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November 16, 1979

1-119-13

Director of Nuclear Reactor Regulation
Mr. R. W. Reid, Chief
Operating Reactor Branch #4
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Subject: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
Outstanding Items Related to
B&W Small Break Analysis
(File: 1510.1)

Dear Mr. Reid:

Pursuant to our October 31, 1979 letter, Arkansas Power & Light Company herein provides information requested in Dr. D. F. Ross' letter of August 21, 1979. Attachment 1 is an interim (qualitative) response to Item 2B addressing a small break LOCA case which causes the reactor coolant system to repressurize to the PORV setpoint. Attachment 2 is the final response to Item 3 and addresses the effect of non-condensible gases on a small break LOCA analysis.

Very truly yours,

David C. Trimble

David C. Trimble
Manager, Licensing

DCT:pw

Attachments

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Question 2B: Provide the reactor coolant system response to a stuck open PORV for the case of a small break which causes the reactor coolant system to pressurize to the PORV setpoint.

Response

The resultant system response for a case of a small break which causes the reactor coolant system to pressurize to the PORV setpoint and result in a stuck open PORV can be qualitatively assessed based on previous analyses and is provided below. As is demonstrated the small break operating guidelines which have been developed are adequate for control of this transient.

Numerous small break calculations have been performed for the operating 177 FA plants. These calculations are provided in References 1 through 6. As is demonstrated by these studies, repressurization to the PORV following a small break is possible only if the break is extremely small (<0.01 ft^2) and if there is no feedwater available to the steam generators.

The system response of a very small break (<0.01 ft^2) with a concurrent loss of all feedwater is presented in Reference 5.

The system will initially undergo a subcooled depressurization. During this period of the transient, the reactor trips, the pressurizer drains, and the initial SG inventory boils off. For these smaller sized breaks (<0.01 ft^2), the SG initial inventory boils off prior to system depressurization to the ESFAS signal. Following the loss of the SG heat sink, the fluid in the RCS increases in temperature and becomes saturated. Since the volumetric flowrate out the break, following the establishment of saturation conditions in the RCS, is less than the volumetric steam production caused by decay heat removal, the RCS repressurizes and the pressurizer starts to refill. Thus, for these breaks, no ECCS equipment is automatically actuated prior to system repressurization.

System repressurization would continue until the PORV setpoint is reached if no operator action is taken to prevent it. The earliest time that the PORV setpoint would be reached is $\approx$ 4 minutes, for a zero break case and $\approx$ 20 minutes for the 0.01 ft^2 break. It should be noted that actuation of the AFW system prior to these times would prevent opening of the PORV.

While analysis of this break combination has not presently been performed, the present operator guidelines for small breaks were constructed to mitigate the consequences of such an event. The operator is instructed to re-establish feedwater to the SG as soon as possible if AFW is not automatically initiated. Also, the guidelines require manual initiation of the HPI system upon loss of the SG heat sink. Should feedwater continue to remain unavailable and the primary system pressure starts to increase, the operator is instructed to open the PORV and leave it open in order to maintain the RCS pressure as low as possible and maximize the

ECCS flows. These operator guidelines thus assure maximum utilization of the ECCS and will minimize the consequences of a small break which repressurizes the RCS.

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References

1. BAW-10103A, Rev. 2, "ECCS Analysis of B&W's 177-FA Lowered-Loop NSS," July 1977

2. Letter from J. H. Taylor to S. A. Varga of July 18, 1978, concerning 177 FA plants small break analysis.

3. BAW-10075A, Rev. 1, "Multinode Analysis of Small Breaks for B&W's 177-Fuel Assembly Nuclear Plants with Raised Loop Arrangement and Internals Vent Valves," March 1976.

4. Letter from J. H. Taylor to R. Mattson of May 7, 1979, "Evaluation of Transient Behavior and Small Reactor Coolant System Breaks in the 177-Fuel Assembly Plant," Volume I, Section 6.

5. Letter from J. H. Taylor to R. J. Mattson of May 12, 1979, "Small Break in the Pressurizer (PORV) with No Auxiliary Feedwater and One HPI Pump."

6. Letter from R. B. Davis to B&W 177 Owners Group, Technical Subcommittee on TMI-2 Incident Related Tasks, Subject: Responses to IE Bulletin 79-05C Action Items, August 21, 1979.

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Question 3 - Noncondensible Gases

Regarding the presence of noncondensible gases within the reactor coolant system following a small break LOCA:

A. Provide the sources of noncondensible gases in the primary system.

B. Discuss the effect of noncondensible gases on:
   (1) condensation heat transfer,
   (2) system pressure calculations and
   (3) natural circulation flow.

C. Describe any operator actions and/or emergency procedures necessary to preclude introduction of significant quantities of noncondensible gases into the primary system.

D. Describe operator actions to be taken in the event of a significant accumulation of noncondensible gases in the primary system.

Response

A. Sources of Noncondensible Gases in the Primary System

Table 1 lists the potential sources and amounts of noncondensible gases for a 177 fuel assembly plant. However, most of these gases would not be released for small break transients. Appendix K evaluations performed for the 177FA plants demonstrate that cladding temperatures remain low and no cladding rupture nor metal water reaction occur. Thus, these sources can be neglected. Also, the steam generator (SG) is a heat sink only if primary system pressure is above that which corresponds to the secondary system safety valve setpoint ($\approx$ 1050 psia). Therefore, gases present in the core flooding tank can be neglected in addressing the effect of noncondensible on SG condensation. The only sources of noncondensibles which might separate in the RCS are the gases dissolved in the coolant, the gases in the pressurizer, gases in the makeup and borated water storage tank and gases released from an allowed 1% failed fuel in the core.

B. Effects of Noncondensible Gases on the Primary System Response Following a Small Break LOCA

There are two possible ways in which the release of noncondensible gases in the primary system could interfere with the condensation heat transfer processes which occur in the steam generator during small loss of coolant accidents. If noncondensible gases filled the U bend at the top of the hot leg, then water vapor would have to diffuse through the noncondensible gases before they could be condensed in the steam generator. This would be a very slow process and would effectively inhibit natural circulation. Lesser amounts of noncondensibles would reduce the heat transfer by condensation because the vapor would have to diffuse through the noncondensibles to get to the condensate on the tubes.

As discussed in response to Part A of this question, the only sources of noncondensibles which might separate in the RCS are the gases dissolved in the coolant, the gases in the pressurizer, gases in the makeup and borated water storage tank and gases released from an allowed 1% failed fuel in the core. Thus, the maximum amount of noncondensible gases in the system, assuming all gas comes out of solution, no noncondensibles are lost through the break flow, that there was one percent failed fuel, and the injection of 6.4×10^4 lbm from the makeup tank and BWST (typical of ≈ 1500 sec of HPI), would be:

Dissolved in coolant	563 scf
In pressurizer	166
Fission gas	2
Fuel rod fill gas	11
MU tank	24
BWST	14
Total	780 scf

This gas would occupy a volume of 22.4 ft^3 at a pressure of 1050 psia, the lowest pressure condition in the primary system for which condensation heat removal will occur. It should be noted that the assumed integrated injection flow does not have a significant effect on the total volume of noncondensibles which might be present in the primary system. Since the volume required to completely fill the U-bend in the hot leg is 125 ft^3, the noncondensible gases will not impede the flow of vapor to the steam generator.

The heat transfer during condensation is made up of the sensible heat transferred through the diffusion layer and the latent heat released due to condensation of the vapor reaching the interface (see Figure 1). The model of Colburn and Hougen[1] gives the following equation for the heat transfer in the vapor phase:

$$\phi = hg(Tg_o - Tg_i) + Kg\ Mg\ h_{fg}(Pg_o - Pg_i) \quad (1)$$

where

ϕ = condensation heat flux, btu/hr ft^2

hg = heat transfer coefficient for vapor layer, Btu/hr ft^2 ^oF

Tg_o = bulk temperature, ^oF

Tg_i = temperature of interface, ^oF

Kg = mass transfer coefficient, $\frac{\text{lb mole}}{lb_f\ hr}$

Mg = molecular weight, lbm/lb mole

h_{fg} = latent heat of vaporization, Btu/lbm

Pg_o = partial pressure of vapor at bulk conditions, $\frac{lb_f}{ft^2}$

Pg_i = partial pressure of vapor at the interface, $\frac{lb_f}{ft^2}$

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$$Kg = \frac{1.02\ D}{z\ RT}\left(\frac{g\ z^3\ \rho\ \left(\frac{\rho o}{\rho i} - 1\right)}{\mu D}\right)^{.373} \qquad p/pam$$

D = diffusion coefficient, ft^2/hr

z = height

R = gas constant, 1545 $\frac{lb_f\ ft}{lb\ mole\ ^oR}$

T = absolute temperature at bulk conditions, ^oR

g = acceleration of gravity, ft/hr^2

ρ = density, lbm/ft^3

ρo = density at bulk conditions, lbm/ft^3

ρi = density at interface conditions, lbm/ft^3

μ = viscosity, lbm/hr ft

$$pam = \frac{pai - pao}{\ell n\ \frac{pai}{pao}}$$

pai = partial pressure of gas at interface, $\frac{lb}{ft^2}$

pao = partial pressure of gas at bulk conditions, $\frac{lb}{ft^2}$

For the application to OTSG condensing heat transfer during small break transients, the term $hg(Tg_o - Tg_i)$ can conservatively be neglected since the vapor velocities would be very low. Thus,

$$\phi = Kg\ Mg\ h_{fg}(Pgo - Pgi). \qquad (2)$$

The heat transfer with noncondensible gases present is obtained by iteration. An interface temperature Tg_i is assumed, which fixes Pg_i, and the heat transfer across the liquid condensate film is computed from

$$\phi = h_f(Tg_i - T_w) \qquad (3)$$

where

$$h_f = .943\left(\frac{\rho_f(\rho_f - \rho_g)g\ h_{fg}\ k_f^3}{\mu_f\ z(Tg_i - T_w)}\right)^{1/4}$$

ρ_f = density of fluid, lbm/ft^3

ρ_g = density of vapor. lbm/ft^3

k_f = thermal conductivity of fluid, Btu/hr ft ^oF

T_w = wall temperature, ^oF

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The partial pressure of the gas at the bulk conditions can be calculated from the mole fraction of noncondensible gases. When the heat flux computed from equation 2 matches that computed by equation 3, the proper interface temperature has been found.

The impact of noncondensibles on the condensation heat transfer process during a small break was examined for the 0.04 ft^2 and 0.01 ft^2 cold leg breaks analyzed for the 177-FA plants. The breaks utilize the SG for heat removal for a significant portion of the transient. Hand calculations were performed, using the theory presented above, to ascertain the effect of non-condensibles on the transient.

The amount of noncondensible gases, assuming that all gases come out of solution, would be 2.61 moles. The effect of these gases is to raise the pressure and primary temperature to obtain the same heat transfer. Assuming that the noncondensibles accumulated only within the steam generator upper plenums and the steam generator tubes, the system pressure increase, due to noncondensibles, would only be 25 psi, for a 0.04 ft^2 break, and 40 psi, for a 0.01 ft^2 break. It should be noted that this effect is predominantly due to the inclusion of the partial pressure of the noncondensibles, which is 24 psi for the 0.04 ft^2 break and 34 psi for the 0.01 ft^2 break, in the total system pressure. These calculations represent the maximum impact as they were computed at the time of maximum condensation heat flux for the respective cases.

As shown, the influence of noncondensibles does not significantly effect the condensation heat transfer process. The estimates made are conservative in that they assumed all the gas is located in the steam generators (none is in the top of the reactor vessel or pressurizer) and no gases escape through the break. Thus, the presence of noncondensible gases in the system should not significantly affect the small break transient.

C. Actions to Preclude Introduction of Noncondensible Gases into the Primary System

Introduction of significant quantities of noncondensible gases into the primary system following a small break LOCA is prevented if the core is not uncovered during a small break. The smallbreak guidelines which have been developed by B&W, are designed to prevent core uncovery by assuring continued ECC injection. Thus, the amount of noncondensibles which might separate in the RCS is small and would not significantly effect the small break transient (See Part B above).

D. Operator Actions During Accumulation of Noncondensible Gases in the Primary System

A significant accumulation of noncondensible gases within the primary system during a small break is not expected. This position is confirmed by small break transient predictions, using conservative Appendix K assumptions, which show that little core uncovery occurs. (2,3,4) As a result of the small core uncovery fuel rod temperature excursions are limited to 1100F; and, fuel rod failure or H_2 gas formation due to metal water reaction will not occur.

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Small amounts of noncondensible gases can be released into the primary system during a small break. For the break size range where noncondensible gases could have a detrimental effect (i.e., breaks where natural circulation is required for energy removal) the quantities of gases that are predicted to exist within the primary system are not significant. For larger quantities of noncondensible gases to exist, a core transient that is not predicted must occur. The probability for such an occurrence is believed to be small because of the detailed emergency procedures for post-LOCA conditions that have been developed and the extensive operator training that has been conducted in their use.

Emergency procedures have been developed to accommodate noncondensible gases, to maintain plant control, and to achieve a stable long term cooling condition. Provided below is a brief summary of plant control measures contained in present emergency procedures which will counteract the effects of noncondensible gases and additional guidance for operator action developed for an inadequate core cooling condition, which will be incorporated into emergency procedures in the near future. To upgrade the RCS venting and/or degassing capabilities, remote operated hot leg vents will be designed and installed by 1981. Small break emergency procedures will also be revised at that time to include use of the hot leg high point vents to aid the re-establishment of natural circulation and to vent noncondensible gases which may evolve during small break transient.

CURRENT PROCEDURAL ACTIONS

During a small break, the principle effect of noncondensible gases is to minimize the performance of the steam generators during natural circulation (either single phase water flow or reflux boiling). Table 2 lists the primary symptoms and the corresponding operator actions identified in current emergency procedures. As indicated in Table 2, a restart of the RC pumps (one per loop) is the optimum action. A return to forced circulation will aid in condensation of existing steam and removal of noncondensible gas (if present) within the hot leg piping. Noncondensible gases, originally within the loop piping, would then tend to be suspended within the coolant stream and collect within the upper regions of the reactor vessel (RV). A substantial quantity (~ 1000 ft.^{3}) of gas can be accommodated within the upper region of the RV; therefore, there is good assurance that natural circulation can be maintained if RC pump operation must be terminated. If the RC pumps cannot be started and/or no secondary side heat sink is available, the operator will utilize the PORV and HPI for core cooling and RC pressure control until the RC pumps can be restarted and/or secondary cooling is re-established.

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The above actions are sufficient to enable the operator to bring the unit to a stable, long term cooling condition based on expected plant performance using Appendix K evaluation methods. Although a large accumulation of noncondensible gases is not expected under these assumptions, the above actions are believed to be sufficient if the anticipated amounts of non-condensible gases are increased by an order of magnitude because of the large volume available for gases in the upper head of the RV and the loss of noncondensible gases out the break.

Once stable long term cooling conditions are established, RCS venting and/or degassing procedures can be initiated. If the RC pump(s) are operative and pressurizer spray is available, the reactor coolant can be degassed within the pressurizer where the steam-gas space can be vented to the Quench Tank inside containment. If letdown is available, the reactor coolant can also be degassed utilizing the makeup tank. The reduction of the amount of gases dissolved in the RC will encourage remaining gas pockets within the RCS to redissolve in the water. The operator can monitor the progress of degassing activities via analysis of pressurizer fluid and/or letdown water samples.

SMALL BREAK - INADEQUATE CORE COOLING CONDITIONS

An inadequate core cooling condition is not expected for B&W 177 FA plants. However, guidelines which identify the symptoms and operator actions for several circumstances, including a small break, have been prepared by B&W. This information is discussed in detail in Reference 5.

The operator actions discussed in Reference 5 are aimed at restoration of core cooling (restart an RC pump) followed by an increased rate of plant cooldown and depressurization (via SG cooling and PORV operation) to acquire use of the high volumetric flow capability of the CFT and LPI system to maintain core cooling. From a noncondensible gas standpoint, the actions accomplished the following:

1. Prevention: By initiating corrective action when cladding temperatures are below those for which metal water reaction is significant, gas accumulation is minimized. RC pump operation (if possible) to restore core cooling and to increase the plants cooldown/depressurization capability is the preferred action.

2. Venting: For the core to be inadequately cooled, the RCS must be in a highly void condition. Therefore, PORV operation in combination with the break should provide a vent mechanism for the noncondensible gas that do exist.

As discussed in the previous section, normal venting and degassing procedures can also be undertaken once stable long term cooling is established.

REFERENCES

1. Colburn, A. P. and Hougen, D. A., "Design of Cooler Condensers for Mixtures of Vapors with Noncondensing Gases", Ind. Eng. Chem. 26(11), 1934

2. R. C. Jones, J. R. Biller, and B. M. Dunn, "ECCS Analysis of B&W's 177 FA Lowered Loop NSS", BAW-10103, Rev. 3, Babcock & Wilcox, July, 1977

3. Letter from J. H. Taylor, B&W, to S. A. Varga, NRC, July 18, 1978

4. "Evaluation of Transient Behavior and Small Reactor Coolant System Breaks in the 177 Fuel Assembly Plant", Babcock & Wilcox, May 7, 1979

5. B&W Owners Group Submittal on Inadequate Core Cooling. (Scheduled for submittal in early November)

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TABLE 1

SOURCES OF NONCONDENSIBLES - 177 FA PLANT

Source	Gas	Total available: Total Volume scf	Individual Gas Volumes scf	Total Mass lb.	Individual Gas Masses lb.	1% FAILED FUEL: Total Vol. scf	Ind. Gas Vol. scf	Total Mass lb.	Individual Gas Masses lb.	1% METAL-WATER REACTION: Total Vol. scf	Ind. Gas Vol. scf	Total Mass lb.	Individual Gas Masses lb.
Dissolved in reactor coolant	H_2 & N_2	563	H_2 - 305 N_2 - 158	14	H_2 - 1.7 N_2 - 12.3								
Pressurizer steam space	H_2 & N_2	136	H_2 - 65 N_2 - 71	5.9	H_2 - 0.4 N_2 - 5.5								
Pressurizer water space	H_2 & N_2	30	H_2 - 20 N_2 - 10	0.91	H_2 - 0.11 N_2 - 0.8								
Fission gases in core	Kr & Xe	186	Kr - 20 Xe - 166	65.5	Kr - 4.8 Xe - 60.7	1.9	Kr - 0.2 Xe - 1.7	0.66	Kr - 0.05 Xe - 0.61	1.9			
Fuel rod fill gas	He & some N_2 & O_2	1133	He - 1092 N_2 - 32 O_2 - 9	14.8	He - 11.5 N_2 - 2.8 O_2 - 0.8	11.3	He - 10.9 N_2 - 0.3 O_2 - 0.1	0.16	He - 0.12 N_2 - 0.03 O_2 - 0.01	11.3			
Metal water reaction (100%)	H_2	416,500	-	2320	-					4165	-	23.2	-
MU tank gas space	H_2 & N_2	726	H_2 - 421 N_2 - 305	26.1	H_2 - 2.3 N_2 - 23.8								
MU tank water space	H_2 & N_2	24	H_2 - 16 N_2 - 8	0.71	H_2 - 0.09 N_2 - 0.62								
BWST	Air (N_2 & O_2)	1383	N_2 - 902 O_2 - 481	121.2	N_2 - 70.3 O_2 - 50.9								
CF tank gas space (two tanks)	N_2	26,248	-	2047	-								
CF tank water space (two tanks)	N_2	964	-	75	-								

Assumptions

1. RCS contains 40 std. cc H_2/K_g water & 20 std. cc N_2/Kg water, with water volume = 10,690 ft^3 at 583F and 2200 psia.
2. Pressurizer water contains 40 std. cc H_2/Kg water & 20 std. cc N_2/Kg water with Henry's Law relation between water space and steam space at 650F. Water volume = 825 ft^3 and steam volume = 716 ft^3
3. Fission gases based on inventory in core at 292 EFPD.
4. Fuel rod gas based on each rod containing 0.0375 gmol He, 0.0011 gmol N_2 and 0.00029 gmol/O_2.
5. Metal-water reaction based on 52,000 lb. Zr cladding.
6. MU tank values based on tank containing 200 ft^3 gas space and 400 ft^3 water space at 120F with the water containing 40 std. cc H_2/Kg and 20 std. cc N_2/Kg with Henry's Law relationship between gases in water and in gas space.
7. BWST contains 450,000 gallons of water saturated with air, i.e., 15 std. cc N_2/Kg and 8 std. cc O_2/Kg.
8. Each CF tank contains 1040 ft^3 water and 370 ft^3 gas space with 600 psig N_2 at 120F with Henry's Law relation between water and gas.
9. Values for 1% failed fuel based on Xe and Kr fission product inventory and fuel rod fill gas (He) in 1% of fuel rods being released to coolant.
10. Values for 1% metal-water reaction based on gases in Item 9 above and H_2 released from 1% of Zr cladding (520 lb.) reacting with coolant.

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TABLE 2: Symptoms and Corrective Actions for a Loss of Natural Circulation During a Small Break (Current Procedures)

SYMPTOMS

1. Saturated coolant conditions

2. Increasing primary system pressure and temperature with stable or decreasing secondary pressure.

CORRECTIVE ACTION

1. Maximize HPI (control HPI if a subcooled margin is re-established)

2. Ensure secondary cooling (i.e., auxiliary feedwater available with proper steam generator level control)

3. Restore RCP flow (one per loop) when possible per the instructions below. If RC pumps cannot be operated and pressure is increasing go to Step 3.5.

   3.1 If pressure is increasing, starting a pump is permissible at RC pressure greater than 1600 psig.

   3.2 If reactor coolant system pressure exceeds steam generator secondary pressure by 600 psig or more "bump" one reactor coolant pump for a period of approximately 10 seconds (preferably in operable steam generator loop). Allow reactor coolant system pressure to stabilize. Continue cooldown. If reactor coolant system pressure again exceeds secondary pressure by 600 psi, wait at least 15 minutes and repeat the pump "bump". Bump alternate pumps so that no pump is bumped more than once in an hour. This may be repeated, with an interval of 15 minutes, up to 5 times. After the fifth "bump", allow the reactor coolant pump to continue in operation.

   3.3 If pressure has stabilized for greater than one hour, secondary pressure is less than 100 psig and primary pressure is greater than 250 psig, bump a pump, wait 30 minutes, and start an alternate pump.

   3.4 If forced flow is established, continue plant cooldown at 100F/hr. to achieve long term cooling with the LPI/DHR systems.

   3.5 If a reactor coolant pump cannot be operated and reactor coolant system pressure reaches 2300 psig, open pressurizer PORV to reduce reactor coolant system pressure. Reclose PORV when RCS pressure falls to 100 psi above the secondary pressure. Repeat if necessary. If PORV is not operable, pressurizer safety valves will reliev overpressure.

3.6 Maintain RC pressure as indicated in 3.5 if pressure increases. Maintain this cooling mode until an RC pump is started or steam generator cooling is established.

3.7 If SG cooling is established, initiate plant cooldown at 100F/hr. to achieve long term cooling with the LPI/DHR systems.

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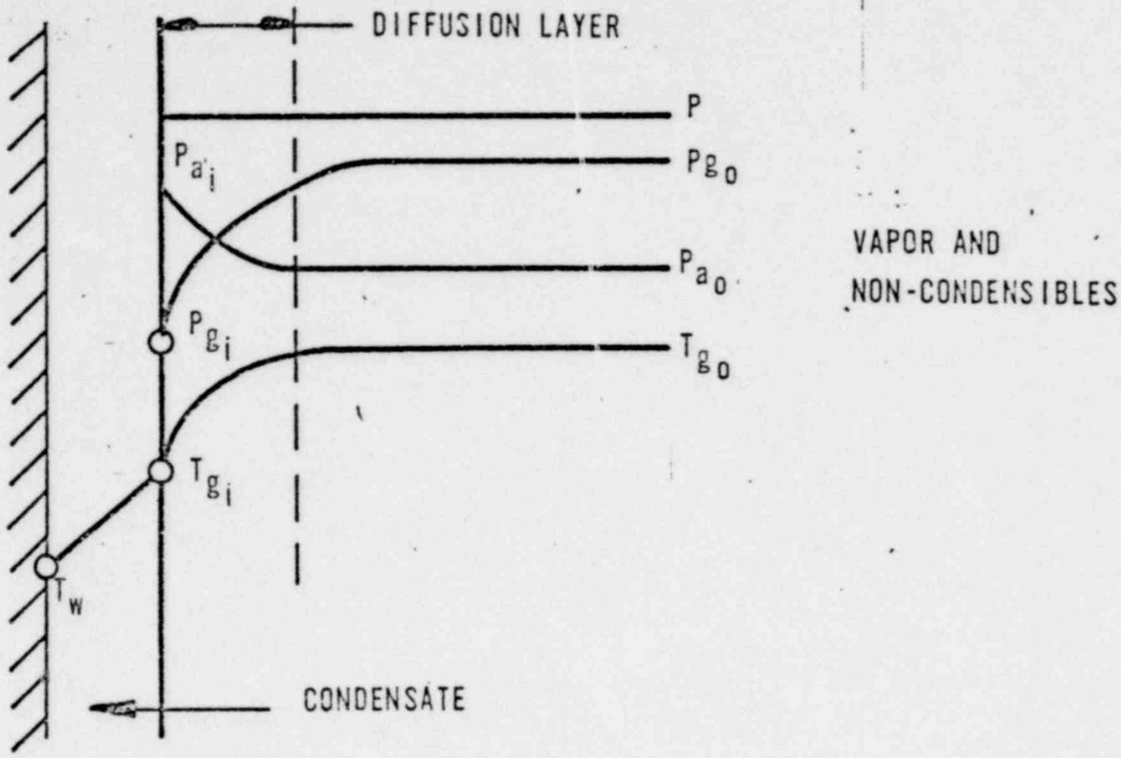
FIGURE 1



P = TOTAL PRESSURE

P_{a_i} = PARTIAL PRESSURE OF GAS AT INTERFACE, lb_f/ft^2

Pa_0 = PARTIAL PRESSURE OF GAS AT BULK CONDITIONS, lb_f/ft^2

Pg_i = PARTIAL PRESSURE OF VAPOR AT INTERFACE, lb_f/ft^2

Pg_0 = PARTIAL PRESSURE OF VAPOR AT BULK CONDITIONS, lb_f/ft^2

T_w = WALL TEMPERATURE, °F

Tg_i = TEMPERATURE AT INTERFACE, °F

Tg_0 = BULK TEMPERATURE, °F

REFERENCE: 1) COLBURN, A.P. AND HOUGEN, O.A., "DESIGN OF COOLER CONDENSERS FOR MIXTURES OF VAPORS WITH NONCONDENSING GASES", IND. ENG. CHEM. 26(11), 1934.

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