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Memorandum

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THRU: Roger S. Boyd, Chief, Research & Power Reactor Safety Branch, Division of Reactor Licensing

FROM : J. T. Telford, Research & Power Reactor Safety Branch, Division of Reactor Licensing J. J. Telford

SUBJECT: CALCULATION OF THE BLOWDOWN PRESSURE PEAK FOR THE INDIAN POINT II CONTAINMENT CONSIDERING THE STORED COOLANT ENERGY, THE INTERNAL CORE ENERGY, THE ENERGY ASSOCIATED WITH THE POSITIVE MODERATOR COEFFICIENT AND THE SECONDARY ~~COOLANT FROM THE~~ RUPTURE OF ONE STEAM GENERATOR

50-247

Introduction

The following calculations were undertaken in an attempt to verify the information submitted by the applicant regarding the initial containment pressure following a loss of coolant accident. The pressure peak considering only the stored coolant energy is 38.55 psig and a small increase to 41.75 psig is obtained by adding the core internal energy which could be transferred to the coolant as it escapes the primary system. These results are in excellent agreement with the information submitted by the applicant.

Considering the energy available as a result of the positive moderator coefficient increases the pressure to an additional 0.47 psi. If one were also to include the energy that could be added due to a rupture of one of the steam generators the pressure would increase an additional 7.4 psi to a maximum of 49.60 psig which is above the design value of 47 psig.

Definition of terms used in the following equations:

m_1 = mass of primary coolant = 5.07×10^5 Lb.

m_2 = mass of core (m_2 and cp were extrapolated from RG&E ans.)

m_3 = mass of secondary coolant = 1.09×10^5 Lb.

m_a = mass of air = 1.955×10^5 Lb.

m_s = mass of steam in containment

c_1 = average heat capacity of H_2O from T_1 to T approx. 1.15 BTU/Lb. °F

c_2 = average heat capacity of fuel

c_3 = average heat capacity of sec. coolant (T_3 to T) = 1.15 BTU/Lb. °F

c_{pa} = heat capacity of air from T_o to T = .24 BTU/Lb. °F

T_o = initial temp. in containment = 120°F

T_1 = initial primary coolant Temp. = 593°F

T_2 = core temp. from RG&E

T_3 = secondary Temp. = T_1

V = volume of containment + primary system 2.62×10^6 ft.^{3}

P_o = initial pressure in containment 16.2 psia.

R = universal gas constant 0.597 $\frac{\text{psia ft.}^3}{\text{Lb. °R}}$

h_{fg} = latent heat of evaporization at T (BTU/Lb.)

P_a = partial pressure due to air in the containment

P = final pressure in containment

T = final temperature in containment

Derivation of equation

The following is a balance of the energy during the blowdown:

Energy into containment = energy absorbed by containment

(1) $m_1c_1(T_1 - T) + m_2c_2(T_2 - T) + m_3c_3\ (T_3 - T) + E_{dk} = m_s\ h_{fg} + m_a\ c_{pa}\ (T - T_o)$

(2) $m_s = \frac{(P - P_a)V}{RT},\ P_a = P_o\ \frac{T}{T_o}$ By substitution and rearrangement

(3) $-(m_1c_1 + m_3c_3 + m_ac_{pa})T^2 + (m_1c_1T_1 + m_2c_2(T_2-T_1) + m_3c_3T_3 + m_ac_{pa}T_o + E_{dk}$
$+ \frac{P_oVh_{fg}}{RT_o})\ T = \frac{V\ h_{fg}\ P}{R}$

Let

$A_1 = m_1c_1 + m_3c_3 + m_ac_{pa}$

$A_2 = m_1c_1T_1 + m_2c_2(T_2-T_1) + m_3c_3T_3 + m_ac_{pa}T_o + E_{dk}$

$A_3 = \frac{P_o\ V}{R\ T_o}$

$A_4 = \frac{V}{R}$

(4) $= -A_1 T^2 + (A_2 + A_3 h_{fg}) T = A_4 h_{fg} P$

Discussion

By assuming a temperature in the containment "T" and finding the associated h_{fg}, one can calculate the resulting pressure by the use of equation (3). This pressure varies slowly with temperature therefore by finding only two values of P(T) the saturation steam pressure in the containment can be found. The attached figure is a plot of saturated steam pressure as of function of temperature. The intersection of the P_s curve and the $P - P_o \frac{T}{T_o}$ line obtained from equation (3) gives the pressure and temperature of the steam in the containment.

The absolute pressure in the containment is found by adding the pressure obtained from the figure to the partial pressure of the air at "T". Subtract 14.7 psi from this value to obtain the gage pressure which is the value plotted in the Safety Analysis.

From equation (3) (considering only the stored primary coolant energy) the pressure "P" is 53.5 psia at 250°F and 52.2 psia at 300°F. The intersection of the line joining the partial pressure due to steam ($P - P_o \frac{T}{T_o}$) at these temperatures crosses the saturation pressure curve at 33.25 psi which corresponds to a temperature of 256.5°F. From these values the absolute pressure in the containment is:

$$P_f = 33.25 + 16.2 \frac{(716.5)}{580} = 53.25$$

The gage pressure therefore is 38.55 psig which is "exactly" the value presented in Fig. 12.1 of the Preliminary Safety Analysis Report (PSAR). This pressure is due to the stored coolant energy only.

To obtain a more realistic limit of the pressure peak immediately following the loss of coolant accident (no metal-water reaction or source due to engineered safeguards) one must also add the core internal energy transferred during the blowdown phase. The most conservative method is to assume the heat transfer coefficient is large enough to transfer all of the energy stored in the core in reducing the temperature to the saturation level. The Rochester answers submitted to DRL on January 17, 1966, contain average values of the core temperature, mass and heat capacity. Since the Rochester core is similar to IP II the ratio of core masses (1.83) will enable one to obtain the approximate internal energy available.

The energy available for transfer is presented in the following table:

Core Zone	(mc_p) BTU/°R	Average Temp. T_2 °R	$T_2 - T_1$	Energy BTU x 10^{-6}
1	930	2507	1486	1.38
2	2780	2110	1089	3.02
3	4600	1890	869	4.00
4	6530	1750	729	4.77
5	8200	1750	729	5.98
				19.15

By including this energy in the energy balance equation the increase in pressure can be determined. The procedure is the same as discussed above with the addition of the core internal energy term. The pressure peak by including this energy is 56.45 psia or 41.75 psig which agrees with the pressure transient analysis of Chapter 12 of the PSAR.

Because the new PWR's with chemical shim will have a positive moderator coefficient over a portion of the first operating cycle, there exists the possibility of adding additional energy as the density of the primary coolant decreases following a loww of coolant accident. I have considered the energy input assuming a one dollar step which is the estimated upper limit suggested by R. French. From a computer calculation presented in PTR-738, p. 134 (IREKIN code) the integrated energy for a 1$ step input into a hot PWR with a doppler coefficient of $- 1.5 \times 10^{-5} \frac{dk}{k/°F}$ is approximately 700 Mw seconds or 6.64×10^5 BTU's.

The IP II core contains 97,800 kg compared to 23,700 kg for the reference core, therefore, a total of 2.74×10^6 BTU's could be added due to the reactivity addition. This amount of energy is only 14.3% of the internal core energy that could be transferred in reducing the core temperature to the normal operating temperature of the coolant. The addition of this energy would increase the pressure by less than 0.5 psi.

If one were also to consider the energy addition due to a rupture of one of the steam generators, there would be a considerable increase in containment pressure. Considering the secondary volume to be 2400 Ft.^{3} at the operating conditions the energy available is 61.8×10^6 BTU's and the containment pressure could increase an additional 7.4 psi. (See attached figures)

Conclusion

The results of the calculation of containment pressure for the case where the stored primary coolant energy is the only source is exactly the value submitted by the applicant. By adding the internal core energy the pressure increases by 3.2 psi which also agrees with their submittal. The peak pressure considering these two energy sources allows a margin of approximately 5 psi to the design value.

By adding the energy associated with the positive moderator coefficient there is a small but finite increase in pressure that should be included in their analysis. I calculate this pressure rise to be 0.47 psi.

A significant increase in pressure will result if there is a rupture in one of the steam generators. If this should occur they would exceed the containment design pressure during the blowdown phase.

The containment pressures considered in this memo are associated with the blowdown phase following a loss of coolant accident and do not consider the possible energy additions due to the engineered safeguards or the metal-water reaction.

Fig. 1

Saturation Pressure vs. Temperature

P_s = Saturated steam pressure

P = final CONTAINMENT Pressure (from eq

CASE	POINT	TEMP. °F	Pressure P	Pressure $P - P_o \frac{T}{T_o}$
I	1	250	53.5	33.65
	2	300	52.2	31.0
	3	256.5	53.25	33.25
II	4	250	56.7	36.85
	5	300	55.7	34.5
	6	261.25	56.45	36.25
III	7	273.0	64.3	43.8

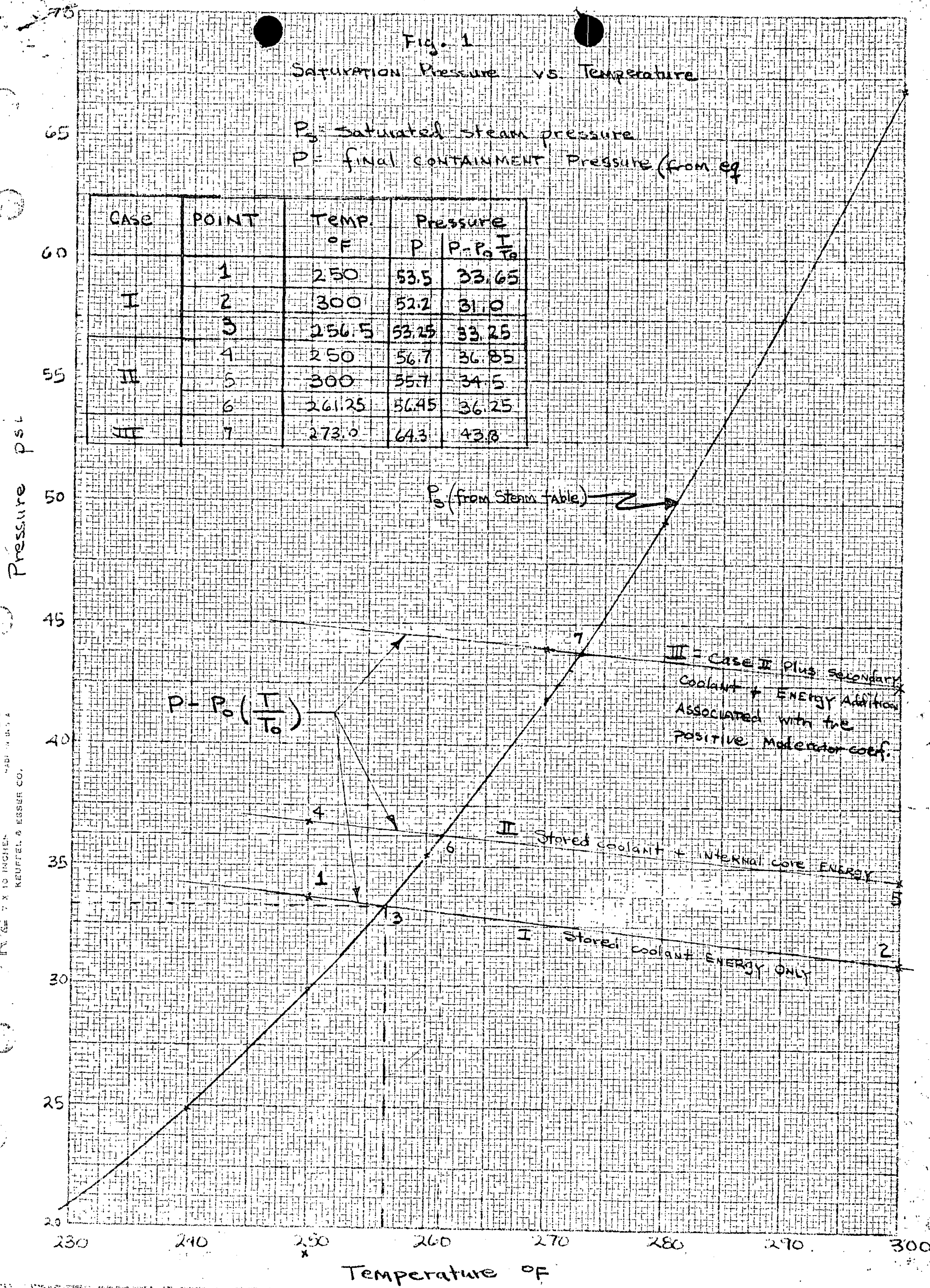
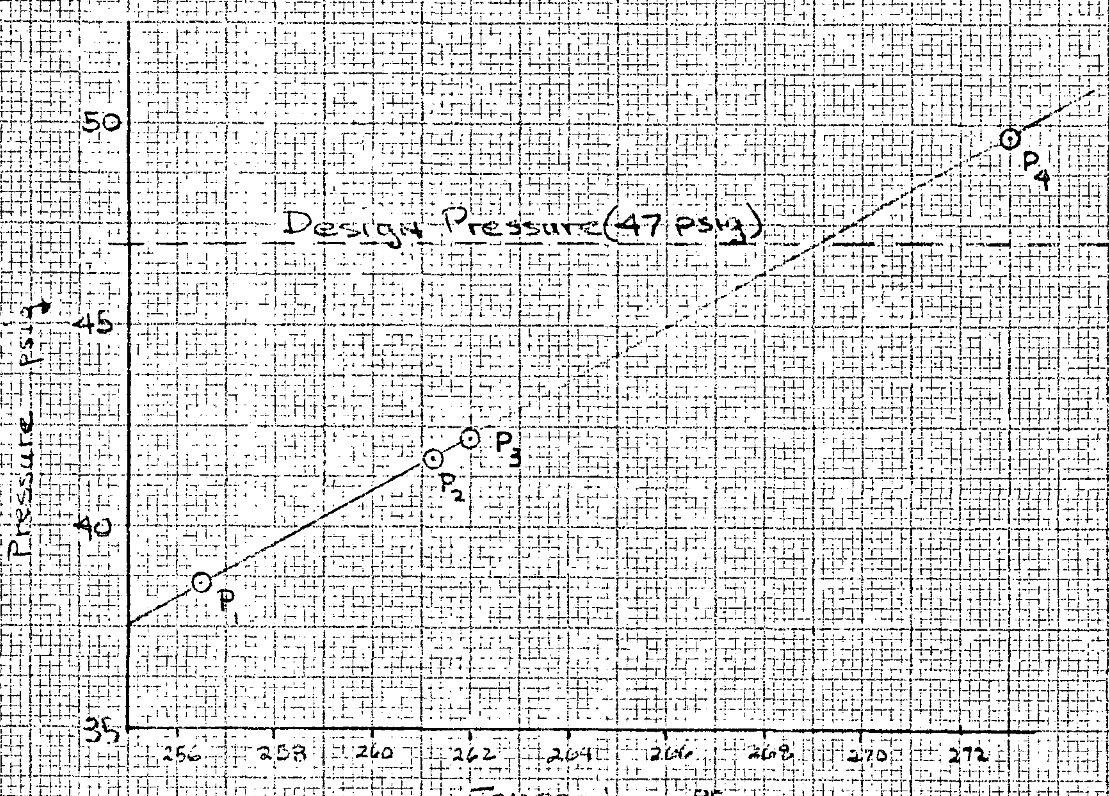


Fig. 2

Available Energy Sources During Blowdown

		$BTU \times 10^{-6}$
1	Primary Coolant Energy	309
2	Internal Core Energy available for Transfer	19.55
3	Secondary coolant energy	61.8
4	Energy associated with positive α_m	2.74



	Energy Sources Included	Magnitude (psig)
P_1	1	38.55
P_2	1, 2	41.75
P_3	1, 2, 4	42.22
P_4	1, 2, 3, 4	49.60