Containment Pressurization – PWR primary break.
Saturated Water in equilibrium with air – b

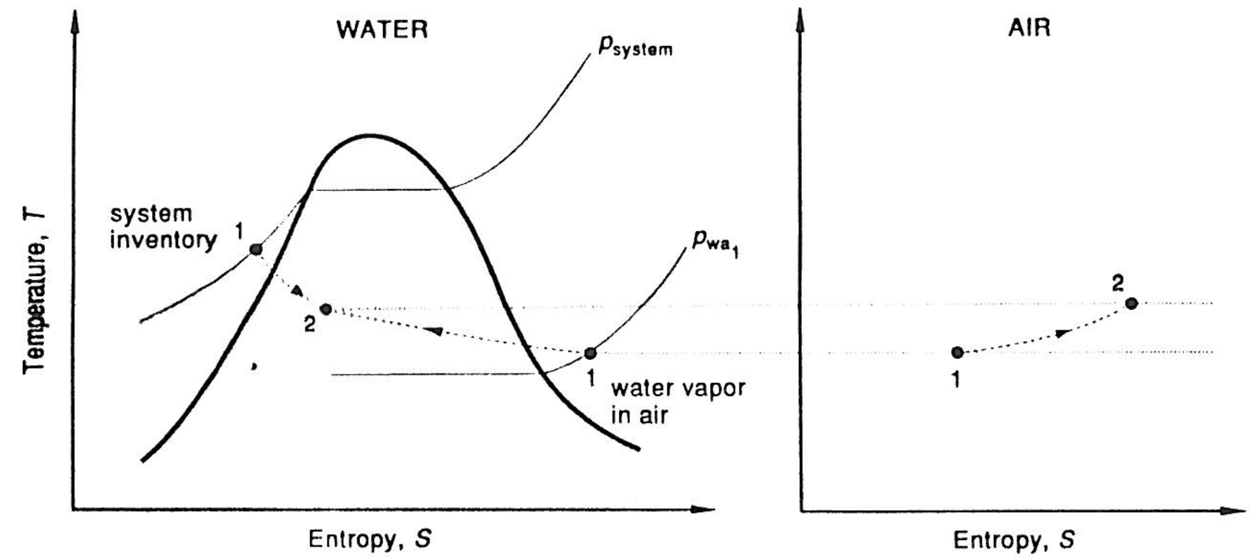

Figure 7-7 Process representation: saturated water mixture in equilibrium with air.

Table 7-2 Conditions for containment examples

Fluid	Heat addition during blowdown (Joules)	Volume (m^3)	Pressure (MPa)	Temperature (°K)	Quality (x_{st}) or relative humidity (ϕ)
		Example 7-1: saturated water in equilibrium with air as final state			
Primary coolant water (initial)		$V_P = 354$	15.5	617.9	Assumed saturated liquid
Containment vessel air (initial)		$V_C = 50{,}970$	0.101	300.0	$\phi = 80\%$
Mixture (final)	$Q = 0$	$V_T = 51{,}324$	0.523	415.6	$x_{st} = 50.5\%$
		Example 7-2: superheated water in equilibrium with air as final state			
Secondary coolant water (initial)		$V_S = 89$	6.89	558	Assumed saturated liquid
Containment vessel air (initial)		$V_C = 50{,}970$	0.101	300	$\phi = 80\%$
Mixture (final)	$Q = 10^{11}$	$V_T = 51{,}059$	0.446 (64.7 psia)	478	$\phi = 17\%$

- Find Peak pressure given V_C – volume of containment

Approach:

First assume final temperature T_2 and calculate x_{st} from equation

$$V_T = m_{W2}\left[v_{f2} + x_{st} v_{fg2}(T_2, sat)\right] \simeq \frac{m_a R_a T_2}{P_{a2}} \quad \text{— (1)}$$

Then use T_2 and find X_{st} from equation.

$$m_W(u_{W2} - u_{W1}) + m_a C_{va}(T_2 - T_{a1}) = Q_{n-wsys} - Q_{c-st} \quad (2)$$

Compare old and new X_{st}; continue iteration

If old and new X_{st} agree search is completed.

If quality is >1, the search fails – unlikely reactor condition.

Calculation.

1. Assume $T_2 = 415^\circ K$

Find m_a (mass of air in the containment)

water partial press. $P_{w1} = \phi\, P_{sat}(T_{a1}) = 0.8(3498\ Pa) = 2798\ Pa.$

Air partial press: $P_{a1} = P_1 - P_{w1} = 101,378 - 2798 = 98,580\ Pa$

Air mass $m_a = \dfrac{P_{a1} V_c}{R_a T_{a1}} = \dfrac{(98,580)Pa\,(50,970)\ m^3}{(286)\ J/kg\,^\circ K\,(300)^\circ K} = 5.9\times10^4\ kg$

Mass of water initially in containment

$$m_{wa} = \frac{V_c}{v_{wa1}} = \frac{50,970}{50.02\ m^3/kg} = 1019\ kg$$

Quality: $X_{st} = \dfrac{\frac{V_T}{m_W} - v_{f2}}{v_{fg2}} = \dfrac{\left(\frac{51324}{2.11\times10^5}\right)\frac{m^3}{kg} - 0.00108\ m^3/kg}{0.485\ m^3/kg} = 0.477$

here

$$m_W = m_{wp} + m_{wa} = \frac{V_p}{v_{wp}} + m_{wa} = \frac{354\ m^3}{1.68\times10^{-3}\ m^3/kg} + 1019. = \underline{2.11\times10^5\ kg}$$

Now check X_{st}:

$$m_{wp}(u_{f2} + X_{st} u_{fg2} - u_{wp1}) + m_{wa}(u_{f2} + X_{st} u_{fg2} - u_{wa1}) + m_a C_{va}(T_2 - T_{a1}) = 0$$

Solve for $x_{st} = 0.505$
Use this new value of quality and find new T_2 .....

Finally: $T_2 = 415.6°K$, $p_{w_2} = 0.386$ MPa.

Final air pressure: $p_{a_2} = \dfrac{m_a R_a T_a}{V_T} = 1.37 \times 10^5$ Pa

Total pressure: $p_2 = p_{w_2} + p_{a_2} = 0.386 + 0.137 = 0.523$ MPa.

- Find V_c - cont. volume given peak pressure (p_2)

Approach: $p_{a_2} \simeq p_{a_1} \dfrac{T_2}{T_1}$; $p_2 = p_{w_2}(T_2) + p_{a_2}$

$$= p_{w_2}(T_2) + p_{a_1} \frac{T_2}{T_1}$$

Iterate p_2 equation by assuming T_2
and $p_{w_2} = p_{sat}(T_2)$. Once T_2 is found,
use equations (1) & (2) solve x_{st} and $\underline{\underline{V_c}}$.

Calculation: Let $p_2 = 0.523$ MPa - (given)

$$p_2 = p_{w_2}(T_2) + p_{a_1}\left(\frac{T_2}{T_1}\right) = 0.523 \text{ MPa}$$

Find T_2 that satisfy above equation.

At: $T_2 = 415.6° \rightarrow = 0.386 + 0.099\left(\dfrac{415.6}{300}\right) = 0.523$ MPa

Now (1) and (2) $\rightarrow$

$$V_c + V_p = \left(m_{wp} + \frac{V_c}{v_{wa_1}}\right)(v_{f_2} + x_{st} v_{fg_2})$$

$$\left(m_{wp} + \frac{V_c}{v_{wa_1}}\right)(u_{f_2} + x_{st} u_{fg_2}) - m_{wp} u_{wp_1} - \frac{V_c}{v_{wa_1}} u_{wa_1}$$
$$+ p_{a_1} \frac{V_c}{R_a T_{a_1}} c_{va}(T_2 - T_{a_1}) = 0$$

V_c and x_{st} unknowns and two-equations

$x_{st} = \underline{0.505}$, $V_c = \underline{51,593}$ m^3

Containment Pressurization: PWR secondary Break
Superheated water in equilibrium with air

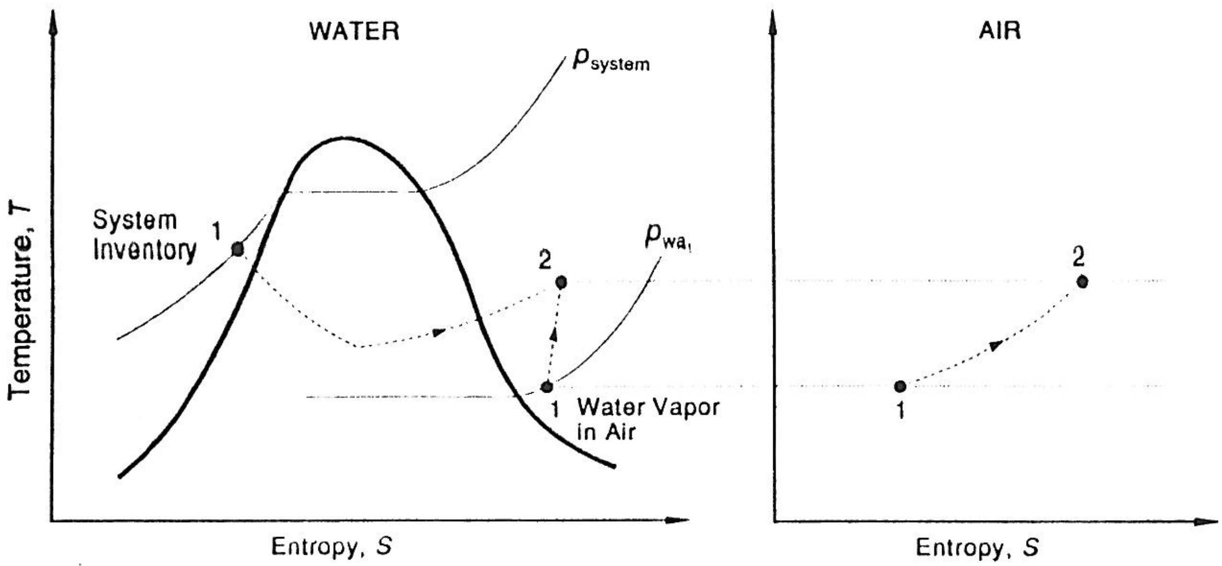

Figure 7-8 Process representation: superheated steam in equilibrium with air.

• Find p_2 given V_c

$$p_2 = \frac{m_w R_w T_2}{V_T} + \frac{m_a R_a T_2}{V_T} \qquad -③$$

Treat superheated water as a perfect gas

$: m_w = m_{wa} + m_{ws}$
$= (\text{cont} + \text{sec. system})$

Three unknowns (T_2, p_2, u_{w2}) : and three equations ② ③ and superheat steam tables.

Procedure: Assume T_2. use ③ calculate p_2, and find u_{w2} by steam tables. Use ② to find u_{w2} (new) and compare to the previous (old) value — iterate until convergence.

Let $T_2 = 450°K$.

$$p_2 = \frac{m_w R_w T_2}{V_T} + \frac{m_a R_a T_2}{V_T} = 0.42 \text{ MPa}.$$

Here:

$$m_a = \frac{p_{a_1} V_c}{R_a T_{a_1}},$$

$$m_{wa} = \frac{p_{wa_1} V_c}{R_{wa} T_{wa_1}}$$

Steam Table

at $p_{w_2} = 0.274$ MPa, $T_2 = 450°K$

find $u_{w_2} = 2.61 \times 10^6$ J/kg

Use 2 $\rightarrow$

$$m_{ws}(u_{w_2} - u_{ws_1}) + m_{wa}(u_{w_2} - u_{wa_1}) + m_a c_{va}(T_2 - T_{a_1}) = Q = 10^{11} J$$

solve for $u_{w_2} = 2.66 \times 10^6$ J/kg

use this value of u_{w_2} - find new $\underline{T_2}$.

Repeat steps: Finally $T_2 = 478°K$, $p_2 = 0.4463$ MPa

humidity $\phi = \dfrac{p_{w_2}}{p_{sat}(T_2)} = \underline{0.17}$

where $p_{w_2} = \dfrac{m_w R_w T_2}{V_T} = \underline{0.291}$ MPa.

- Find the V_c given p_2