Reactor, Boiler & Auxiliaries - Course 233

SHIELD COOLING SYSTEMS

I. INTRODUCTION

The general types of shields used in our reactors are:

Thermal Shields:	used to protect equipment and structures, mainly concrete walls from the effect of heat generated by the absorption of nuclear and thermal radiation emitted by the reactor.
Calandria End Shields:	used to reduce γ radiation in the reactor vault to a level allowing personnel access during shutdown only.
Biological Shields:	used for personnel radiation protection from fast neutrons and γ rays for areas continuously accessible during full power operation.

All these shields need continuous cooling as a result of absorbing radiation. We will look at the different types which are used in our stations and also at the typical cooling circuits associated with them. Table 1 summarizes the different types of shields in use at PNGS A/B and BNGS A/B. This table illustrates how the detailed design has changed over the years with regard to shielding.

II. THERMAL SHIELDS

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 by the moderator. Its purpose is to absorb nuclear radiation (fast neutrons and γ's) and thermal radiation from the core to limit the amount otherwise reaching the biological shield so the cooling capacity of the biological shield system can be minimized. If the shield is steel, as at PNGS-A its high thermal conductivity and ease of cooling by use of moderator D_2O will then substantially reduce the heat load on the biological shield. (At Douglas Point, by

TABLE 1

Comparison of Reactor Shield Systems

STATION	THERMAL SHIELD	CALANDRIA END SHIELD	BIOLOGICAL SHIELD
PNGS-A	Stainless steel plates inside calandria shell. moderator D_2O cooled.	Stainless steel tubesheets and carbon steel slabs. H_2O cooled.	Water cooled heavy concrete walls of reactor vault.
PNGS-B and 600 MW(e)	Provided by light water in the calandria vault which is part of the biological shield.	Stainless steel tubesheets filled with steel balls and H_2O.	Steel lined, H_2O filled concrete calandria vault
BNGS-A/B	Provided by light water in the shield tank around the calandria.	Stainless steel tubesheets filled with steel balls and H_2O.	H_2O filled shield tank and concrete walls of calandria vault.

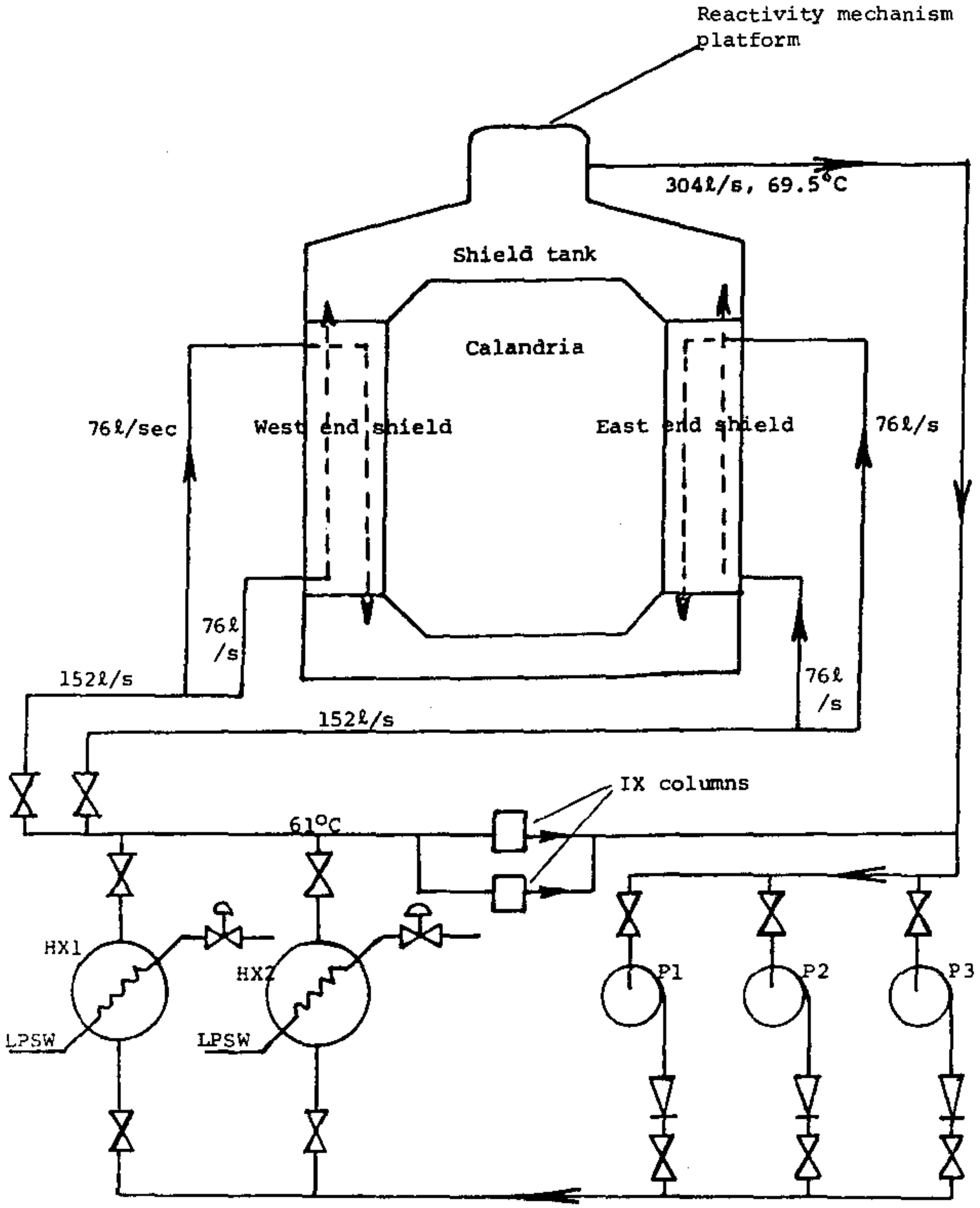


Figure 1: Simplified Flow Diagram for End Shield Tank Cooling System BNGS-A

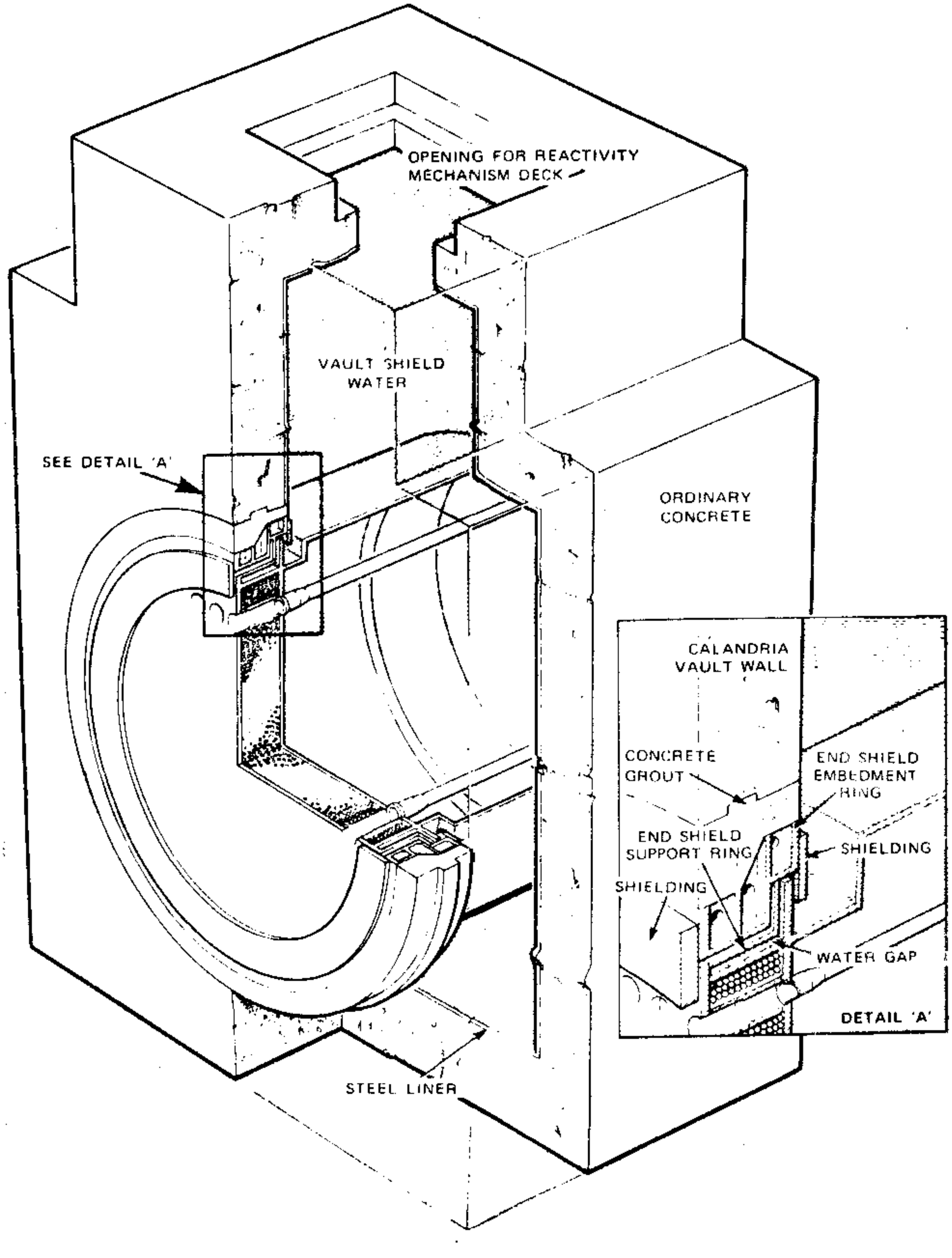


Figure 2: Concrete Calandria Vault (600 MW(e), PNGS-B)

way of contrast, this thermal shield consists of an air cooled steel liner inside the biological concrete shield, the calandria shell thickness being only thick enough for that required for structural strength).

Bruce NGS, Pickering NGS-B, and 600 MW(e) Units

The approach to thermal 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 1. 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 shielding adequate for shutdown access elsewhere.

The advantages of this system are the reductions in construction time and cost compared to the Pickering A system, which has embedded cooling pipes in the biological shield of the reactor vault.

A similar arrangement is used on the 600 MW(e) units, and on Pickering B, except that the thermal/biological shield is a light water filled concrete vault in which the calandria is supported by the end shields, see Figure 2.

III. CALANDRIA END SHIELDS

The primary purpose of these shields is to provide γ shielding to allow personnel access to the vault during a shutdown. Heat is generated in the end shield components by both radiation absorption (neutron plus γ on power, and γ radiation on shutdown) and by heat conduction from the hot end fittings. This heat will typically be $\sim$0.5 - 1.0% of total reactor thermal power with the reactor at full power. For instance, at Bruce, this is $\sim$9 MW(th), and is removed by the end shield water cooling system. Upper and lower limits are placed on the operating temperature of the end shield cooling system to prevent thermal stresses developing between the shield structure and the calandria shell to which the shield is connected.

Pickering A

These units each have water cooled steel end shields, see Figure 3. The end shields are constructed of four layers of carbon steel slabs keyed together making up a thickness of 1 m and also of 5 cm thick 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 tube sheets, and contain and support the end fittings. Flow is directed by baffle plates as shown.

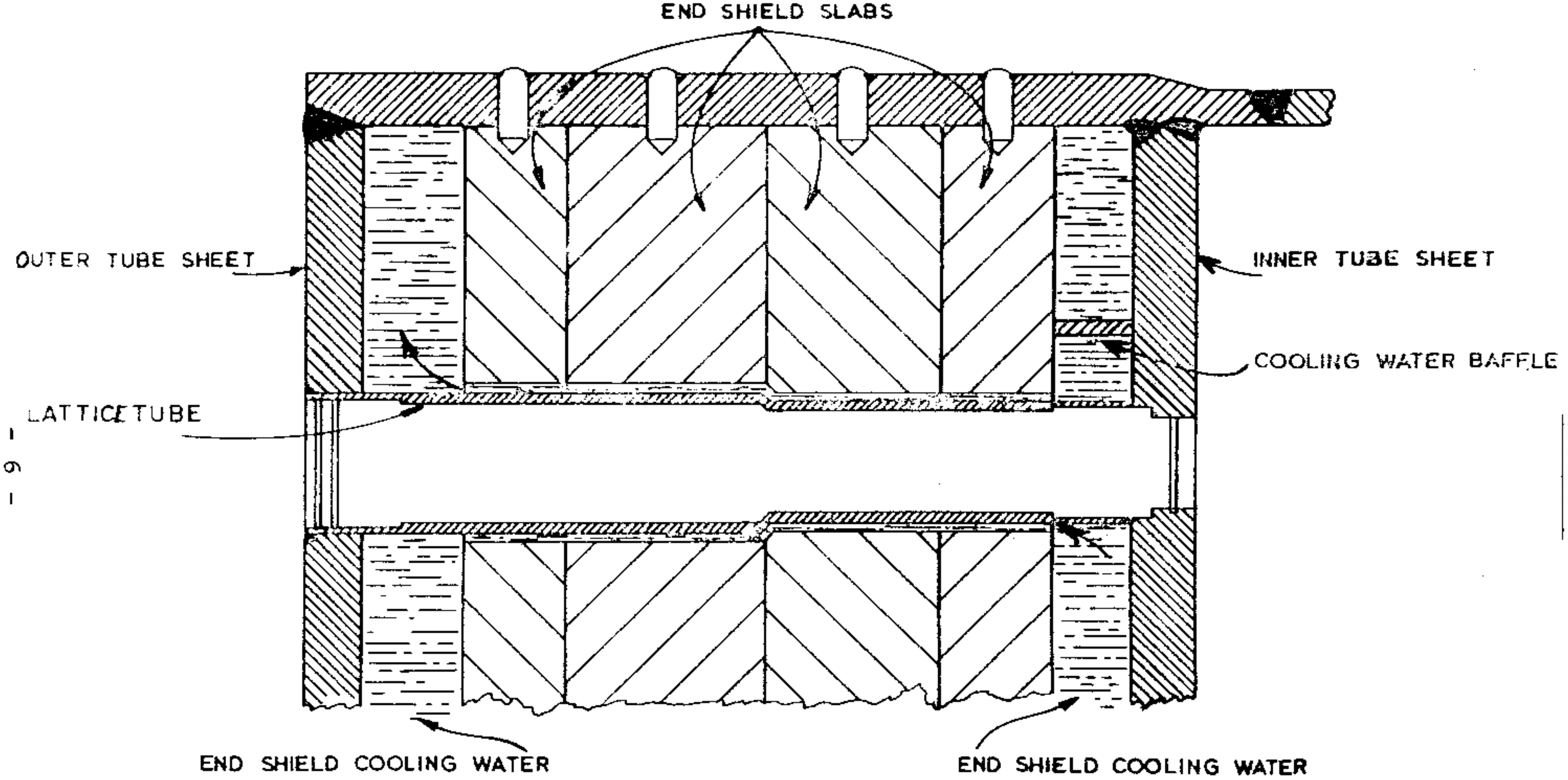


Figure 3: Pickering NGS-A End Shields.

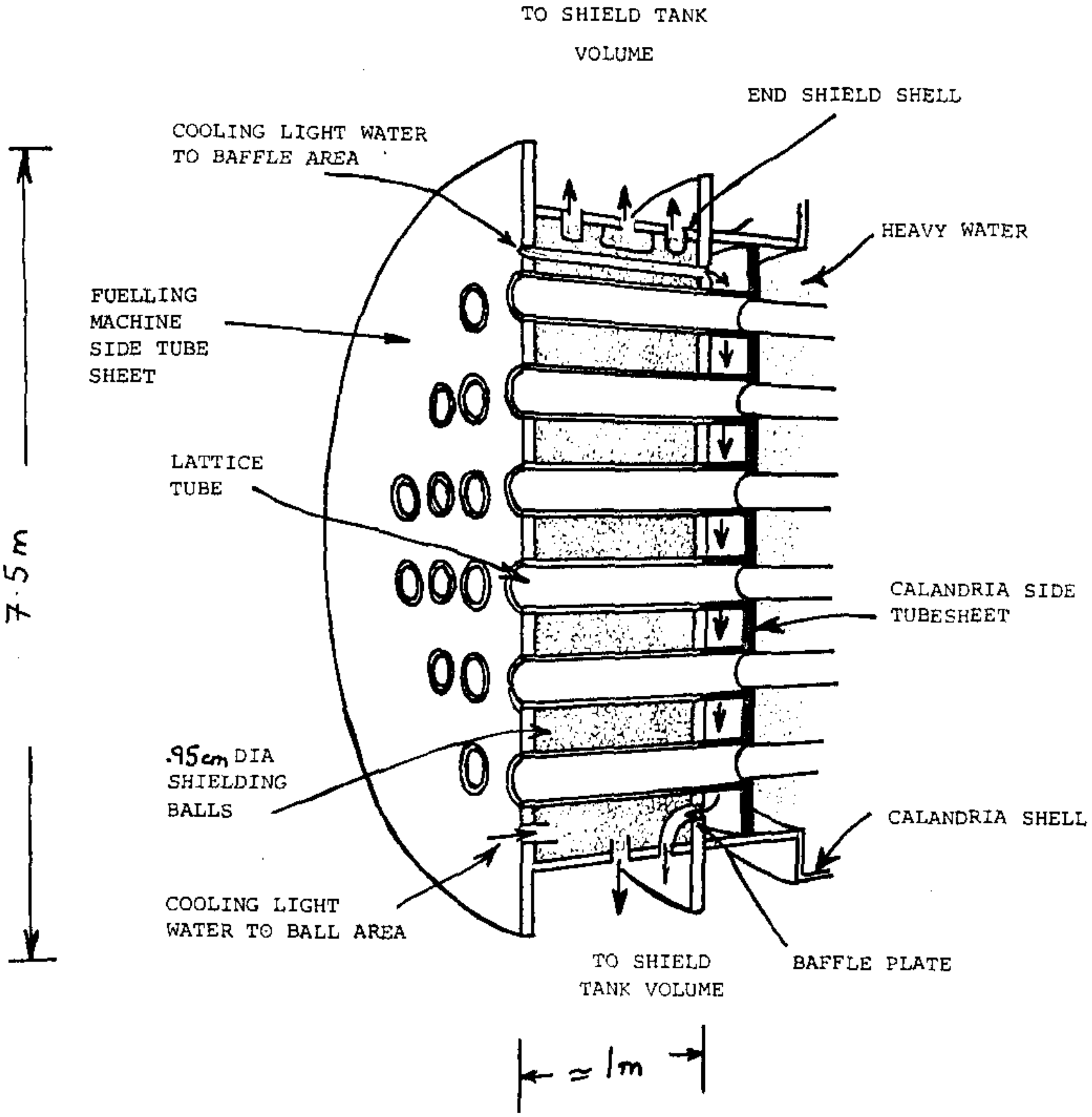


Figure 4: End Shield-Shield Tank Cooling (Bruce NGS-A)

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

Each end shield is composed of a calandria tube sheet connected to a tube sheet on the fuelling machine side by lattice tubes and an outer shell, see Figure 4. The end shields are filled with steel balls and water. This design features better heat transfer for cooling and lower fabrication costs than the steel slab design of PNGS-A.

A baffle plate in the Bruce A design of Figure 4 divides the ball and water filled region from a water filled region adjacent to the calandria tube sheet. This water filled region exists only at Bruce, where end shield heating is greater than in other stations.

A Bruce A end shield cooling system is shown in Figure 1. It consists of 3 x 50% pumps, 2 x 50% heat exchangers and a bypass IX purification circuit. All pumps can be run on Class III power, as high cooling system reliability is necessary due to possibility of thermal stresses between end shield and calandria. Temperature control of the end shield water is achieved by using control valves on the service water side of the heat exchangers.

IV. BIOLOGICAL SHIELDS

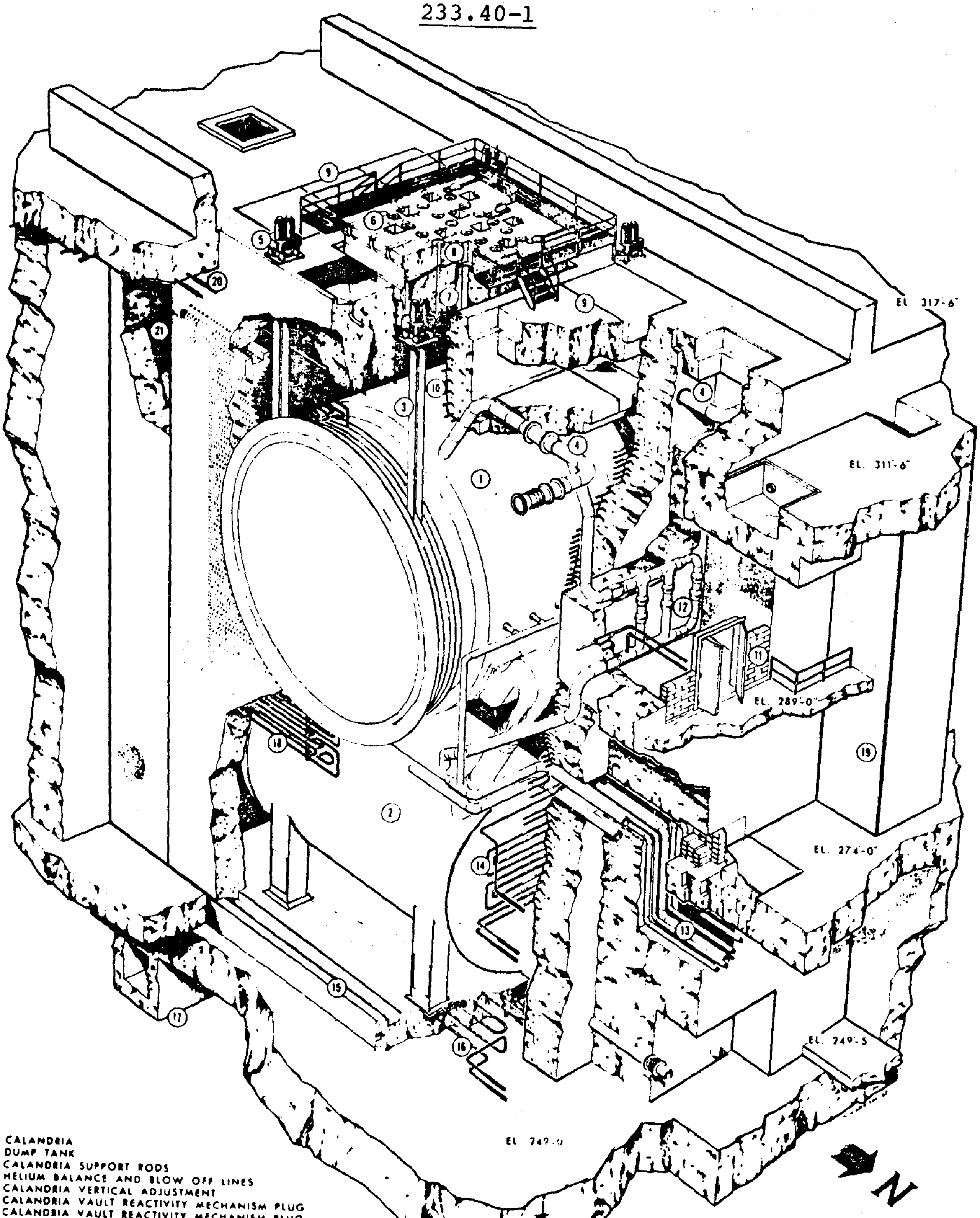
Pickering A

PNGS-A units use water cooled, heavy concrete shielding for the biological shield. This shield consists of the calandria vault walls, calandria vault floor, calandria vault roof and the vault hatches, illustrated in Figure 5.

The biological shields are heated as a result of the absorption and slowing down of neutrons, absorption of γ's and heat conduction and convection from the reactor core and components. Cooling is necessary to limit the concrete temperature to $\sim$ 60°C and pipe runs are usually made in horizontal loops, spaced according to the amount of heat to be removed in any particular region. The poor thermal conductivity of concrete makes heat removal difficult and the $\sim$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. This makes the shield less effective as a neutron shield.



1 CALANDRIA
2 DUMP TANK
3 CALANDRIA SUPPORT RODS
4 HELIUM BALANCE AND BLOW OFF LINES
5 CALANDRIA VERTICAL ADJUSTMENT
6 CALANDRIA VAULT REACTIVITY MECHANISM PLUG
7 CALANDRIA VAULT REACTIVITY MECHANISM PLUG COOLING PIPES
8 REACTIVITY CONTROL MECHANISM PENETRATIONS
9 CALANDRIA VAULT HATCHES
10 CALANDRIA VAULT ROOF BIOLOGICAL SHIELD COOLING
11 HEAVY CONCRETE BLOCK WALL
12 HELIUM VALVE CHAMBER
13 CALANDRIA VAULT PIPING
14 NORTH WALL BIOLOGICAL SHIELD COOLING
15 CALANDRIA VAULT FLOOR
16 CALANDRIA VAULT FLOOR BIOLOGICAL SHIELD COOLING
17 SPENT FUEL TRANSFER DUCT
18 EAST WALL BIOLOGICAL SHIELD COOLING
19 PIPE CHASE
20 FUELLING MACHINE VAULT COOLING
21 CALANDRIA VAULT BOILER ROOM INTER SPACE

Figure 5: Water Cooled Heavy Concrete Biological Shielding PNGS-A (NPD and Douglas Point are similar)

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

These plants use a water shield, combining biological and thermal shielding requirements. Bruce used the water filled shield tank described previously. Biological shielding is provided by this tank, Figure 3, on the reactivity mechanism platform (a few mr/h at full power). The calandria vault walls and roof provide biological shielding outside these areas, and as a result of the water shield tank do not require any imbedded cooling coils.

For the 600 MW(e) and Pickering B units, a similar but more economical 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 5. Ordinary concrete with no embedded cooling pipes is then adequate for the calandria vault walls.

V. RADIATION HAZARDS FROM SHIELD COOLING SYSTEMS

The equipment in the above systems will be located in areas outside containment and accessible on power. This can be done as the γ radiation fields from nitrogen-16 and oxygen-19 are not sufficient to produce any problem. Delay in the circulation of the water from the shields to the pumps and heat exchangers will be adequate to help keep the fields acceptably low around these components. The neutron flux producing the N-16/O-19 fields in the shields is also much lower than it is in the HT/moderator water and this is the major reason the γ fields are low. In addition the absence of tritium in the shield system also makes it practical to locate most of the system components outside containment. Some active corrosion products will build up with time in the system especially on the filters and ion exchange columns and so these components will usually be provided with some γ shielding. The fields will be small compared to those caused by corrosion products in the moderator or heat transport systems, however.

ASSIGNMENT

1. Explain what the heat source is in the thermal shield and why a thermal shield is needed in addition to a biological shield.

2. What type of radiation shielding is the end shield designed for? Explain why?

3. Explain why temperature limits are set on the operation of the:

   (a) end shield cooling system
   (b) biological shield cooling system (if used).

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