Introduction to Containment

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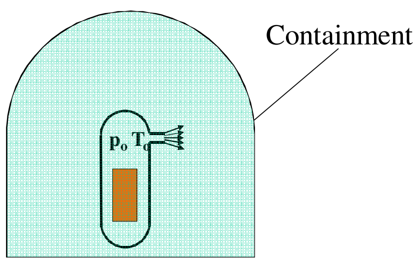
Need for a Containment-I

- The fundamental difference between a conventional fuel power plant and nuclear fuel power plant is that once the fuel supply is stopped, the conventional power plant ceases to liberate heat
- However, a nuclear power plant continues to produce heat due to radioactive decay of the fission products.
- Thus, if we have a loss of coolant accident and the core gets overheated, the radioactive fission products can be released to the ambient as the contents from inside are directly thrown out of the reactor.
- In order to ensure that these expelled radioactive products do not reach atmospheric air a leak free building is necessary

Single-Phase Depressurisation-I



- During LOCA, the high pressure steam that leaks out pressurizes the containment
- During LOCA, hydrogen may also be generated that can catch fire and increase the pressure of the containment

Need for a Containment-II

- In addition to protecting the public from radioactive products, the containment also serves the purpose of protecting the reactor from external influences
- The external influences include:
  - Cyclones and tornadoes,
  - Tsunami
  - Aircraft crashes and attacks
  - Terrorist bombs

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Design Criteria-I

- Should withstand pressure and temperature transient
- Should withstand forces generated by blowdown, pipewhip effect and associated vibrations.
- Should cope up with hydrogen buildup and possible explosion hazards.
- The highest pressure following an accident would depend on the energy released into the containment.
- For external influences, it should withstand forces from cyclone, Tsunami, aircraft crash, bomb attack, earthquake, etc.
- In general it is expected to be a very strong building

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Design Criteria-II

- The internal energy release will depend on:
  - Stored energy from the fluid structure
  - Nuclear excursion energy
  - Decay heat (not important in early stages)
  - Energy release from metal water reaction and consequent burning of hydrogen, if applicable
- While the estimation of containment load is too complex, we shall do a simplified analysis using a lumped thermodynamic model.

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Dry Containment Pressurisation-I

- Dry Containment is a simple building enveloping the reactor. No engineered cooling mechanisms like spray injection, ice box, etc., are present.
- Assumptions:
  - Internal constituents in thermal equilibrium.
  - No pressure and temperature gradients.
  - No leakage of mass from the containment
  - Heat added is modelled in a simple manner.

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Dry Containment Pressurisation-II

- If we are considering an adiabatic containment, the maximum pressure is reached at the end of the blowdown. The mass of fluid in the reactor system and the atmosphere in the containment before blowdown reach equilibrium
- The containment fluid consists of air and water (liquid+vapour)
- Free containment volume = Volume of gas phase (air+vapour) + Volume of liquid

Energy Balance

$$\Delta U = Q_{in} - Q_{out}$$

Dry Containment Pressurisation-III

- To illustrate the application an example is chosen

Fluid	Vol(m^3)	P(Mpa)	T(K)	x / RH
Coolant Water	354	15.5	618	x = 0
Containment Air	70,970	0.101	300	RH = 80%

- Energy added = 10^{11} J (Given).

Saturated vapour pressure at 300 K = 3567 Pa.
Partial pressure of vapour = 0.8 x 3498 = 2854 Pa.
Partial Pressure of air = 101,000 – 2854
= 98,146 Pa.

Dry Containment Pressurisation-IV

$$\text{Mass of air} = \frac{pV}{RT} = \frac{98146 \ \text{x} \ 70970}{287 \ \text{x} \ 300} = 80899 \ \text{kg}$$

$$\rho_g \text{ of vapour} = \rho \ (2854\text{Pa}, 300\text{K}) = 0.0206 \ \text{kg}/\text{m}^3$$

$$\text{Mass of vapour} = \rho_g V = 0.0206 \ \text{x} \ 70970 = 1464 \ \text{kg}$$

$$\rho_f \ 15.5 \ \text{MPa} = 594.36 \ \frac{\text{kg}}{\text{m}^3}$$

$$\text{Mass of water} = \rho_f V_{Coolant} = 594.36 \ \text{x} \ 354 = 210403 \ \text{kg}$$

$$\text{Total mass of water} = 210403 + 1464 = 211867 \ \text{kg}$$

Dry Containment Pressurisation-V

$$u_f \ (15.5 \ \text{Mpa}) = 1603772 \ \text{J}/\text{kg}$$

$$u_g \ (15.5 \ \text{Mpa}) = 2412170 \ \text{J}/\text{kg}$$

From First Law $U_2 = U_1 + Q$

$$U_1 = U_{Vapour} + U_{Air} + U_{Coolant}$$
$$= 1464 \ \text{x} \ 2412170 + 80899 \ \text{x} \ 714 \ \text{x} \ 300 + 210403 \ \text{x} \ 1603771$$
$$= 3.583 \ \text{x} \ 10^{11} \text{J}$$

$$U_2 = U_{wet\text{-}Vapour} + U_{Air} = U_1 + Q$$
$$= 3.583 \ \text{x} \ 10^{11} + 10^{11} = 4.583 \ \text{x} \ 10^{11}$$

Dry Containment Pressurisation-VI

- Assume final Temperature = 400 K
- $U_{air\text{-}final} = 80899 \ \text{x} \ 714 \ \text{x} \ 400 = 2.310 \ \text{x} \ 10^{10}$

$U_{vap\text{-}final} = 4.583 \ \text{x} \ 10^{11} - 0.2310 \ \text{x} \ 10^{11}$
$= 4.352 \ \text{x} \ 10^{11}$

$$u_{vap\text{-}final} = 4.352 \ \text{x} \ 10^{11} / 211867 = 2054090 \ \text{J}/\text{kg}$$

$$v_{wat\text{-}mix\text{-}final} = (70979 + 354)/211867 = 0.3367 \ \text{m}^3/\text{kg}$$

At 400 K

u_f(400K)(J/kg)	533323
u_g(400K) (J/kg)	2536390
v_f(400K) (m^3/kg)	0.001067
v_g(400K) (m^3/kg)	0.7272

Dry Containment Pressurisation-VII

- x from v = $(v-v_f)/(v_g-v_f) = 0.4621$
- x from u = $(u-u_f)/(u_g-u_f) = 0.7592$
- x from both do not agree. This implies that the assumed T is wrong and needs adjustment
- Use root finding method and solve
- Solution for $T_{final} = 417.3$ K
- Final Volume of water $= m_f/\rho_f = m(1-x)/\rho_f = 59.5\ m^3$
- Final Volume of air = 71264 m^3
- Partial Pressure of air = 1.36 bar
- Partial Pressure of vapour = 4.08 bar
- Total Pressure = 5.44 bar

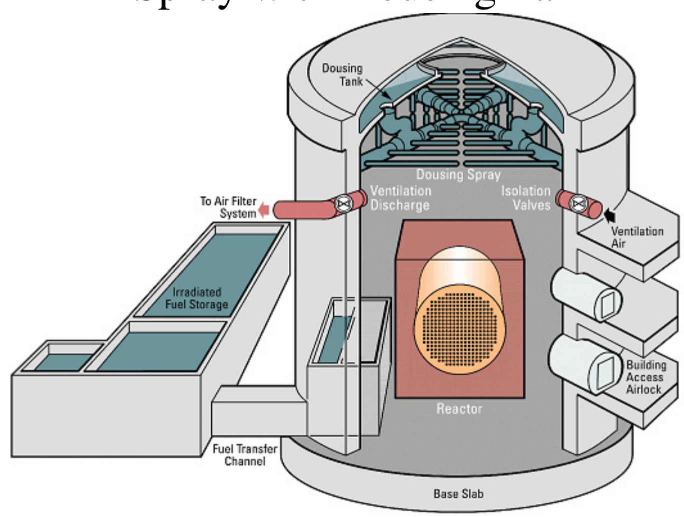
Engineered Heat Removal-I

- While Dry containment works for smaller systems, the pressure will be too high for larger systems
- For a system that was computed, if the primary system volume is increased to 500 m^3, the final pressure increases to 6.6 bar.
- This will put a heavy load on the design of containment
- If we can reduce the heat added by engineering cooling mechanisms, we can reduce the final pressure.
- In practice many methods are used for this purpose

Engineered Heat Removal-II

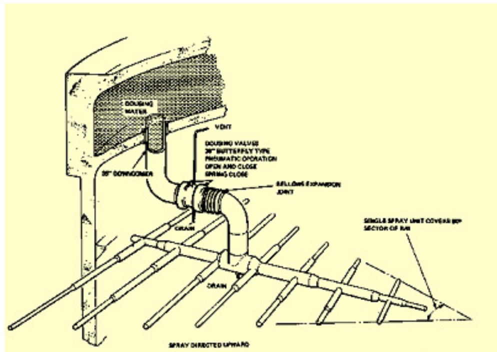
- Some of the methods adopted are :
  - Spray systems with dousing tank
  - Pumped spray systems
  - Suppression pool systems
  - Ice Condenser Systems
  - Containment Fan Coolers (only can be used for long term cooling due to limited cooling capacity)
- Another method used is to provide a vacuum building which is shared between several reactors.

Spray with Dousing Tank



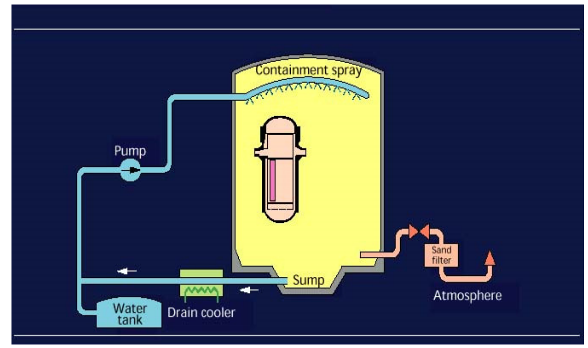
Spray with Dousing Tank

1. Used in CANDU-6
2. Capacity of Tank 15600 m^3.
3. 4500 kg/s for four out of 6 headers in operation
4. Triggered by two valves in series to avoid accidental dousing



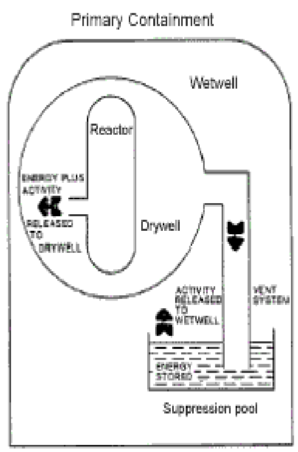
Pumped Spray Systems

1. Instead of having a Dousing tank at the top, one can use pumped sprays.
2. While it can be more effective, it needs an active pump



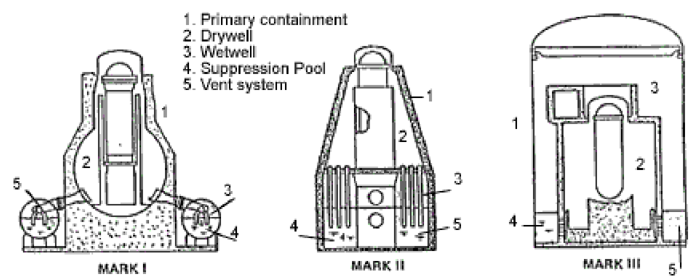
Suppression Pool Systems-I

1. One can have a completely passive system by employing a suppression pool.
2. In these systems, the containment is divided in two parts, viz. Dry Well and Wet Well.
3. The reactor vessel is housed in Dry Well and LOCA will occur here.
4. The steam pressure that builds is directed into a large pool of liquid in Wet well



Suppression Pool Systems-II

1. BWRs have traditionally used this type of systems.
2. They have evolved with time with improvements and are often denoted by MARK-I, MARK-II and MARK-III types.



General Electric pressure suppression system designs

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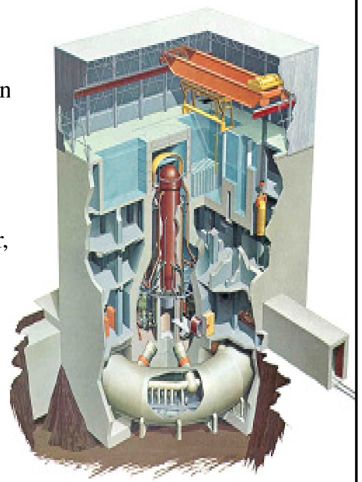
MARK-I Containment

1. The drywell surrounds the reactor vessel and recirculation loops.
2. A suppression chamber (also known as the torus) stores a large body of water (suppression pool).
3. An interconnecting vent network communicates the hot fluid from drywell to the suppression chamber,
4. The secondary containment, which surrounds the primary containment (drywell and suppression pool) houses the spent fuel pool and emergency core cooling systems.



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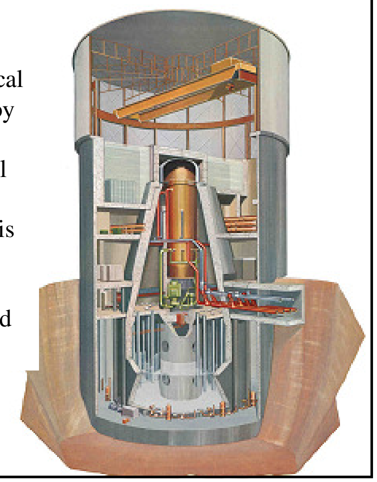
MARK-II Containment

1. Drywell, in the form truncated cone, located directly above the suppression pool.
2. Suppression chamber is cylindrical and separated from the drywell by a reinforced concrete slab.
3. Drywell head is an elliptical steel dome on top of the drywell.
4. The inerted drywell atmosphere is vented into the suppression chamber through as series of downcomer pipes penetrating and supported by the drywell floor.



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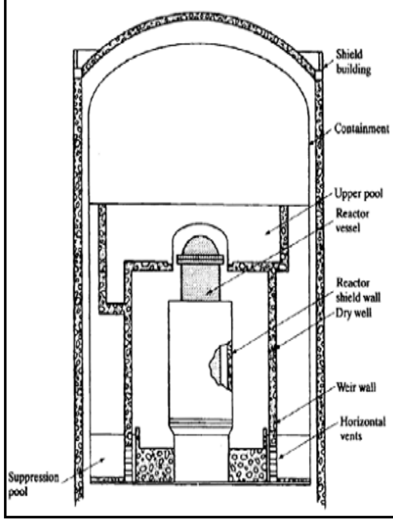
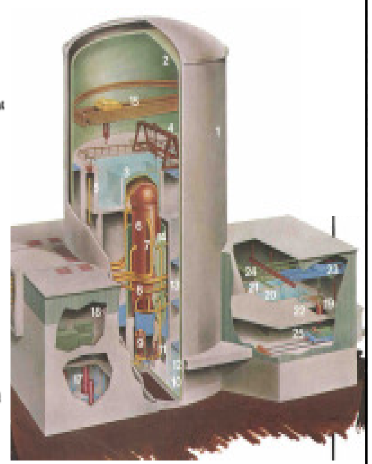
MARK-III Containment-I





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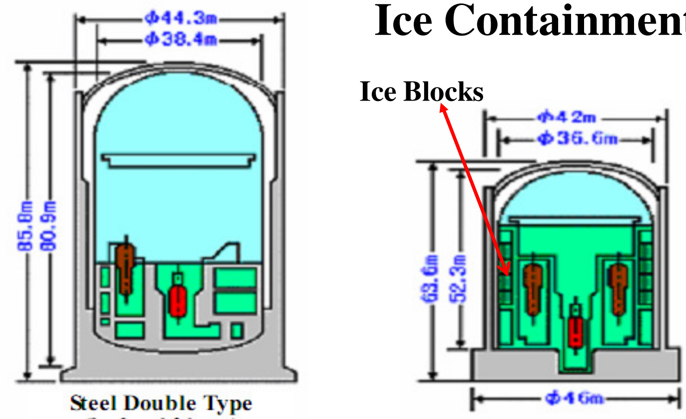
MARK-III Containment-II

1. Drywell is a cylindrical, reinforced concrete structure with a removable head, designed to withstand and confine steam generated during a pipe rupture inside the containment and to channel the released steam into the suppression pool via a weir wall and horizontal vents.
2. The suppression pool contains a large volume of water for rapidly condensing steam directed to it.
3. A leak tight, cylindrical, steel containment vessel surrounds the drywell and the suppression pool to prevent gaseous and particulate fission products from escaping to the environment following a pipe break inside containment.

Vacuum Building

1. A single Vacuum building connects 8 units.
2. During LOCA type incidents, pressure relief valve opens into vacuum building.
3. Water sprays in vacuum building keeps the pressure sub-atmospheric for a long time thereby containing the leaked products.
4. This system has enabled siting of a reactor near a population centre.

Ice Containment



Steel Double Type
(for 2 and 3 loops)
Licensed output: 500 - 600 MW: Genkai-2, Ikata-2, Tomari-1 & 2 etc.
Licensed output: 800 – 900 MW: Mihama-3, Ikata-3 etc.

Ice Condenser Type
(for 4 loops)
Licensed output: 1100 MW: Ohi-1 &2

Closure

- As outlined earlier, if the primary system volume is increased to 500 m^3, the final pressure increases to 6.6 bar for the case of Dry Containment.
- If 90% of the 1 x 10^{11} J heat released in the fluid is diverted to the engineered systems, the pressure reduces to 5.39 bar
- For this purpose, if only latent heat is assumed to be removed, then 268 tonnes of ice is required
- If we have water cooled systems, we need 536 tonnes of water, assuming a 40 ^{o}C rise in temperature
- The above are thermodynamic estimates, Detailed dynamics have to be worked out to obtain transient variation of pressure and temperature