conditions at an ambient air temperature of 130°F, the cask pressure will not exceed 77.6 psia. Under accident conditions and 130°F ambient temperature the cask pressure will not exceed 253.6 psia. The lifting pressure of the relief valve is 375 psig, which is substantially higher; hence, the cask will not relieve any contents under these extreme conditions.

N

6.4 COOLING SYSTEM SIZING

This is presented for information only since the cooling system is not a safety related item. The calculation for cooling system sizing is based on the following criteria:

a. Minimum air flow with one fan operating shall not be less than 10,000 cfm at standard atmospheric temperature and pressure.

b. The jet nozzle arrival velocity with one fan operating shall be not less than 47 ft/sec.

c. A pressure drop of not less than 0.60 inches of water shall be assumed to occur in the jet nozzles.

(This page left intentionally blank.)

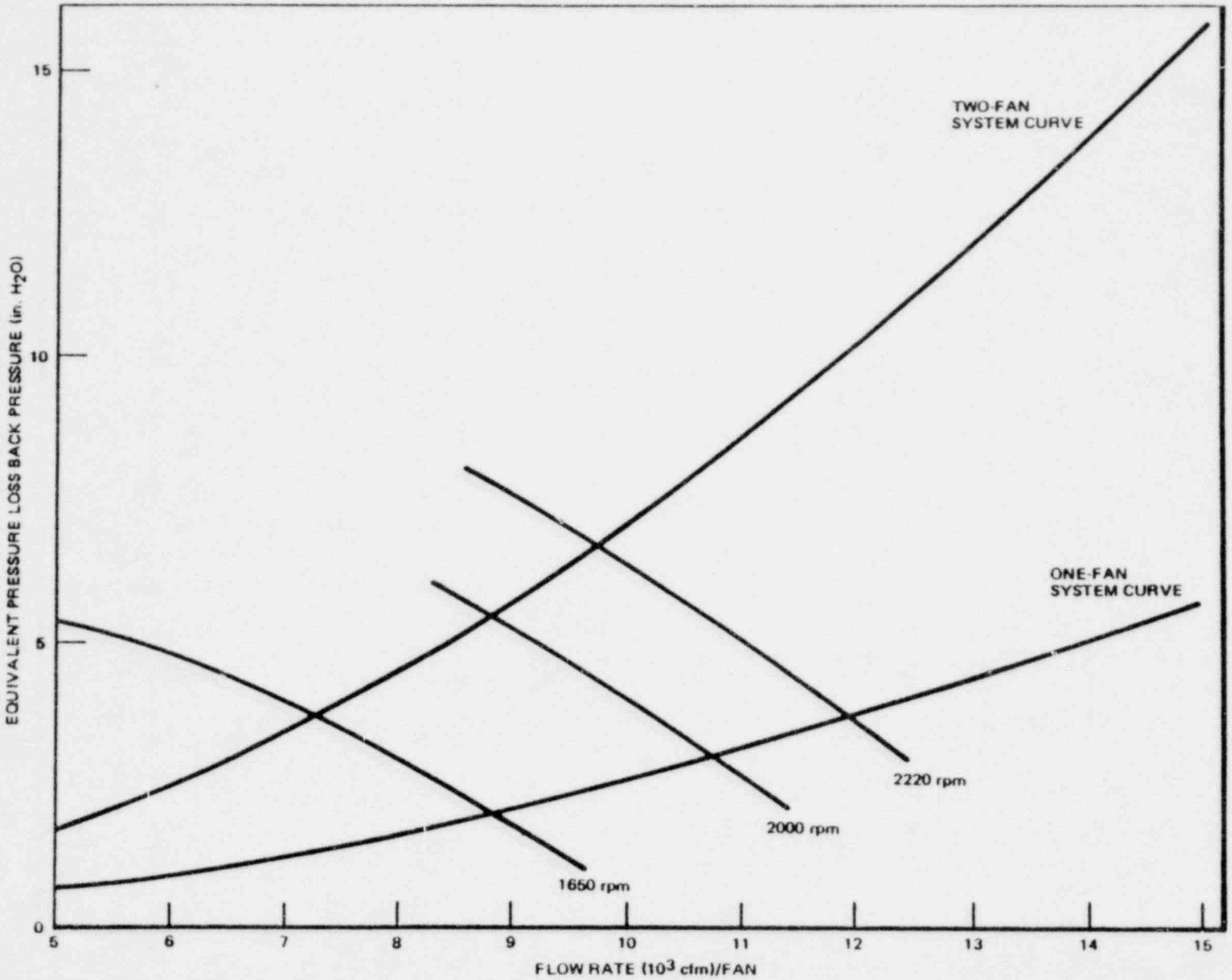


Figure VI-26. IF-300 Cooling System Curves
IF-300 Fan Characteristic Curves

6.5 CAVITY RELIEF VALVE

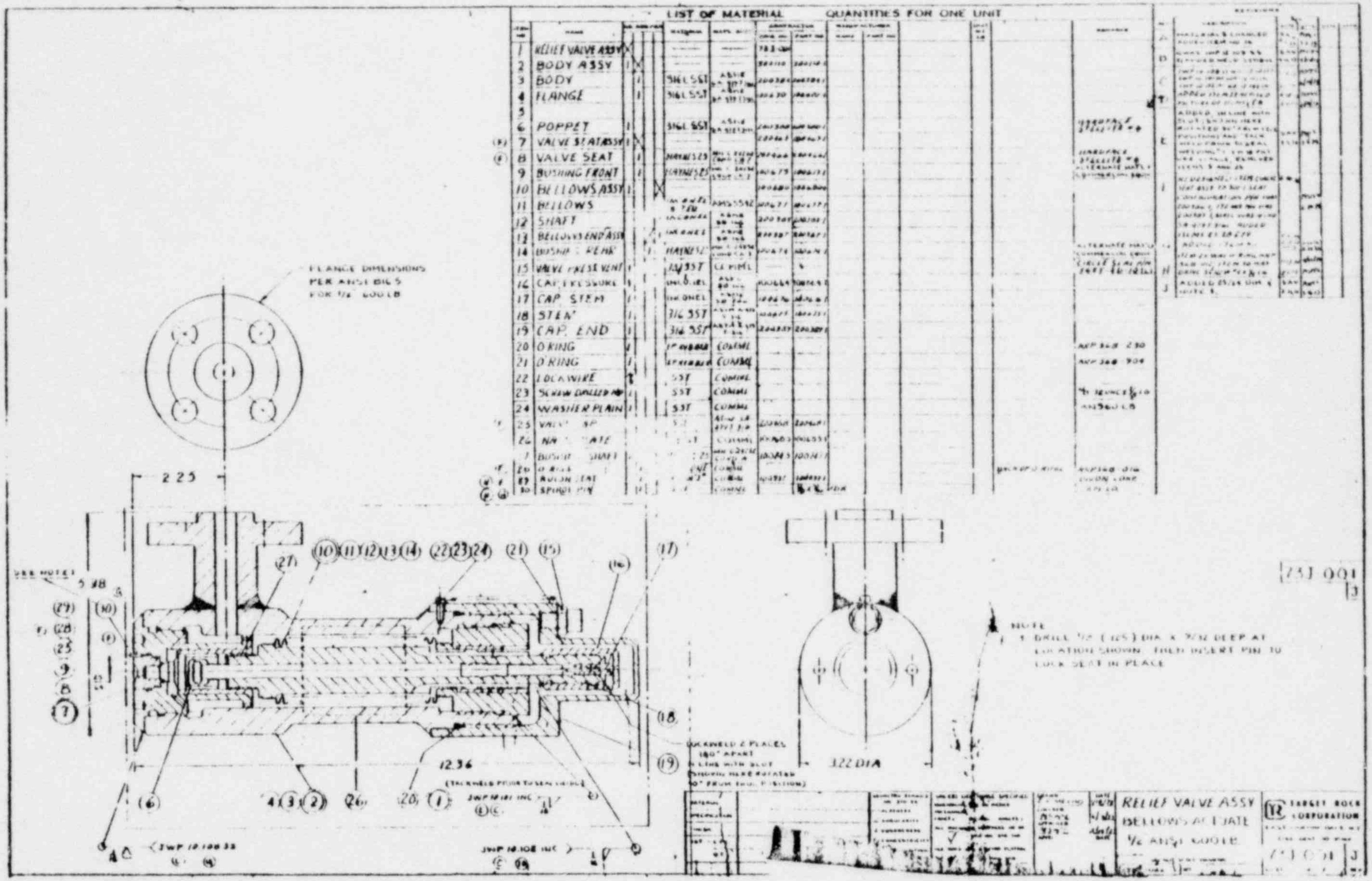
The IF 300 cask cavity is equipped with a pressure relief valve. This unit is located in the valve box closest to the cask head (see Section IV). The relief valve serves two functions:

- to protect the cavity from overpressure; and
- to limit the fission gas release in the post-fire period.

6.5.1 Description and Characteristics

Figure VI-27 shows the 73J-001, Rev. H and J cavity relief valve. This | N
unit is manufactured by Target Rock Corporation - a company which supplies similar types of valves to the commercial nuclear power industry as well as the U.S. Navy nuclear program. The valve body is stainless steel with Inconel X-750 for the spring, bellows, shaft assembly, and bellow end assembly. The valve is designed for continuous service at 750°F and intermittent service at 1000°F. The body is hermetically sealed. The unit is "fail safe" in that a leaking bellows will still permit the valve to function. The chances of a leaking bellows are rather remote since it is capable of sustaining a 12000 psi external pressure without failure.

The replaceable valve seat is fabricated from a filled-Teflon called Rulon-J. This material has a service temperature range from -400°F to +550°F with higher temperatures permitted for short time spans. For use on the IF300 cask the normal service range is more than adequate since maximum valve temperatures, under all conditions, are less than 450°F. Rulon like Teflon has practically universal chemical inertness. Of the chemicals encountered in commercial practice, only molten sodium and fluorine, at elevated temperatures and pressures, show any signs of attack. Mechanical properties are equally resistant to wear and fatigue.



1	RELIEF VALVE ASSY			
2	BODY ASSY	1		
3	BODY	1	316L SST	ASME
4	FLANGE	1	316L SST	ASME
5				
6	POPPET	1	316L SST	ASME
7	VALVE SEAT ASSY	1		
8	VALVE SEAT	1	HAYNES 25	[illegible]
9	BUSHING FRONT	1	HAYNES 25	[illegible]
10	BELLOWS ASSY	1		
11	BELLOWS		[illegible]	AMS 5552
12	SHAFT		INCONEL	ASME
13	BELLOWS END ASSY		INCONEL	ASME
14	BUSHING REAR		HAYNES 25	[illegible]
15	VALVE PRESS VENT	1	316 SST	COMML
16	CAP PRESSURE	1	INCONEL	ASME
17	CAP STEM	1	INCONEL	ASME
18	STEM	1	316 SST	[illegible]
19	CAP END	1	316 SST	[illegible]
20	O RING	1	[illegible]	COMML
21	O RING	1	[illegible]	COMML
22	LOCKWIRE		SST	COMML
23	SCREW DRILLED HD	1	SST	COMML
24	WASHER PLAIN	1	SST	COMML
25	VALVE [illegible]		[illegible]	[illegible]
26	NA[illegible]ATE		[illegible]	COMML
27	BUSHING SHAFT		[illegible]	[illegible]
28	O RING		[illegible]	COMML
29	CUSHION SEAT		[illegible]	COMML
30	SPIROL PIN		[illegible]	COMML

NOTE
1. DRILL 1/8 (.125) DIA x 7/32 DEEP AT LOCATION SHOWN. THEN INSERT PIN TO LOCK SEAT IN PLACE

Figure VI-27. Relief Valve Assembly – Bellows Actuated

6.5.1.1 Valve Performance Specification

The following are the 73J-001, Rev H and J relief valve operating parameters: N

a. Set pressure = 375 psig ± 1% at 450°F ± 2%

b. Reseat pressure = 95% to 99.5% of set pressure.

c. Nominal steam flow at 10% overpressure = 275 lbs/hr (sat.)

d. Nominal water flow at 10% overpressure = 3 gpm

e. Leakage: (room temperature)

200 psig, nitrogen	$\leq$12 bubbles/hr
300 psig, nitrogen	$\leq$24 bubbles/hr.
90% of set pressure, water	$\leq$2 cc/hr.

f. Blowdown: 7.6% max.
<5% ave.

6.5.1.2 Valve Functioning

Referring to Figure VI-27:

a. The relief valve bellows is mechanically compressed at assembly from its live length. This compression produces a preload pressure on the bellows effective area (1.54 in.^{2}) of 260 psi. This effective pressure acting in the bellows area produces 400 pounds preload force. This preload force presses the valve poppet against its seat. The projected conical seat area is 0.0077 in.^{2}, making the contract pressure 52,000 psi at 0 psig and 32,000 psi at 100 psig (operating). This high pressure and the "soft" Rulon-J seat assures gas leak tightness.

b. As the cavity pressure increases the bellows and disk remain motionless. At 260 psig, the bellows end rod starts to move away from the valve disk, pulling the enlarged end with it.

compatibility with the cask design criteria. Repairs will follow approved procedures. Maintenance or repair will be conducted by the cask licensee or by subcontract under the direction of the licensee. Audits of the maintenance system will be periodically conducted.

11.2.2.2 Maintenance — Frequency Philosophy

The purpose of periodic maintenance and testing of the cask is to assure that it will function as designed. Periodic tests on an inactive unit are not necessary as long as such tests are performed prior to the next usage period. During usage periods, periodic testing is appropriate. The frequency varies with the component under consideration.

11.2.2.3 Responsibility

It will be the responsibility of the cask licensee to ensure that the IF 300 shipping casks are maintained to meet all applicable state and federal regulations. Safety and reliability will be emphasized.

11.3 TESTING

This subsection discusses or references the tests which will be applied to the cask or to selected cask components. These tests may be initial determinations or they may be periodic.

11.3.1 Tests at Fabrication

11.3.1.1 Cask Cavity

The cask cavity cavity, closure, closure seal, piping and valves will be hydrostatically tested to 600 psig at room temperature.

11.3.1.2 Neutron Shielding Containment

The neutron shielding barrels, piping, valves and closure valves will be hydrostatically tested to 200 psig at room temperature. Both barrel sections will be simultaneously tested.

11.3.1.3 Cavity Relief Valve

See: Section VI

11.3.1.4 Neutron Shielding Containment Relief Valve

See: Section VI

11.3.1.5 Cavity and Neutron Shielding Containment Vent and Fill Valves

See: Section VI

11.3.1.6 Thermal Testing

See: Section VI

11.3.1.7 Gamma Shield

During fabrication, the uranium castings shall be radiographed and N
then checked after stacking by gamma scan techniques to assure that
there are no radiation leaks and the uranium material is sufficiently
sound such that the requirements in 8.5.1 can be satisfied. N

11.3.1.8 Functional Testing E

Prior to delivery for use, the IF-300 cask will be given a complete functional test. This involves the removal and replacement of the two baskets and the two heads, rotation and removal of the cask from the mounting skid, operation of the cooling systems, operation of the enclosures and remote engagement and disengagement of the lifting systems.

11.3.2 Periodic Maintenance Tests

11.3.2.1 Cask Cavity

The cask cavity with fill/drain and vent valves attached will be tested annually at a hydrostatic pressure of 400 psig (room temperature).

11.3.2.2 Neutron Shielding Containment

The neutron shielding containment with vent/fill valves attached will be tested annually at a hydrostatic pressure not to exceed 200 psig.

11.3.2.3 Cavity Relief Valve

The cavity relief valve will be tested quarterly. Testing will consist of cracking pressure verification and leakage examination.

6.12 *Trane Ductulator*, Form D100-10-1067, The Trane Company, 1950.

6.13 *Trane Air Conditioning Manual*, The Trane Company, 1965.

6.14 Thermophysical Properties Research Center, *Thermophysical Properties of High Temperature Materials*, Vol. 1, Macmillan, 1967.

6.15 H. E. Baybrook, Personal Communication, Allegheny Ludlum Corp., Research Center, Brackenridge, Pa., June, 1969.

6.16 *Chromium-Nickel Stainless Steel Data*, Section I, Bulletin B, Int'l. Nickel Co., 1963.

6.17 H. C. Hottel and A. F. Sarofim, *Radiative Transfer*, McGraw-Hill, 1967.

6.18 E. R. G. Eckert and R. M. Drake, Jr., *Heat and Mass Transfer*, McGraw-Hill, 1959.

6.19 C. A. Meyer, etc., *Thermodynamic and Transport Properties of Steam*, American Soc. of Mech. Engrs., 1967.

6.20 R. Gordon and J. C. Akfirat, *Heat Transfer of Impinging Two-Dimensional Air Jets*, Journal of Heat Transfer, February, 1966.

6.21 Chen-Ya Liu, W. K. Mueller, and F. Landis, *Natural Convection Heat Transfer in Long Horizontal Cylindrical Annuli*.

6.22 A. K. Oppenheim, *Radiation Analysis by the Network Method*, Transactions of ASME, Vol. 78, pp. 725-735, (1956).

6.23 R. O. Wooton and H. M. Epstein, *Heat Transfer From a Parallel Rod Fuel Element in a Shipping Container*, Battelle Memorial Institute, 1963.

6.24 J. K. Vennard, Elementary Fluid Mechanics, 4th Edition, John Wiley and Sons, 1962.

6.25 Heat Transfer Data Book, General Electric Company, Corporate Research and Development, Schenectady, N.Y., 1970.

6.26 E. M. Sparrow and R. D. Cess, Radiation Heat Transfer, Wadsworth Publishing Company, Inc. 1966. N

6.27 R. L. Cox, Radiative Heat Transfer in Arrays of Parallel Cylinders (ORNL-5239), June 1977. N