

CONTAINMENT DESIGN REQUIREMENTS AND THEIR  
APPLICATION TO 500 MWe PLANT

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A B S T R A C T

Containment is the final barrier to the release of fission products from the reactor system to the environment. In the defence in depth philosophy to reactor safety, the containment is one of the four special safety systems. Therefore, the design of the containment is subjected to a set of comprehensive requirements as specified by Atomic Energy Regulatory Board (AERB) in its design code of practice. The code stipulates that in case of double containment, the secondary containment should completely envelope the primary. Further, the annulus space between the primary and secondary containment envelope shall be provided with a purging arrangement to maintain a negative pressure in the space thus ensuring zero ground level release consistent with ALARA principles.

In this presentation the various AERB requirements and how these requirements have been met in 500 MWe containment design are discussed. Also containment response to some major accident types have been briefly described.

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## 1.0 INTRODUCTION

In a nuclear power plant, the containment is the ultimate barrier to the release of radioactivity from the reactor system to the environment. The containment design requirements are mainly attributable to the fundamental arrangements of the reactor and secondary side systems and their demonstrated behaviour during normal operation and following accident conditions. The other important considerations that strongly influence design are national regulatory requirements, the number of generating units and other installations handling radioactive materials in the site. Indian Atomic Energy Regulatory Board (AERB), in its code of practice on design for safety, stipulates basic philosophy in containment design and its functional requirements. 500 MWe containment is designed in compliance with these requirements.

## 2.0 BASIC REQUIREMENTS

AERB code of practice on design for safety in Pressurised Heavy Water Based Nuclear Power Plants [1] requires that a containment system shall be provided to enclose completely the reactor coolant system and other radioactive fluid containing systems to keep the release of radioactivity to the environment within acceptable limits in normal operation and accident conditions. In case of double containment, the secondary containment should completely envelop the primary containment. The annular space between the primary and secondary containment envelopes shall be provided with a purging arrangement to maintain a negative pressure in the space. The containment system to include:

- i) containment structures and appurtenances.
- ii) equipment required to isolate the containment envelope and assure its integrity following an accident.
- iii) equipment required to reduce the pressure or free radioactive material within the containment envelope.
- iv) equipment required to limit the release of radioactive material from containment following an accident.

In 500 MWe PHWR, the above requirements are met in the following manner:

- i) The principle of double containment has been adopted. The primary containment is a free standing prestressed concrete structure with a prestressed concrete dome. The secondary containment is made of reinforced concrete which completely surrounds the primary containment. The reactor, primary heat transport system, moderator system, fuelling machines and the steam generators are completely enclosed within the primary containment. Fig. 1 shows the schematic of the containment system. The containment structures have access openings viz. main air lock, emergency air lock and fuelling machine air lock. Fuelling machine air lock has been kept underground for movement of the fuelling machines from R.B. to the calibration and maintenance facility for repair and servicing. Double containment philosophy is also extended in the design of air locks and other penetrations to the extent possible.
- ii) The containment must be boxed up and isolated from the outside atmosphere in accident condition. This is done by auto closure of isolation dampers in the ventilation ducts sensing high building pressure or high radioactivity in the containment. Two isolation dampers in series are proposed to be provided. One of the isolation dampers is proposed to have passive design features.
- iii) For reducing the overpressure, a passive suppression pool system has been provided. This system consists of four vent shafts placed at four corners of the reactor building at an angle of about  $90^\circ$  with each other. These vent shafts run from 115 m floor (pump room) to 85 m floor basement where they are connected to two distribution headers. There are about 40 vent holes on each distribution header vertical faces which are submerged in the suppression pool water in the basement. In the event of an accident, hot steam-air mixture passes through the vent shaft and the steam gets quenched in the pool water. Fig.2 shows the schematic of the vent shaft-distribution header system. Emergency coolers have been provided in the reactor building which are powered by class III power supply system. In addition, provisions for cleaning up of radioactivity on a long term basis by means of filtration and pump back system and mixing of the air inside the reactor building for avoiding hydrogen buildup in local pockets are also made.

- iv) In order to minimise the integrated leakage from the primary containment in the long term at low pressures, a controlled gas discharge system has been provided which is an optional manual feature to relieve the residual overpressure in the containment towards the end of depressurisation transient. This controlled release via the stack takes place through charcoal filters, thus preventing the possibility of any uncontrolled release of radioactivity to the outside environment. Further, the secondary containment, effectively intercepts the leakage from the primary during the overpressure period. The secondary containment is provided with a filtration, purge and recirculation system which provides multiple filtration by recirculation within the secondary containment space, and also maintains a negative pressure by purging to stack via filters. The negative pressure maintained in the secondary containment space brings the net ground level release down to virtually zero.

### 3.0 DESIGN REQUIREMENTS

The major AERB design requirements and how they are addressed for 500 MWe containment are discussed below:

#### 3.1 Integrity of the Containment Structure

The code requires that the containment structure including the air-locks and isolation valves shall be designed based on the internal pressures and temperatures and dynamic effects resulting from the accident conditions. This requirement is met by designing the containment for peak pressure and temperature considering rupture of the largest heat transport system piping and steam line break. The calculation methodology and the results are described in an adjoining paper in this conference [2]. The containment structure is designed for uniform internal pressure of  $1.44 \text{ kg/cm}^2$  and test pressure of  $1.66 \text{ kg/cm}^2$  gauge. The design also takes into account the thermal loads due to temperature gradients experienced by the containment following the postulated accidents with maximum inner temperature reaching  $125^\circ \text{C}$ . The static and dynamic analyses of the containment structure are carried out by the working stress method considering appropriate combination seismic loads, wind loads, hydrodynamic loads etc. as per the applicable Indian Standard Codes and AERB Manual for Civil Engineering Design [3]. In addition to safety margins provided in the calculational results as well as conservative assumptions, additional safety margins are achieved indirectly by limiting the allowable stress in such a way that minimum overload of about 1.8 is required before the extreme-most highly stressed fiber reaches the failure limits. This gives much large safety factors before the ultimate strength is reached in intermediate structures.

### 3.2 Containment Leakage

The code specifies that the design leak rate shall be kept to a minimum in keeping with ALARA principle and that the prescribed maximum leakage rate shall not be exceeded throughout the service life of the plant. To meet this requirement, the design target specification for the leak rate is kept to a very low value, typically 0.1% of the contained volume per hour. However, the maximum permissible leakage rate is worked out based on the calculated pressure history of the containment, assumed source term, Pasquill F weather conditions and the leakage rate vs. pressure correlation applicable for the containment envelope. Typically this value is greater than 0.3% per hour. Activity release calculations are done conservatively with higher leakage rate to allow for deterioration in the containment leak tightness over the service life.

Our experience with earlier reactors has shown that the major sources of leakage are: the construction joints, penetrations and shrinkage cracks. Appropriate measures are now taken to minimise the leakage due to the above causes, for example, the inner containment is kept under net residual compression, construction joints will be avoided by using slip forming technique. In addition, both the inner and outer faces of the primary containment and inner face of the secondary containment will be painted with specially developed epoxy paint to render the containment leak tight. It should be noted that because of double containment concept with the annular space between the two containment kept under vacuum, the net ground level release to the outside environment will be near zero.

### 3.3 Containment Penetrations

The code requires that all penetrations, for example, the process and safety system pipings; air locks for movement of equipment and personnel; I & C system tubings; cable penetrations etc., shall meet the same design requirements as the containment structure itself and they should automatically and reliably get sealed in the accident conditions. It is clear that all these penetrations must satisfy the basic requirement of limiting release to the environment. To meet the above requirements in general two isolation valves in series are provided. Double containment philosophy is also proposed to be extended in design of air locks and penetrations by providing three doors in airlocks and providing separate EPs for primary and secondary containments. Three doors in airlocks ensure isolation even during normal operation. Design criteria of these access openings and penetrations have been specified same as that of containment structure.

### 3.4 Pressure Suppression System

The code requires that the system shall have adequate capacity and capability to condense all the steam, sufficient contact with water in the suppression pool to dissolve soluble radioactive releases, proper sealing between volumes V1 and V2 and consideration of effects of hydrodynamic loadings such as vent clearing, pool swell and chugging loads [4].

The above requirements are met by keeping sufficient depth of submergence of the vent holes (1.62 m) which will ensure 100% condensation of the passing steam and sufficient contact to dissolve soluble radioactive species. The interface between volume V1 and V2 are provided with pressure sealings. The maximum leakage path area is not to exceed 0.093 m . Suppression pool hydrodynamic loadings are also considered as described in Ref.4.

### 4.0 CONTAINMENT RESPONSE

The design basis accident which will result in maximum pressure rise in the containment is the hypothetical loss of coolant accident involving double ended rupture of the pump suction header. Steam line break within the containment has also been postulated and analysed for, while evaluating containment design pressure, though no activity release is associated with this accident.

#### 4.1 Loss of Coolant Accident

With a pessimistic assumption of 0.093 m by-passing the suppression pool the containment peak pressure and temperature have been estimated to be 1.44 kg/cm<sup>2</sup> gauge and 117°C respectively in case of full PHT system blowdown. The maximum pressure and temperature in volume V2 will be about 1.39 kg/cm<sup>2</sup> gauge and 98°C respectively. It is to be noted that, two loop design of PHT circuit will restrict the blowdown of coolant to half of the circuit by way of automatic closure of the isolation valves in the pressure balancing line. Also the civil design will ensure leak tightness between V1 and V2. So leakage path for steam by-passing will be almost nil. Taking all these factors into account, the building pressure rise is expected to be about 0.8 kg/cm<sup>2</sup> gauge, thus giving a large margin on the design pressure.

During and after a LOCA, air contaminated with radioactive fission products may leak into the secondary containment through primary containment wall and various penetrations. The secondary containment air gets recirculated through a combined iodine and HEPA filter to prevent the buildup of air borne activity. A small part of the filtered air is purged to the stack to maintain the secondary containment under negative

pressure which practically eliminates ground level release and also considerably reduces the concentration of air borne activity that may be released through the stack.

#### 4.2 Steam Line Break

In case of steam line break, the containment response will be different depending on whether class IV power is available or not. Both the cases have been considered. In the first case when class IV power is available, full feed flow is maintained. High containment pressure signal will be initiated when R.B. pressure reaches  $0.0176 \text{ kg/cm}^2$  resulting in boxing up of containment and opening up of ASDVs, electromatic relief valves and CSDVs in crash cool mode. In the second case, an auxiliary feed flow of 3% normal flow will be maintained as soon as class III power is available, till then the flow coast down of main feed pumps will continue. In the secondary side, the absence of class IV power denies any possibility of steam dumping through CSDVs, and in the primary side, main coolant circulation pumps are rendered unavailable. Thermosyphoning will prevail after the trip of the main PHT pumps, till shutdown cooling system (SDCS) is valved in manually.

The maximum building pressure for the above two cases is about  $1.43 \text{ kg/cm}^2(\text{g})$  and temperature is  $136^\circ\text{C}$ . Though the maximum temperature is above the design value of  $125^\circ\text{C}$ , the R.B. pressure corresponding to peak temperature of  $136^\circ\text{C}$  is about  $1.00 \text{ kg/cm}^2(\text{g})$ . This loading combination is found to be less severe than the  $1.44 \text{ kg/cm}^2(\text{g})$  pressure and  $125^\circ\text{C}$  temperature in case of LOCA.

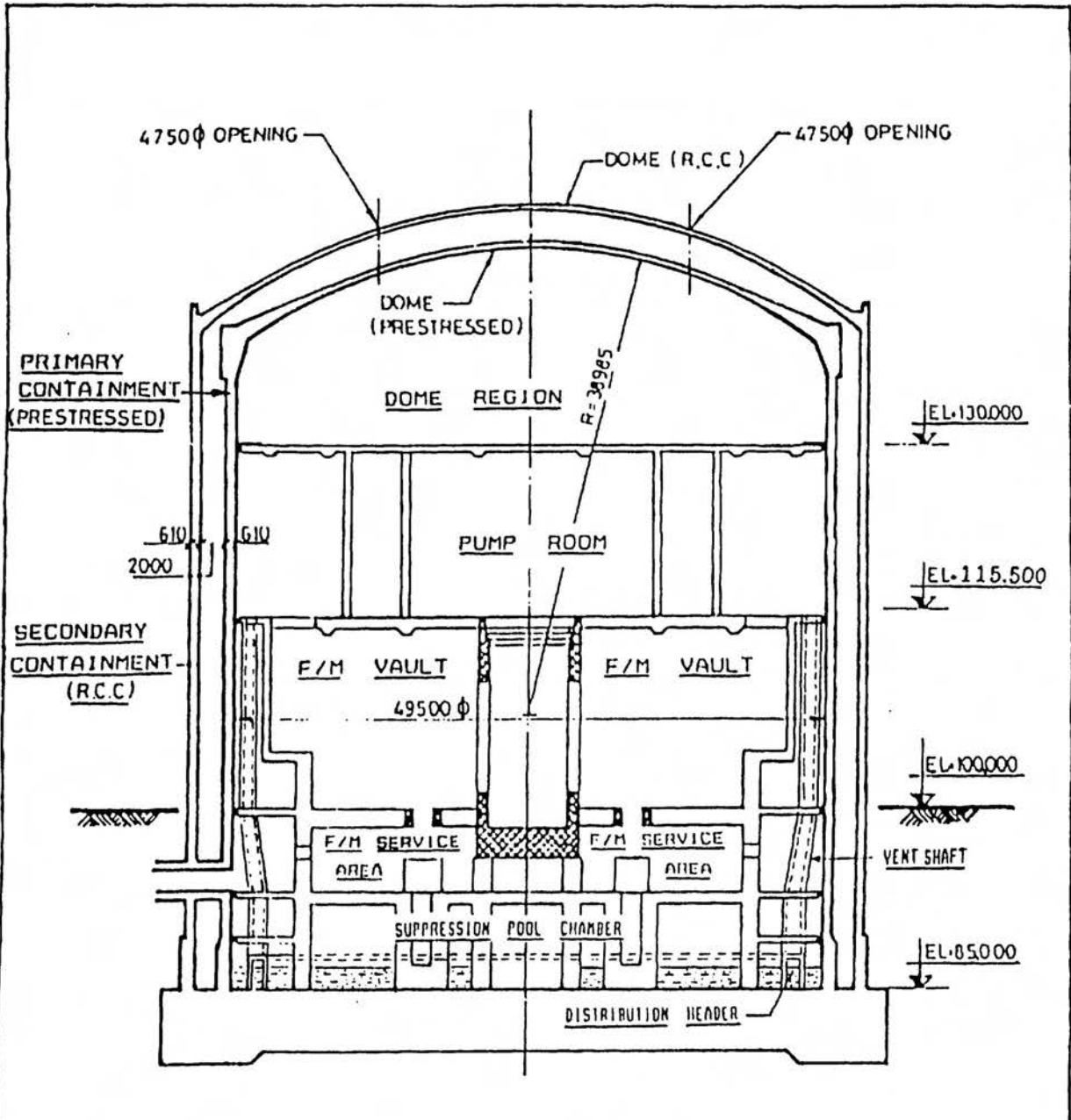
#### 5.0 CONCLUSIONS

The design of R.B. containment has to meet a set of stringent requirements as stipulated by AERB. Double containment design along with associated engineered safety features and appropriate design considerations meet all these requirements. The adoption of double containment concept with the annular space between the primary and the secondary, kept under vacuum, practically eliminates ground level release to the outside environment.

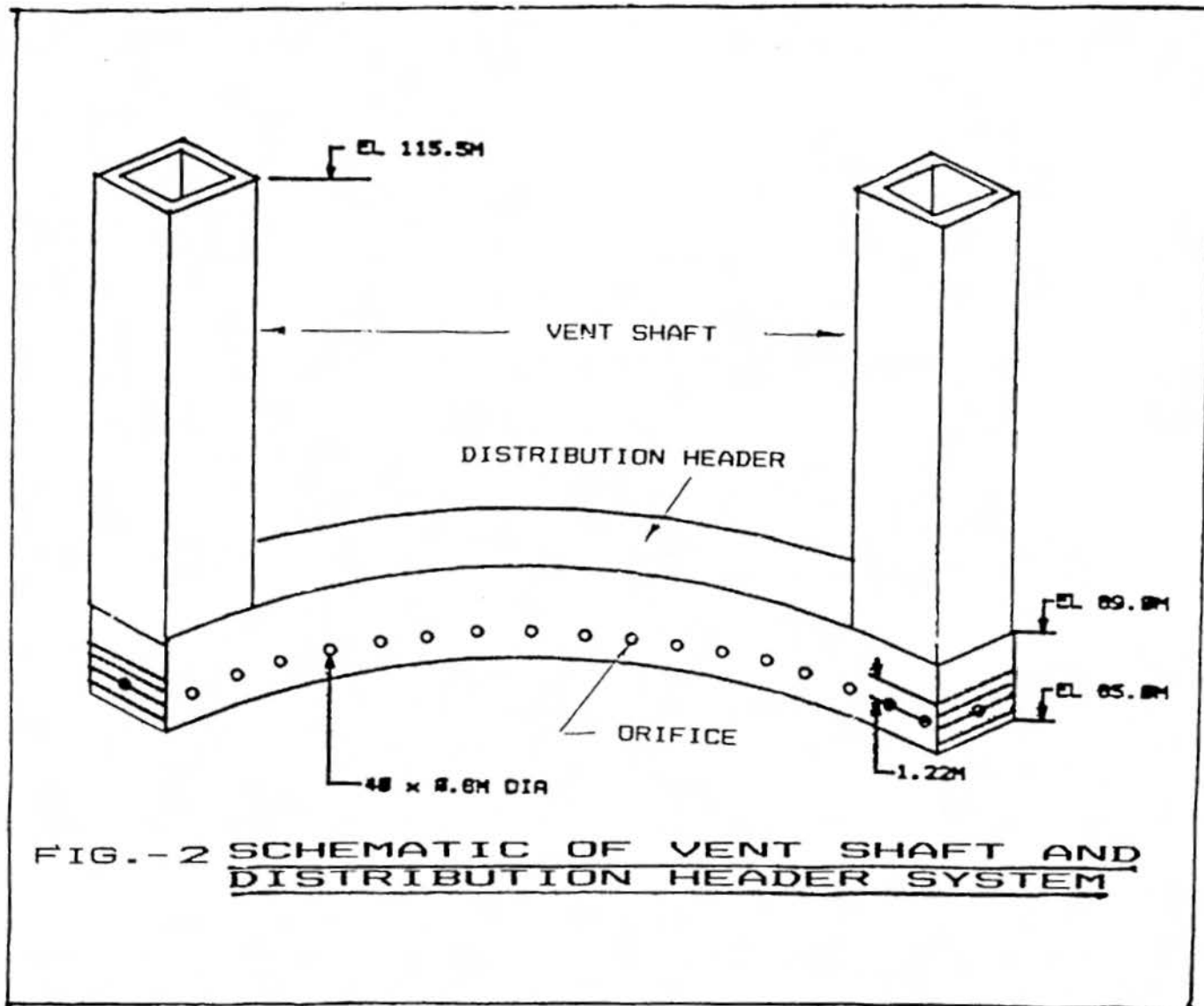
#### 6.0 REFERENCES:

- [1] Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plant, AERB/SC/D, Draft, Rev.F, Atomic Energy Regulatory Board, India, November, 1989.

- [2] R.N. Bhawal, M. Das, Pressure and Temperature Transient Analysis of 500 MWe PHWR Containment by Computer Code PACSR, Paper presented in the Second International Conference on Containment Design and Operation, Toronto, Canada, 1990.
- [3] AERB Manual No.AERB/SM-S-1: 'AERB Safety Manual for Civil Engineering and Building Works of Nuclear Power Plants', Atomic Energy Regulatory Board, Bombay.
- [4] S.S. Bajaj, Nalini Mohan, G.M. Mustafa, M. Das et.al, Pressure Suppression Pool Hydrodynamic Effects in Containment System of Indian PHWRs, Paper presented in the Second International Conference on Containment Design and Operation, Toronto, Canada, 1990.



**FIG.-1** SECTION OF CONTAINMENT FOR 500 Mwe PHWR



**FIG.- 2 SCHEMATIC OF VENT SHAFT AND DISTRIBUTION HEADER SYSTEM**

