Reactor, Boiler & Auxiliaries - Course 133

SHIELD SYSTEMS

The general types of shields used in Ontario Hydro and AECL reactors are the:

Thermal Shields: used to protect equipment and structures, mainly concrete walls, from the effect of thermal radiation from the reactor.

Calandria End Shields: used for personnel radiation protection and provide shielding to reduce γ radiation in the calandria vaults to a level allowing access during shutdown only. (These are sometimes called shutdown shields.)

Biological Shields: used for personnel radiation protection from fast neutrons and γ rays for areas continuously accessible during full power operation. (These are sometimes called the operational shields.)

All these shields need continuous cooling as a result of absorbing the radiation they provide protection against. We will look at the different types which have been used in our units and also at the typical cooling circuits associated with them. Table I gives a summary of the types used.

This table illustrates well how the basic concept and also detailed design has changed over the years with regard to shielding. From comparisons of previously discussed reactor systems other basic design changes have been noted and discussed also. This continual development again indicates that at the present time, we are still not at the stage where we have arrived at a standardized reactor unit design although the 600 MW(e) design is the closest approach to this at the moment.

THERMAL SHIELDS

NPD

At NPD this is provided by using a 30 cm thick annulus of light water around the moderator. This also acts as a neutron reflector and is referred to as the reflector circuit. It is integral with the core design itself and also provides radiation shielding from fast neutrons and γ rays. Light water was chosen to act as a reflector rather than D_2O because of the

TABLE I

Comparison of Reactor Shield Systems

STATION	THERMAL SHIELD	CALANDRIA END SHIELDS	BIOLOGICAL SHIELD
NPD	Extension of H_2O reflector.	Rotating concrete end shields, remote from reactor face.	Water cooled heavy concrete walls of calandria vault.
DPGS	Air cooled stainless steel vault liner plates.	Stainless steel tube-sheets and carbon steel slab, H_2O cooled.	Water cooled heavy concrete walls of calandria vault.
PGS (A)	Stainless steel plates inside calandria shell.	Stainless steel tube-sheets and carbon steel slabs, H_2O cooled.	Water cooled heavy concrete walls of calandria vault.
BGS (A&B)	Provided by end shields and biological shield.	Stainless steel tube-sheets filled with carbon steel balls and H_2O.	H_2O filled shield tank and concrete walls of calandria vault.
600MW(e) PGS (B)	Provided by end shields and biological shield.	Stainless steel tube-sheets filled with carbon steel balls and H_2O	Steel lined, H_2O filled concrete vault.

extra cost of D_2O when NPD was built. It was then easy to extend the H_2O thickness needed to act as a reflector only (5 cm) to that sufficient for a thermal shield in addition.

The cooling system has its own circulating pumps P1, P2, P3, isolating and check valves, heat exchanger, HX1, head tank, TK1, and by-pass purification circuit shown in Figure 1. Because the reflector/thermal shield is enclosed in the outer annulus of the calandria the temperature differential between it and the moderator is maintained small during start up, or following a trip, to reduce thermal stresses in the calandria.

Cooling must also be maintained during a shutdown and for the required operating reliability one of the pumps will be on Class III power.

Douglas Point

The reflector here, a 74 cm radial extension of the moderator, is insufficient to act as a thermal shield, in particular after a dump, so a separate thermal shield was designed to protect the concrete walls of the calandria vault from overheating. The shield takes the form of two sandwiched plates of steel supported between a stainless steel vault liner and a carbon steel liner of the heavy concrete of the reactor vault walls, Figure 2.

Cooling is provided by forcing air up through the passages between the stainless steel liner, the shield plates and the carbon steel liner, through a heat exchanger. This then forms a closed circulating system.

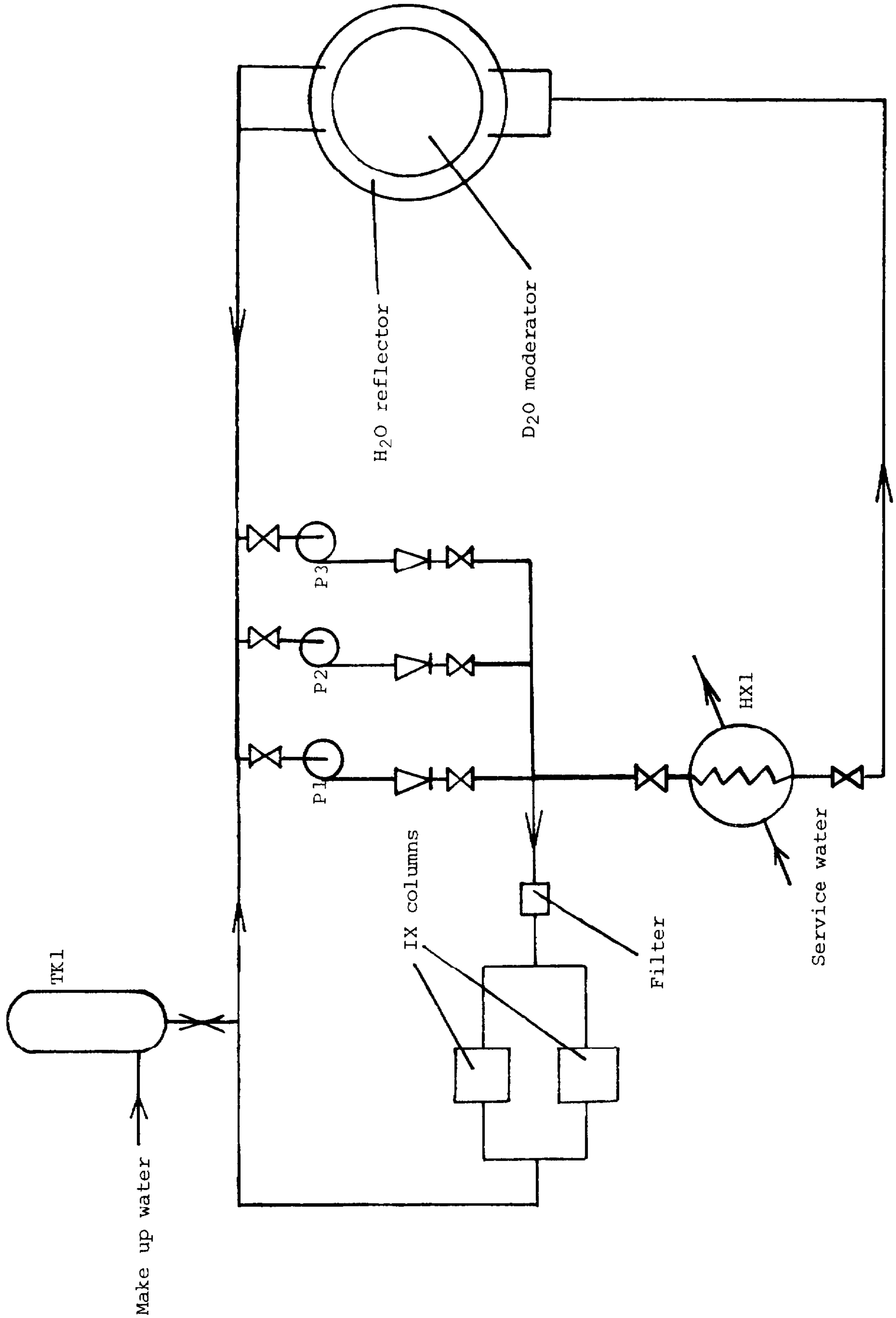
(Air cooling rather than water cooling was chosen because of the difficulty of repairing leaks in a water cooled system, and the additional cost of the shields needed for the higher stresses that would be experienced in a water cooled system.)

In addition to this thermal shield the stainless steel calandria was made about 1 cm thicker than necessary for its internal pressure to provide some extra thermal shielding.

Pickering A

The thermal shield at Pickering A was designed to use the cooling facilities already provided for the moderator circuit. It consists of 11 cm thick stainless steel liner plates supported inside the calandria and cooled therefore by the moderator. Its main purpose is to limit the nuclear heating of the biological concrete shielding in particular after a moderator dump. This approach was considered more economical than the vault liner air cooled system used at Douglas Point.

<u>Figure 1:</u> Reflector System NPD



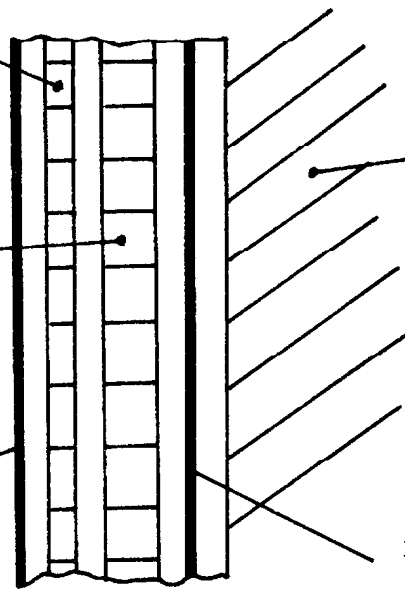


Figure 2: Typical Douglas Point Thermal Shield (Sidewall of Calandria Vault)

Bruce A and B

The approach to shielding at Bruce was to combine the thermal shielding with the biological shield as far as possible. The result is a water filled shield tank surrounding the calandria, Figure 3. This shield tank encloses and supports the reactor core and provides full biological shielding at the top of the tank (called the reactivity mechanism platform) and shutdown shielding elsewhere.

(The advantages of this system are the reduction in on-site construction work time and in the overall costs compared to the Pickering system which required a separate end shield system and embedded cooling pipes in the biological concrete shield of the reactor vault.)

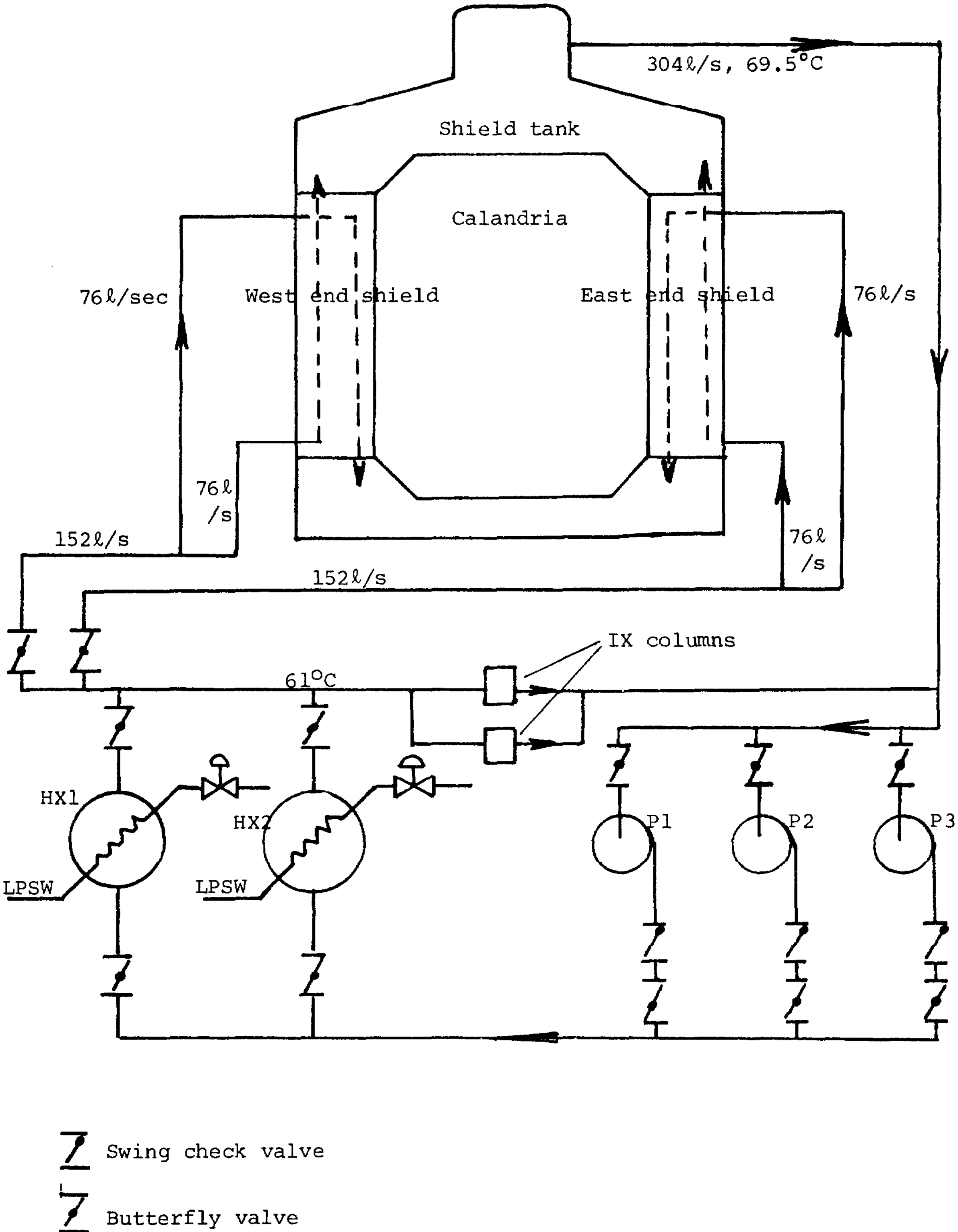


Figure 3: Simplified Flow Diagram for End Shield Tank Cooling System BGSA

A similar arrangement is used on the 600 MW(e) units, and on Pickering B, except here the thermal/biological shield is a light water filled concrete vault in which the calandria is supported by the end shields. (The 125 MW(e) net Pakistan reactor KANUPP made use of this same concept.)

CALANDRIA END SHIELDS

NPD

Unlike all subsequent units the reactor vault at NPD is inaccessible at all times because of the lack of end shields on the calandria. Instead of end shields, circular "rotating end shields" are provided 4 m from both ends of the reactor face, constructed of 1.3 m thick concrete with 17 plugged holes arranged so that each reactor tube may be aligned with one of the holes, hence the rotating feature of the shields. If a coolant tube or end fitting requires maintenance the appropriate hole is positioned in line with the tube and the work done using remote tooling from either the "end access room" or the "tube removal room", as the rooms adjacent to the end shields away from the reactor are called. Like all end shields only shutdown shielding is provided by these shields.

Douglas Point and Pickering A

These units each have water cooled steel end shields, Figure 4, with coolant channel end fittings penetrating the end shields on both faces of the core. Shutdown shielding is then available in the calandria vault. The end shields are constructed, at Pickering (Douglas Point being similar but smaller) of four layers of carbon steel slabs keyed together making up 1 m total thickness, 10 cm total thickness of inner and outer stainless steel tube sheets, plus two 6 cm thick layers of cooling water adjacent to the tube sheets. Cooling flow is from bottom to top of each shield via the space provided by lattice tubes, as shown, which are welded to the tubesheets, and contain and support the end fittings. Flow direction within the water space is directed by baffle plates as shown.

Bruce A and B, Pickering B, 600 MW(e)

Each end shield is composed of a common calandria/end shield tubesheet connected to an outer tubesheet, on the fuelling machine side, by lattice tubes and an outer shell, see Figure 5. The end shields are filled with carbon steel balls and water providing shutdown shielding resulting in better heat transfer and lower fabrication costs than the steel slab design described above.

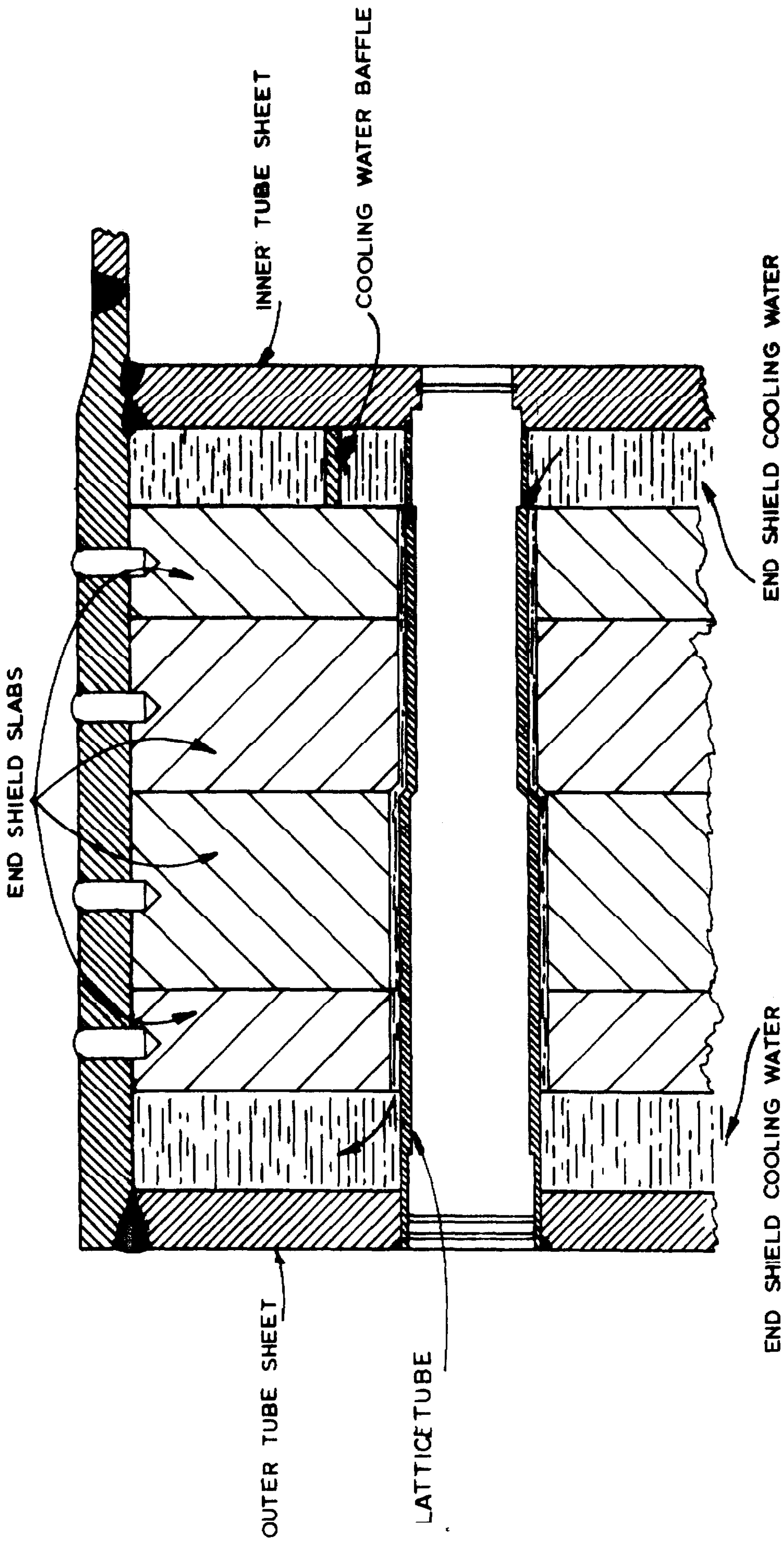


Figure 4: Pickering GSA End Shields

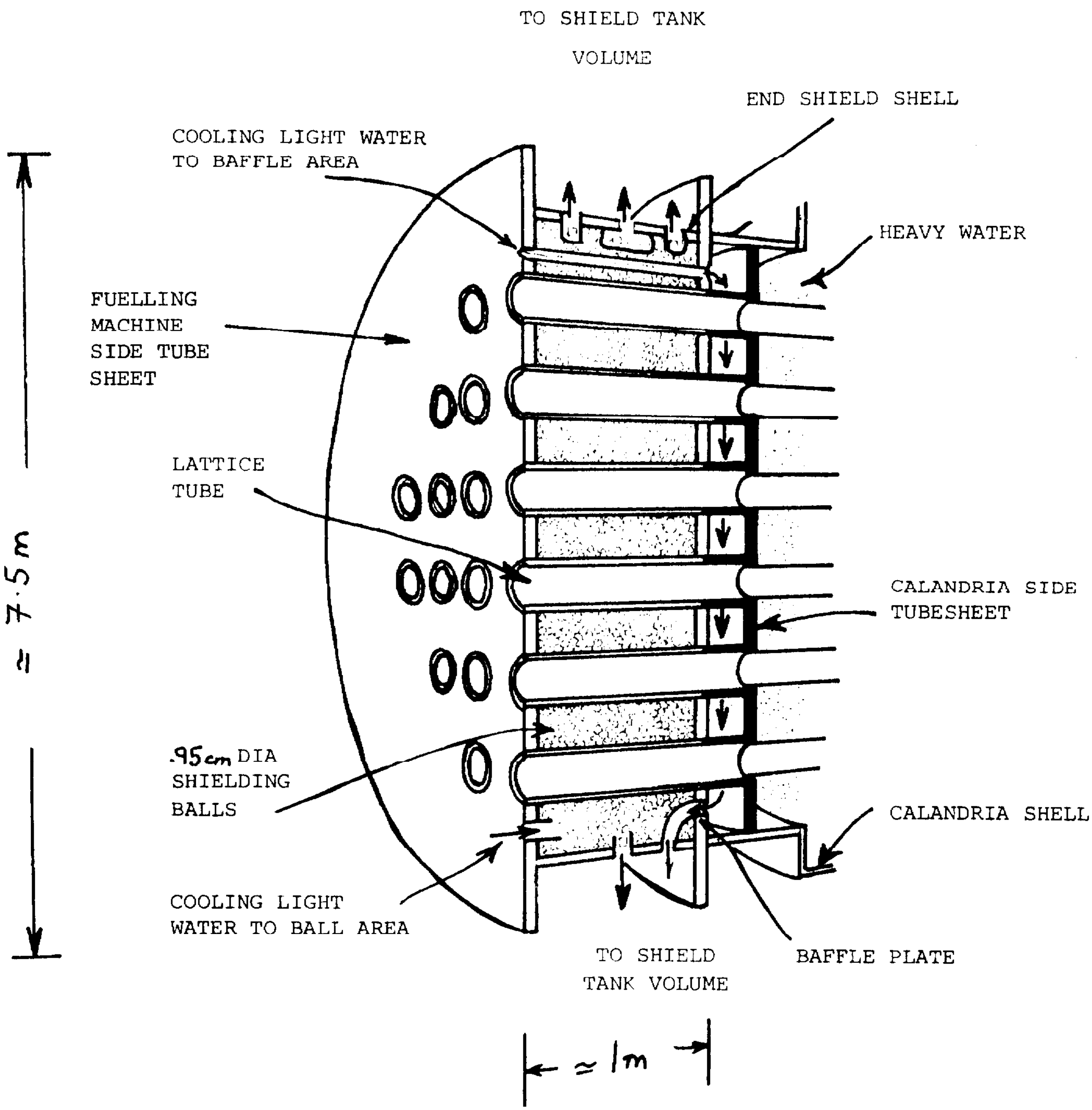


Figure 5: END SHIELD-SHIELD TANK COOLING (BRUCE GSA)

The Bruce A arrangement, as shown, actually has a baffle plate close to the calandria side tubesheet which separates the carbon steel balls/H_2O area from the H_2O in the baffle/calandria tubesheet area. Only Bruce has this baffle region as a result of the higher expected heat generation in the end shields than in other units. The flow in this region is of higher velocity than in the ball filled region to remove the larger amount of heat deposited in the calandria side tubesheet, large flows over the balls being avoided to reduce erosion.

A typical end shield cooling system is shown in Figure 3 for Bruce A, consisting of 3 x 50% pumps, 2 x 50% heat exchangers and a by-pass IX purification circuit. All pumps can be run on Class III power as loss of cooling for this system is not acceptable.

BIOLOGICAL SHIELDS

NPD, Douglas Point, Pickering A

These plants all use water cooled heavy concrete shielding for the biological shield. This shield in general will consist of the calandria vault walls, calandria vault floor, calandria vault roof and the vault hatches illustrated typically for PGSA in Figure 6. The cooling is necessary to limit the concrete temperature to 60°C and pipe runs are usually made in horizontal loops being spaced according to the amount of heat to be removed in any particular region. With concrete in particular, its poor thermal conductivity makes the heat difficult to remove and the 60°C temperature limit is imposed because of two problems.

(a) Thermal stresses may cause spalling and cracking and hence a reduction in the physical strength of the concrete.

(b) Water is driven out of the shield by the high temperatures and the retained water content in the shield decreases. This will make the shield less effective as a neutron shield.

(The latter effect is in fact the most critical of the two factors.)

Bruce A and B, Pickering B, 600 MW(e)

These plants use the concept of a water shield combining biological and thermal shielding requirements. Bruce uses the water filled shield tank described previously. Biological (ie, operational) shielding is provided by this tank, Figure 3, on the reactivity mechanism platform ($\simeq$ 4 mr/h at full power is the expected field). The calandria vault concrete walls and

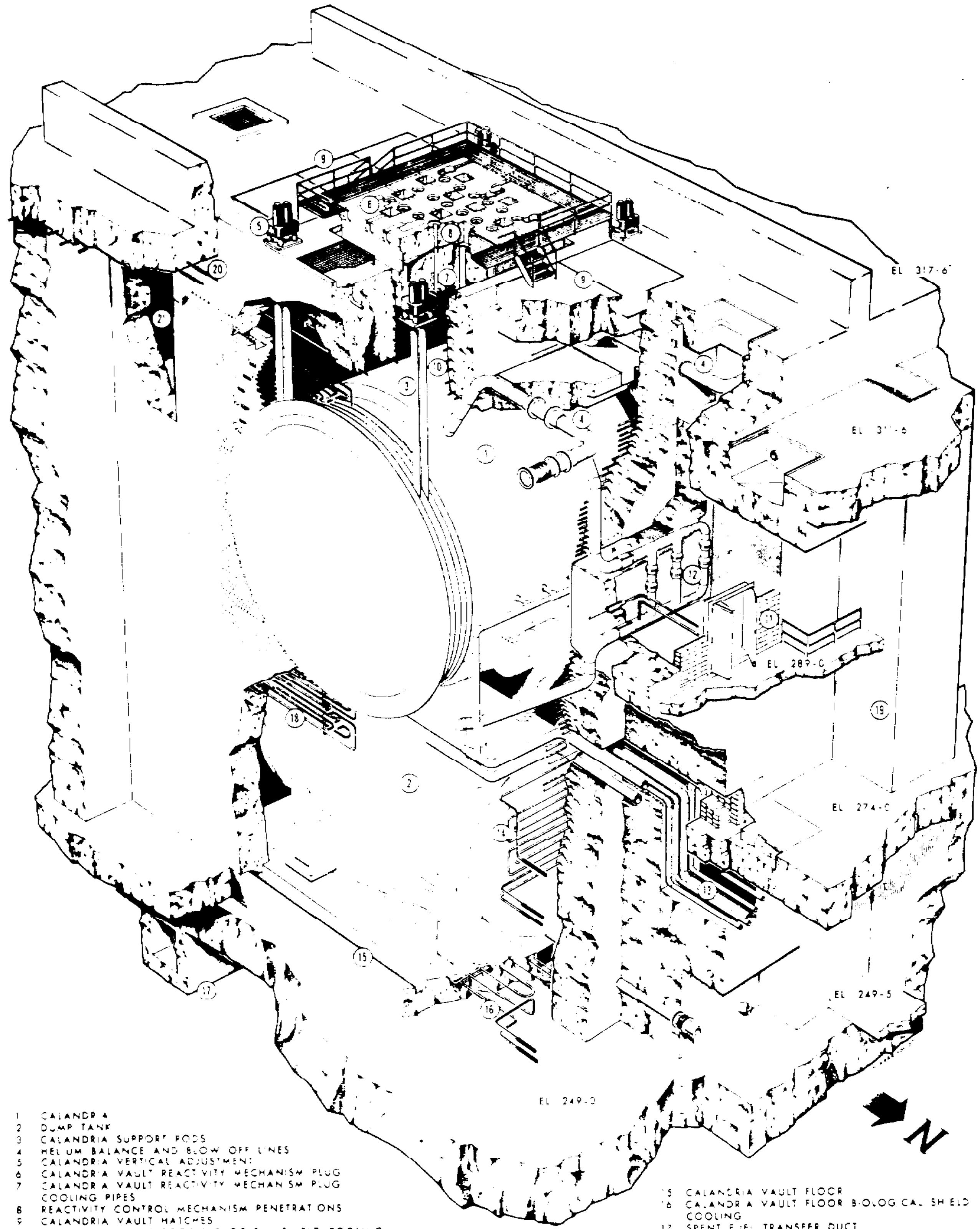


Figure 6: Water Cooled Heavy Concrete Biological Shielding PGSA
(NPD and Douglas Point are similar)

roof provide biological shielding outside these areas and as a result of the water shield tank do not require any embedded cooling coils.

For the 600 MW(e) and Pickering B (5-8) units a similar but cheaper concept is being utilized for the biological/thermal shield. Instead of the shield tank these units use a light water filled steel lined concrete vault, Figure 7. Steel ball shielding is retained in the end shields for the same reasons as in Bruce, ie, lower cost relative to steel slabs. Ordinary concrete with no embedded cooling pipes is then adequate for the calandria vault walls.

ASSIGNMENT

1. Using table I, discuss the reasons our various stations have changed the design of their shield systems over the years.

D. Winfield

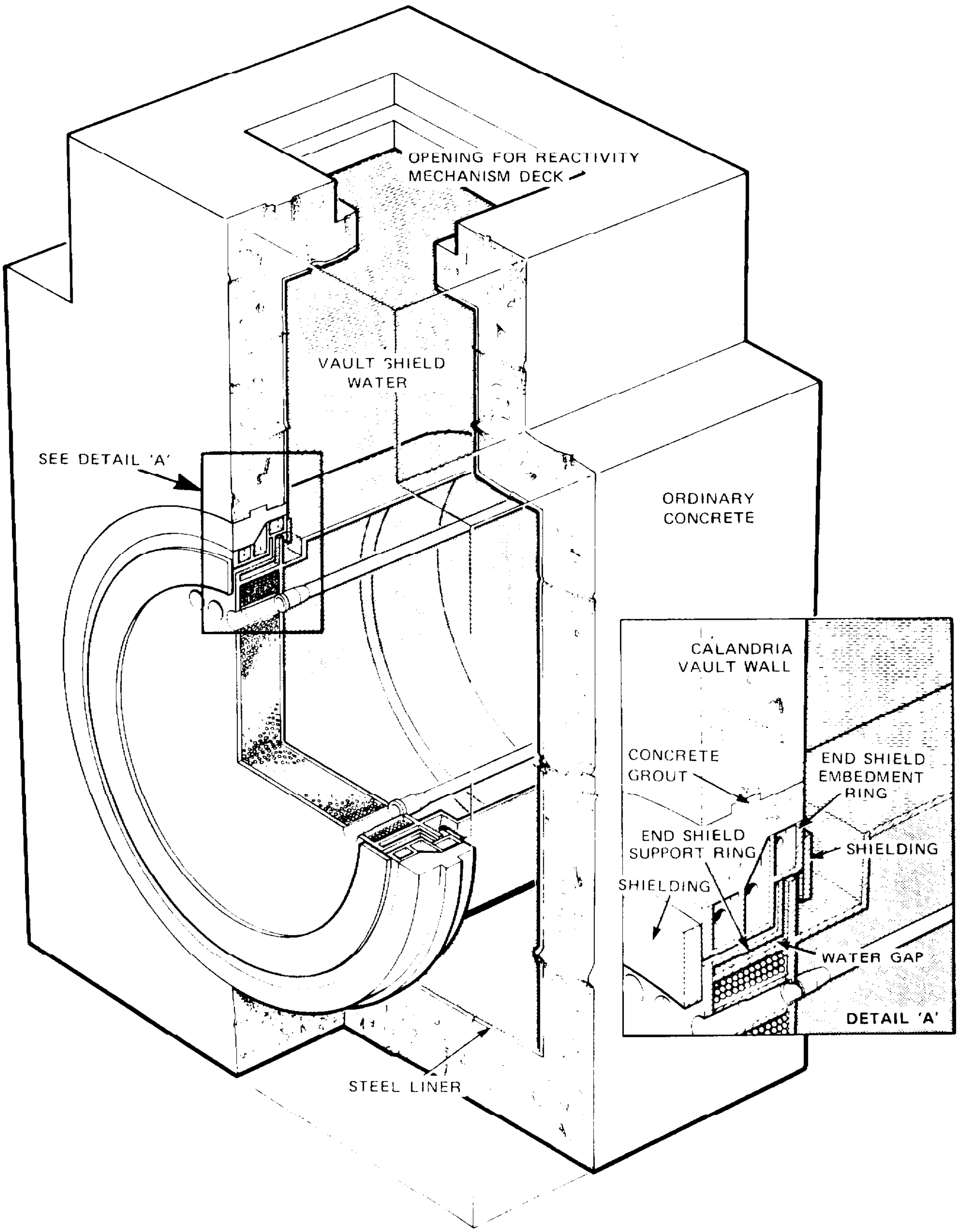


FIGURE 7: CONCRETE CALANDRIA VAULT
(600 MW(e), PGSB)