ATOMIC ENERGY OF CANADA LIMITED
Power Projects, Sheridan Park, Ontario

Lecture 10

Nuclear power symposium

PLANT LAYOUT

R. B. V. Simmons

HEAD, RADIATION AND INDUSTRIAL SAFETY BRANCH

ATOMIC ENERGY OF CANADA LIMITED
Power Projects

NUCLEAR POWER SYMPOSIUM

LECTURE NO. 10: PLANT LAYOUT

by

R. B. V. Simmons

1. INTRODUCTION

This lecture not only covers the subject of its title but a wide range of other topics. Some of the additional topics are brought in here because, while important, they do not warrant a complete lecture. It seemed practical and convenient, however, to cover them at this stage.

The lecture starts with a discussion on site selection and goes on to plant layout before coming to building arrangement and design, the consequences of accidents and the measures required to limit radiation exposure. This last item, under the general title of Radiation Exposure Management, includes radiation protection of the public and plant staff. It is followed by a section on active waste management. Finally, the relationship of a CANDU plant to the environment is discussed.

References are made to different CANDU plants as convenient for illustration and to show the general application of the points discussed.

2. SITING

2.1 General

When a utility undertakes the provision of additional generating facilities, siting studies are always necessary before the construction is undertaken of a power plant at a specific location. Such factors as availability of cooling water, transmission system planning, heavy equipment delivery routes, availability of skilled labour, land and site preparation costs and foundation conditions are normally investigated in the selection of any power plant site.

However, certain special items such as meteorology, seismic characteristics, land use and population distribution also require particular careful study in the case of a nuclear plant site. There has been so much interest in recent years about the safety of nuclear plants throughout the world that an acceptable report on a site is required by the licensing authorities in all countries before its use for a power reactor is authorized. And even more recent than the interest in safety is the public interest in concern for the environment. In the nuclear industry, of course, that has always been a serious consideration. While a development on the scale of a nuclear plant may be very welcome in a particular locality for economic reasons, environmental groups are likely to be anxious about the effects they foresee on the local ecology. Also the larger issue of the value of growth in itself may be brought into question when the project is announced.

It is useful to list those items which it is necessary to investigate to some degree in the preliminary studies to demonstrate the suitability of a site for a nuclear station.

2.2 Population Distribution

This includes the position of larger population centres and specific items such as schools, hospitals, campgrounds, etc., where concentrations may occur. Any relevant demographic forecasts which are available should be studied. A complete survey is desirable out to about 5 miles radius and typically the area out to about 40 miles is studied sufficiently that density figures can be obtained to give cumulative population totals in, say 10^{o} sectors.

2.3 Land Use and Planning

This covers residential and industrial land use, traffic routes and agriculture, in particular dairy farming and leaf crops. In addition, a study is required of local planning policy and zoning by-laws, recreational land uses - beaches, etc., the nature and extent of extractive industries, forestry, fishing, etc., in the area, and the ways in which these factors may be changing.

2.4 Geology and Seismology

This includes the normal bedrock examination and establishment of the suitability of foundation conditions as well as finding of aggregate sources. The ground water conditions must also be established. A very thorough study of the seismic history and characteristics of the site and general area is essential. It has been found that areas where nuclear power plants are needed are often those with a significant risk of earthquakes. Considerable research has been done recently in several countries to arrive at sound design practices to meet this problem.

2.5 Meteorology

This covers the study of past records to identify any likely extreme weather conditions both in relation to building design and to accident consequences and airborne and liquid effluent control. In Canada the National Building Code forms the normal basis for building design and gives meteorological data on a regional basis. For this setting of diffusion coefficients to use in the control of active airborne effluents, whether routine or accidental, the practice has been to make conservative assumptions based on a survey of the local climate and topography and to verify the realism of these assumptions by trials during the early stages of plant operation. It has not generally been considered useful or practical to try to establish a fully detailed picture of the diffusion meteorology of a particular site other than as a specific scientific research study in a few cases. The extreme conditions which may need to be taken into account, however, include for example, wind channeling, hurricanes, persistent inversions, etc.

2.6 Hydrography

The cooling water supply is an essential consideration for any thermal or nuclear power plant. The patterns of flow and the physical characteristics of the body of water to be used are studied therefore, whether the source is a lake, river or the sea. Activity discharge practices and "thermal pollution" can have greater importance at a nuclear power plant site than the normal temperature and water quality considerations which are required for the engineering of a conventional thermal plant.

Careful studies must be made of these items, including such details as, for example: the risk of ground water contamination, the sources of domestic water supplies, the frequency of stable inversion (poor diffusion) atmospheric conditions and the record of tsunamis. When this has been done the suitability of the site can be assessed and a proposal made to the licensing authority.

It is worth mentioning that the recent increase in concern for the environment is leading to an interest in the overall cost benefit analysis of power stations in the same way as other large enterprises. This is a very large and growing topic. Under today's conditions and given the growing energy demand, nuclear plants stand up well because of their cleanliness, small area requirements and fuelling arrangements.

Acceptance of the site and any limitations which may be imposed from the studies depend upon, among other things, the Atomic Energy Control Board (AECB) guidelines. These have the effect of relating the site to population distribution and operating release limits in requiring adherence to internationally accepted standards of radiation exposure. A separate lecture on the licensing process treats this in more detail.

The site proposed must be such as to allow for a minimum exclusion area within which the owner can give assurance that there will be no residences or uncontrolled public access during the life of the plant. To date, 3,000 feet minimum radius from the reactor building has been required in Canada. For security reasons it is normal to enclose the plant buildings and auxiliary structures within a closer fence with a guarded gate.

A good deal of experience has been gained over the years not only by AECL and some of the utilities but also by the AECB in the selection and assessment of sites for nuclear stations in Canada. It is now true to say that, in general, a site which is acceptable to the utility for overall economic and engineering reasons is likely as a rule to be found acceptable for licensing.

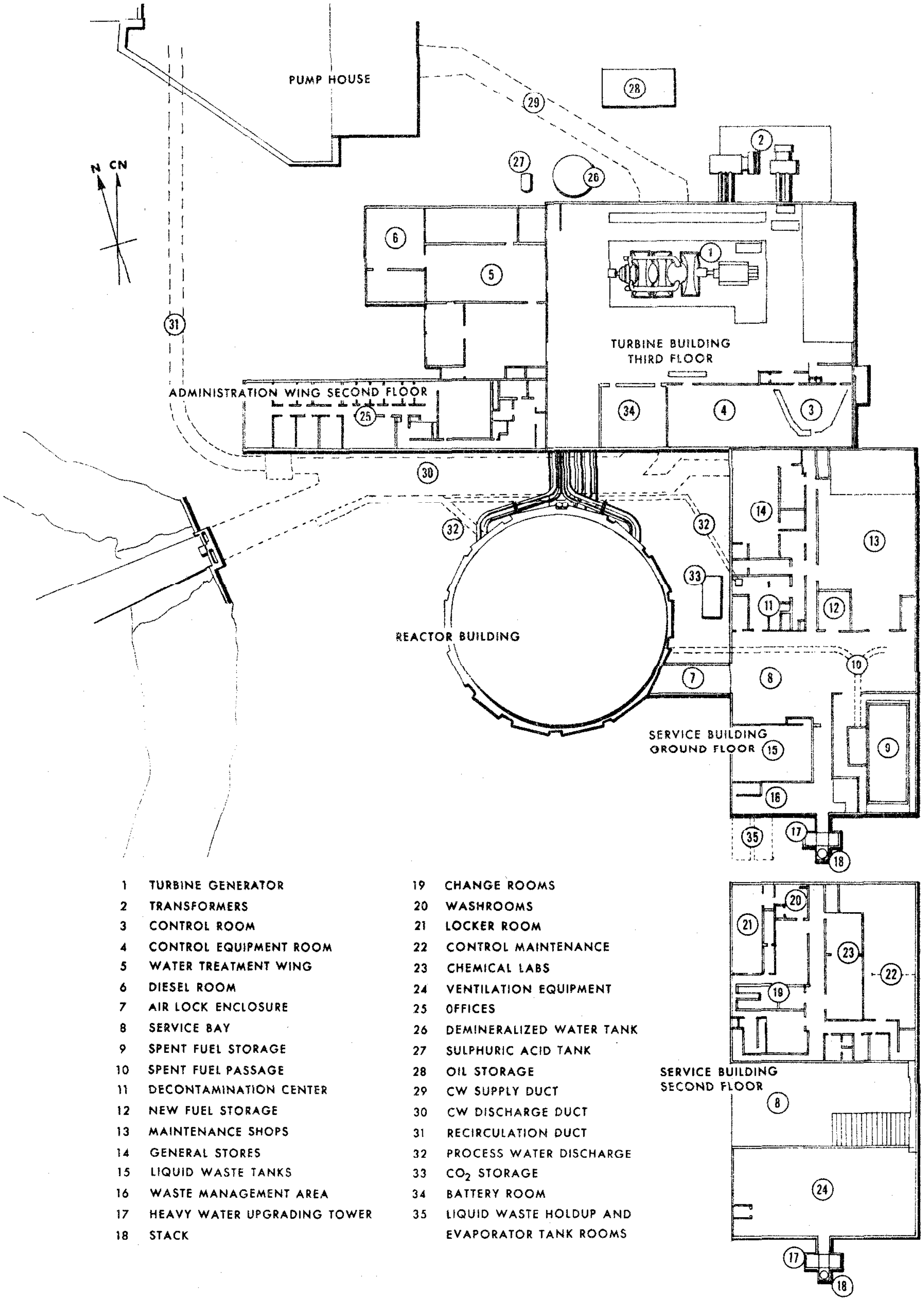
3. PLANT BUILDING LAYOUT

3.1 General

The plant buildings generally follow the flow of the process - Reactor Building, Turbine Building, Switchyard. In the single unit plant this leads to an L-shape to accommodate the Service Building. This gives short connections for steam lines and control cables and also convenient arrangements for cooling water and fuel handling.

As the Douglas Point arrangement shows (Figure 1) it is also possible in this layout to provide convenient means of establishing parts of the plant where contamination can be isolated and practical entry and exit routes established.

The Gentilly arrangement (Figure 2) shows a slightly different approach which serves similar functions. In this case the Turbine Building requires special consideration because of the activity carried with the steam.



1	TURBINE GENERATOR
2	TRANSFORMERS
3	CONTROL ROOM
4	CONTROL EQUIPMENT ROOM
5	WATER TREATMENT WING
6	DIESEL ROOM
7	AIR LOCK ENCLOSURE
8	SERVICE BAY
9	SPENT FUEL STORAGE
10	SPENT FUEL PASSAGE
11	DECONTAMINATION CENTER
12	NEW FUEL STORAGE
13	MAINTENANCE SHOPS
14	GENERAL STORES
15	LIQUID WASTE TANKS
16	WASTE MANAGEMENT AREA
17	HEAVY WATER UPGRADING TOWER
18	STACK
19	CHANGE ROOMS
20	WASHROOMS
21	LOCKER ROOM
22	CONTROL MAINTENANCE
23	CHEMICAL LABS
24	VENTILATION EQUIPMENT
25	OFFICES
26	DEMINERALIZED WATER TANK
27	SULPHURIC ACID TANK
28	OIL STORAGE
29	CW SUPPLY DUCT
30	CW DISCHARGE DUCT
31	RECIRCULATION DUCT
32	PROCESS WATER DISCHARGE
33	CO_2 STORAGE
34	BATTERY ROOM
35	LIQUID WASTE HOLDUP AND EVAPORATOR TANK ROOMS

Figure 1 General Arrangement of Buildings - Douglas Point G. S.

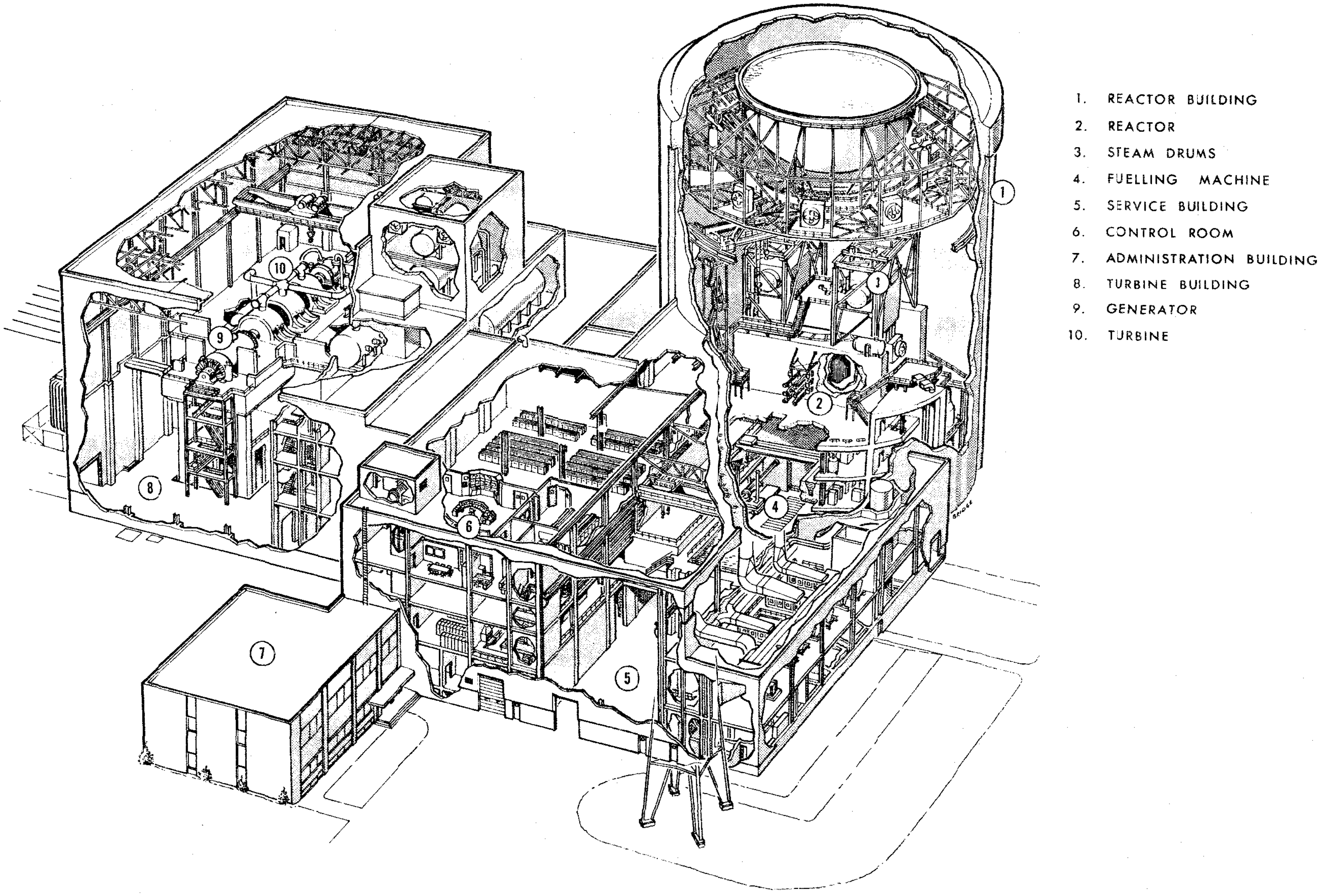


Figure 2 General Arrangement of Buildings - Gentilly G. S.

For a multi-unit plant, of which Pickering is a good example, the L-shape is extended. It had been thought that the Service Building would be central for a possible 8 units and this may yet be the case. Distances become important in a layout of this type and a control room central to four units is about the maximum from the point of view of cable lengths where relay rooms may have to be added for the outer unit connections. Similar considerations apply to spent fuel transfer depending upon the storage system selected. An important aspect of such a plant is the economy of modular repetition which is difficult to achieve unless all units are committed within a short space of time and the entire plant concept is clear at the outset. For example, it was visualized that Douglas Point might be a two-unit station. This was not carried through, but for the RAPP project the decision was ultimately made to add the second unit on the Douglas Point model. Difficulties arose in that, as it was intended to share the Service Building, it seemed logical to make a mirror image of the Reactor Building for the second unit. The difficulty of "handing" components and systems leads to a considerable extra cost for equipment and re-engineering of layouts. At Pickering (Figure 3) a large measure of uniformity was achieved and for Bruce the units are virtually identical. There is a significant reduction in engineering and drafting costs in this case. It is also possible to obtain economies from the larger orders of components which can be made. Unit operating costs also are lower in a multi-unit plant because of better maintenance work planning possibilities.

The arrangement of the Plant Building Complex is a compromise between minimum lengths of steam, water and service piping, cables, personnel and material routes, the number of units and the effect of fuel transfer and accident containment principles. As the slides have shown, the interconnection of reactor buildings as at Bruce (Figure 4) and Pickering imposes a constraint on the positioning of these buildings. The philosophy and the economics of these factors are under constant study and circumstances, building design and construction techniques and experience can influence a particular plant layout significantly. The CANDU plant is of course an evolutionary concept and improvements are always to be expected.

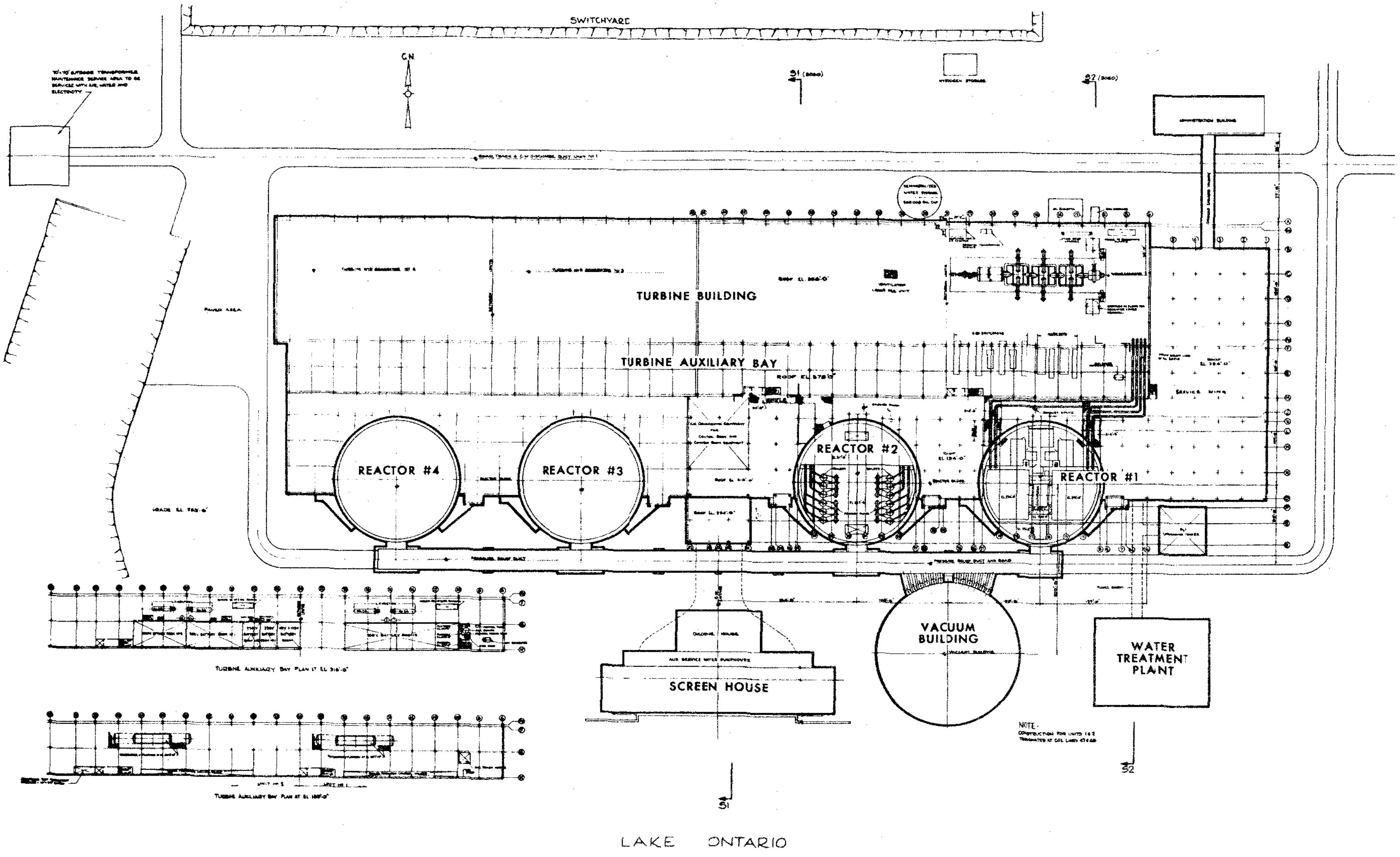
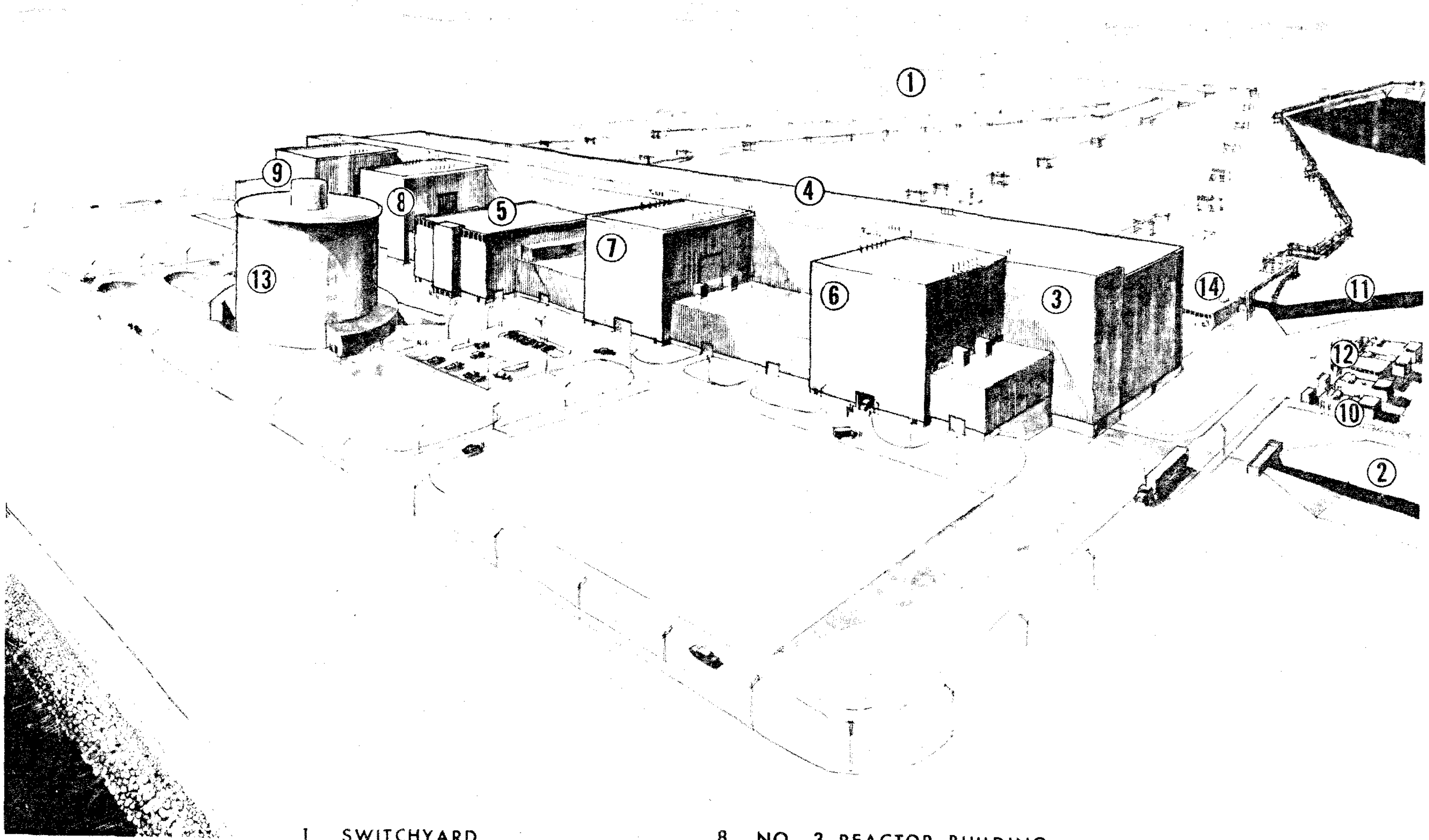


Figure 3 Pickering G.S. Plant Layout



1	SWITCHYARD	8	NO. 3 REACTOR BUILDING
2	DISCHARGE DUCT	9	NO. 4 REACTOR BUILDING
3	POWER HOUSE	10	STANDBY AUXILIARY GENERATOR
4	TURBINE HALL	11	INTAKE
5	SERVICE BUILDING	12	FUEL OIL PUMPHOUSE
6	NO. 1 REACTOR BUILDING	13	VACUUM BUILDING
7	NO. 2 REACTOR BUILDING	14	PUMPHOUSE UNIT 1

Figure 4 Bruce Generating Station

3.2 Reactor Building

The Reactor Building houses the nuclear reactor and auxiliaries, the primary heat transport system, the fuel handling equipment and instrumentation.

Three major structural components constitute the Reactor Building (Figures 5 and 6). They are:

- the concrete containment structure which may be pre-stressed.
- the internal reinforced concrete structures.
- the reinforced heavy concrete calandria vault.

The description which follows takes these three parts in turn.

3.2.1 Containment

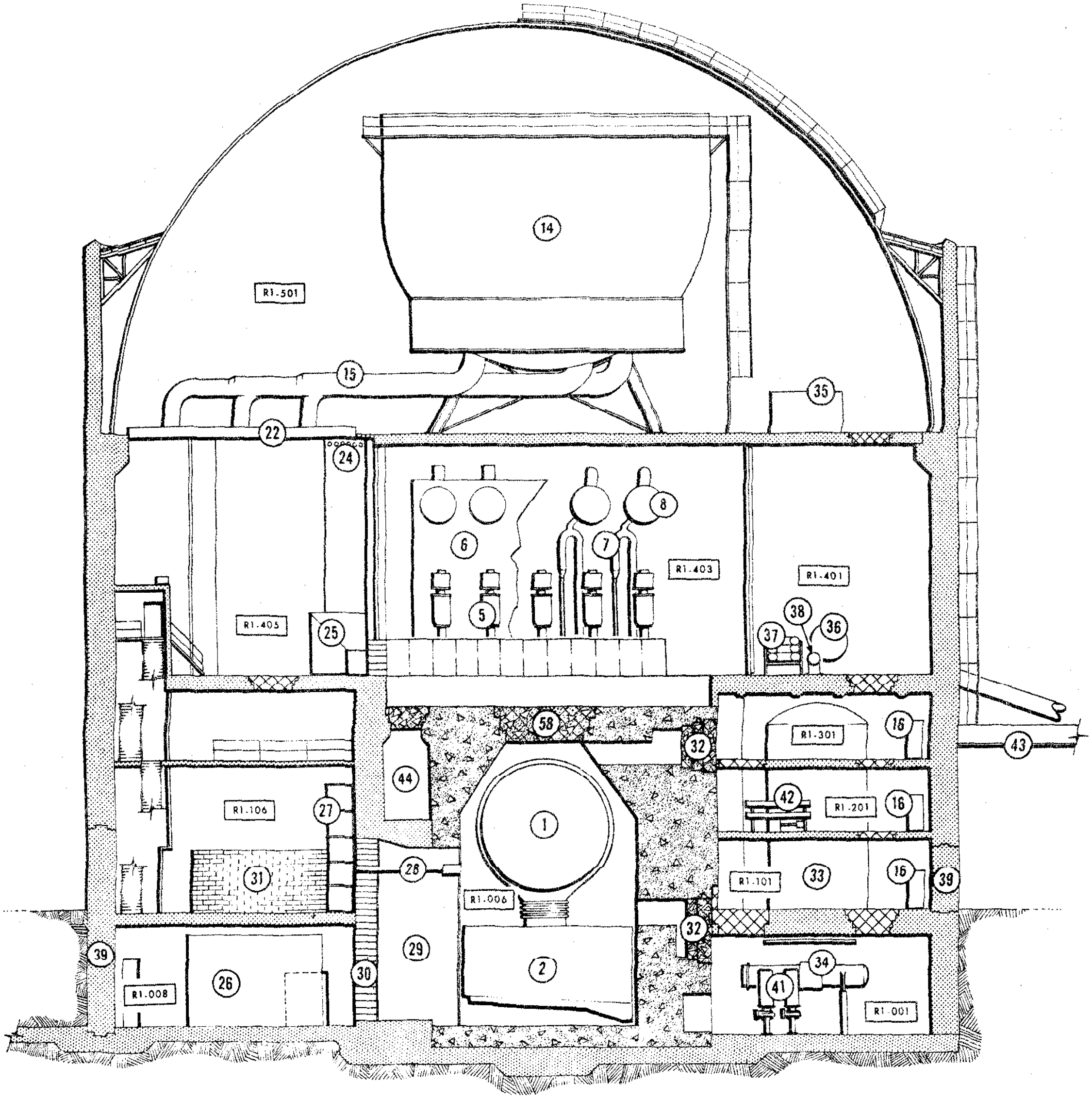
The containment system is provided to limit the escape of activity carried in the steam or water released by an accidental rupture of the main coolant system and to ensure that the public outside the exclusion area would not be exposed beyond the limits set by the AECB.

The containment system main component is the reactor building outer shell which comprises a cylindrical wall, a dome and a base slab attached to the wall. Although the reactor building is rectangular in the Bruce arrangement, the principles remain the same.

To assist in leakage control the structure has an internal lining comprising a plastic coating or paint system applied to the inner surfaces of the dome and wall. In addition, all service lines which pass through the cylinder wall, e.g. steam pipes, water pipes, ventilation ducts, electrical power and instrumentation lines, are designed to limit leakage through the wall at the location of these penetrations (Figure 7).

Of the penetrations, the largest are the personnel and equipment airlocks. The latter may have a shell diameter of up to 13 feet.

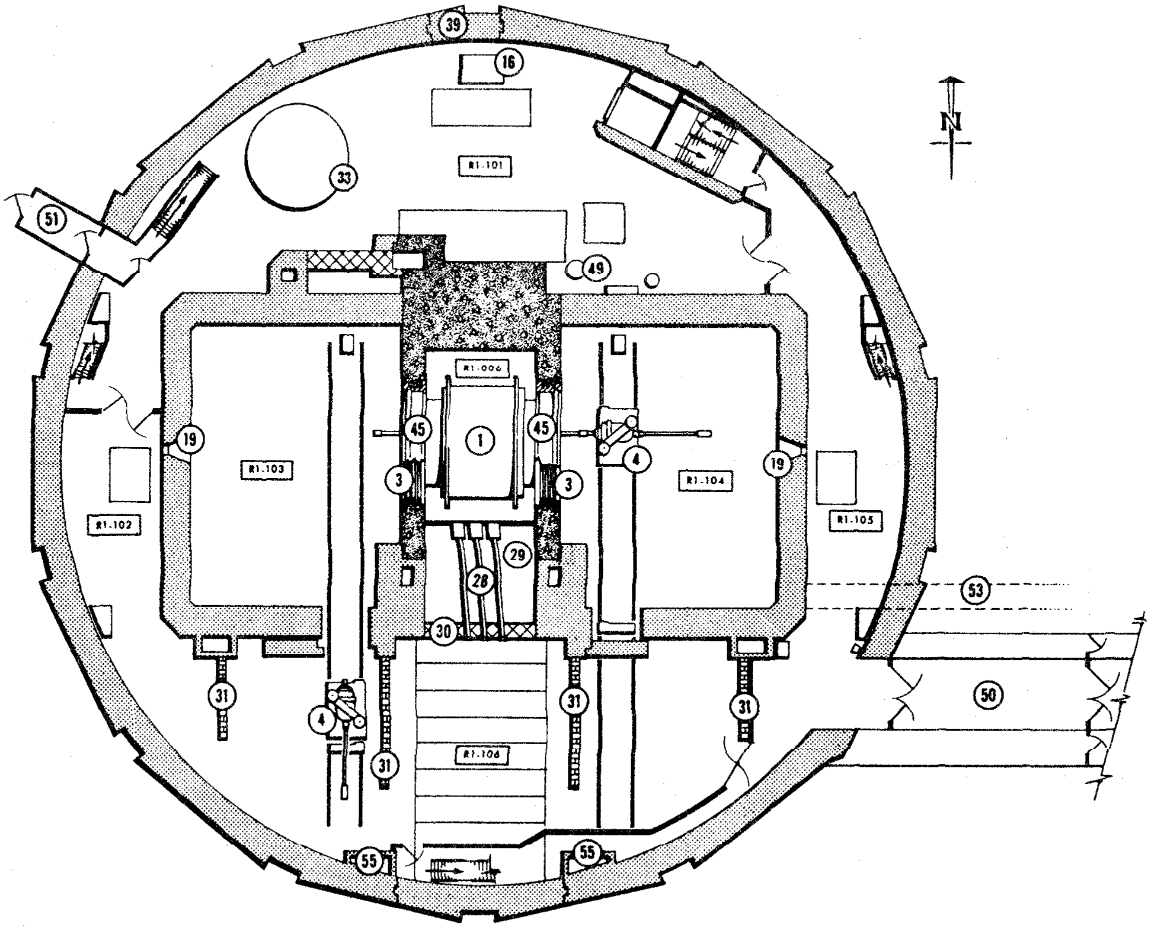
The containment structure is structurally separate from all internal structural systems. This provides flexibility in overall building construction including the ability to use slip forming techniques if desired. It also avoids structural inter-dependence between the containment wall and internal structures. The design minimizes the number of attachments to the wall, consequently reducing potential leakage sources.



16 AIR CONDITIONING UNITS
17 VAULT ACCESS AIR LOCKS
18 PRESSURE RELIEF CHAMBERS
19 RADIATION SHIELDING WINDOWS
20 THERMAL SHIELD COOLING DUCTS
21 CALANDRIA VAULT PRESSURE RELIEF
22 DOUSING SPRAY TANK
23 BLOWOUT PANELS
24 SPRAY TUBES
25 THERMAL SHIELD FAN UNIT
26 DECONTAMINATION TANK
27 NEW FUEL MAGAZINE
28 ION CHAMBER
29 SHIELD TANK
30 REMOVABLE SHIELDING

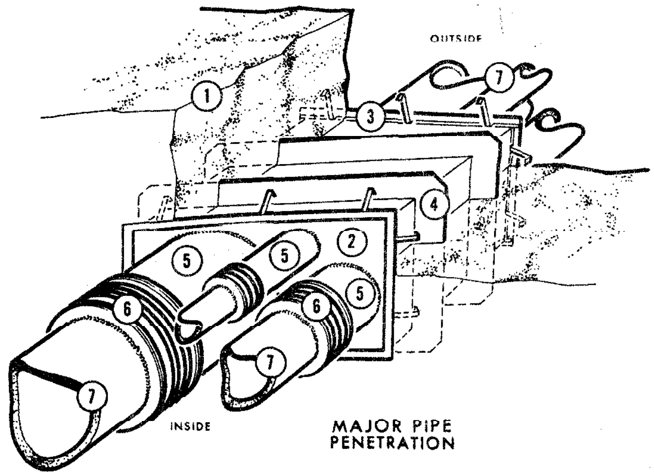
31 REMOVABLE BLOCK WALL
32 REMOVABLE SHIELD PLUGS
33 HELIUM STORAGE TANK
34 MODERATOR HEAT EXCHANGER
35 PRIMARY SYSTEM HELIUM GAS HOLDER
36 D_2O STORAGE TANK
37 BLEED COOLER
38 GLAND COOLER
39 WALL CLOSURES
40 PRESSURE WALLS
41 MODERATOR PUMPS
42 END SHIELD COOLING EQUIPMENT
43 PIPE AND CABLE BRIDGE
44 FUEL TRANSFER ROOM
45 END SHIELDS
58 CALANDRIA VAULT HATCH

Figure 5 Douglas Point G. S. Reactor Building - Elevation

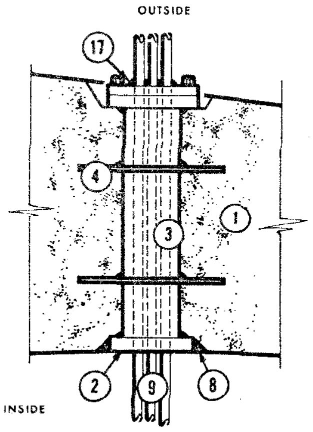


1	CALANDRIA
2	DUMP TANK
3	REACTOR END SHIELD RINGS
4	FUELLING MACHINE
5	PRIMARY CIRCUIT MAIN PUMPS
6	BOILER INSULATION CABINETS
8	STEAM DRUMS
9	ABSORBER ROD MECHANISMS
10	BOOSTER ROD MECHANISMS
11	PRIMARY FEED PUMPS
13	STEAM HEADERS
16	AIR CONDITIONING UNITS
19	RADIATION SHIELDING WINDOWS.
20	THERMAL SHIELD COOLING DUCTS
25	THERMAL SHIELD FAN UNITS
26	DECONTAMINATION TANK
28	ION CHAMBERS
29	SHIELD TANK
30	REMOVABLE SHIELD BLOCKS
31	REMOVABLE BLOCK WALLS

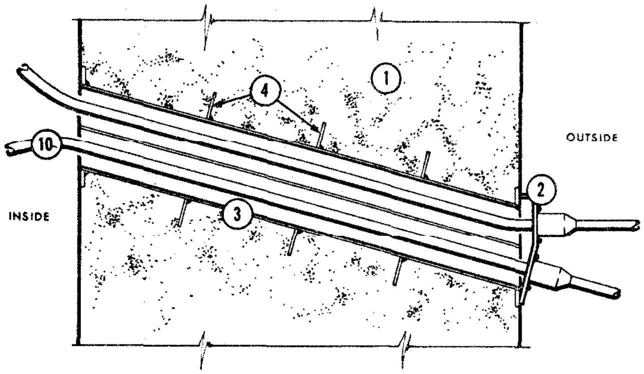
Figure 6 Douglas Point G. S. Reactor Building - Plan



MAJOR PIPE
PENETRATION



TYPICAL WATER PIPE
PENETRATION



ELECTRICAL CABLE
PENETRATION

1	WALL
2	SEALING PLATE
3	SEALING FRAME
4	ANCHOR PLATES
5	SEALING PLATE EXTENSIONS
6	SEALING BELLOWS
7	STEAM AND WATER LINES
8	THIOKOL CAULKING COMPOUND
9	WATER PIPES
10	CABLES

Figure 7 Reactor Building Penetrations

Design criteria for the containment structure include all operating and accident loads and situation-dependent loads, including dynamic earthquake analysis.

From the Pickering Reactor Building, as an example, the following points in the containment structure design may be of interest.

Foundation Slab - 5 feet thick concrete carrying all dead load, live load equipment and accident loads; carried on steel H-piles approximately 50 feet in length on minimum 4 feet centres embedded 6 inches into the slab and about 10 feet into very dense till on rock.

Perimeter Wall - 4 feet thick concrete with construction joints arranged to minimize cracking due to shrinkage provided with a one-third key against streaming of radiation and PVC waterstop type seals to make it leakproof. The bottom of the wall rests in a key on the base slab. Reinforcing does not pass through this point as there is no uplift force. The dome, where uplift does occur during accident conditions, is anchored into the wall by means of reinforcing. Stresses of 22,500 psi were permitted in the reinforcing steel for a test pressure of +7.5 psig + temp. diff. and for a test pressure of -8.5 psig + temp diff., while steel stresses of 24,000 were used for wind and earthquake conditions acting simultaneously with these loads.

The dome followed the same design considerations with a thickness varying on the basis of shielding requirements from 1 ft 6 in at the crown to 2 feet at the springline. The dome was designed as a thin shell taking account of the effect of restraint due to the perimeter wall. During construction, a 12 foot diameter opening was left to enable the formwork supporting trusses to be removed.

The penetrations through the containment structure are designed taking account of the structural loads, for leak tightness and to facilitate shielding against radiation.

The design of the containment structure and system must permit periodic retesting of the containment leak tightness. Initially the system is tested by a proof overpressure test followed by a leakage rate test which is used to demonstrate the soundness of the construction and to provide a basis for later routine tests.

Containment may be provided by the Reactor Building alone as at Douglas Point, Gentilly and RAPP. Different means of controlling the pressure and hence leakage may be employed, such as cooling sprays, filtered pressure let-down or high strength shell design. The negative pressure containment system as used for Pickering and Bruce can be economically comparable in the appropriate multi-unit plant arrangement for which the additional cost of the Vacuum Building and pressure relief duct can be justified.

To compare two examples of the single reactor building containment and one of the negative pressure type, where the reactor building must withstand a possible vacuum, the following table (Figure 8) shows some parameters and characteristics of interest.

Name	Reactor Power MW(e)	Design Pressure	Leakage Spec. at Design Pressure	Shell	Liner Type	No. of Penetrations	Building Volume	Dome
Douglas Point	203	6 psig	0.1%/hr	4 ft thick reinforced concrete	Vinyl epoxy	100	1.53×10^6 ft^3	Hemispherical steel $\frac{1}{2}$ in thick
Gentilly	250	17 psig	0.5%/24 hr	4 ft thick pre-stressed post-tensioned concrete	Vinyl epoxy	114	1.8×10^6 ft^3	Shallow spherical pre-stressed post-tensioned concrete 2 ft thick
Pickering	508	6 psig	1%/hr	4 ft thick reinforced concrete	Vinyl	300	2.4×10^6 ft^3	Elliptical concrete $1\frac{1}{2}$ to 2 ft thick

Figure 8 Reactor Building Containment Shell Comparisons

3.2.2 Reactor Building Internals

The details of the structure within the Reactor Building are governed first by the reactor arrangement, the reactor/boiler system requirements and the space for the fuelling machine operations.

We can use the Pickering Reactor Building to trace the influences which are taken into account:

(1) Horizontal calandria and pressure tubes with feeders connected to headers servicing the boilers and pumps overhead. This vertical arrangement ensures that the fuel remains flooded in case of a major system break and that thermal syphoning can come into effect if pumped circulation breaks down.

(2) Open space for reactivity mechanisms over the calandria with headroom for the removal of control rods. This and the boiler/pump arrangement leads to the structural steel support arrangement shown in Figures 9 and 10, together with the crane arrangement shown. The height of the building shell is largely governed by these dimensions and an allowance for the dousing tank spray header system where this applies.

(3) The fuelling machines must have clearance at each end of the reactor sufficient for ram travel. This end-to-end arrangement is one practical solution to the basic on-power refuelling feature of CANDU reactors. It is not fundamental, as the BLW-CANDU arrangement shows. Fuelling machine maintenance calls for a shielded space and the elevating bridge structure used at Pickering provides a closure for the fuelling machine service room when it is in the lower position. The vault and the service room are connected when in operation and the combined space is shielded so that access to the areas outside can be obtained. For Douglas Point, where the machines are withdrawn sideways through a shielded door for servicing, and for Pickering, the diameter of the building shell is set essentially by the fuelling machine vault dimensions and necessary clearance in the passageways immediately outside.

(4) The moderator system, pumps and heat exchangers with the associated purification equipment, etc., must be close to the calandria because, as in all D_2O systems, pipe lengths are kept to a minimum to limit the cost of D_2O held up in the system. It is convenient to set this system close in and low down on one side but outside the basic reactor/fuelling equipment block.

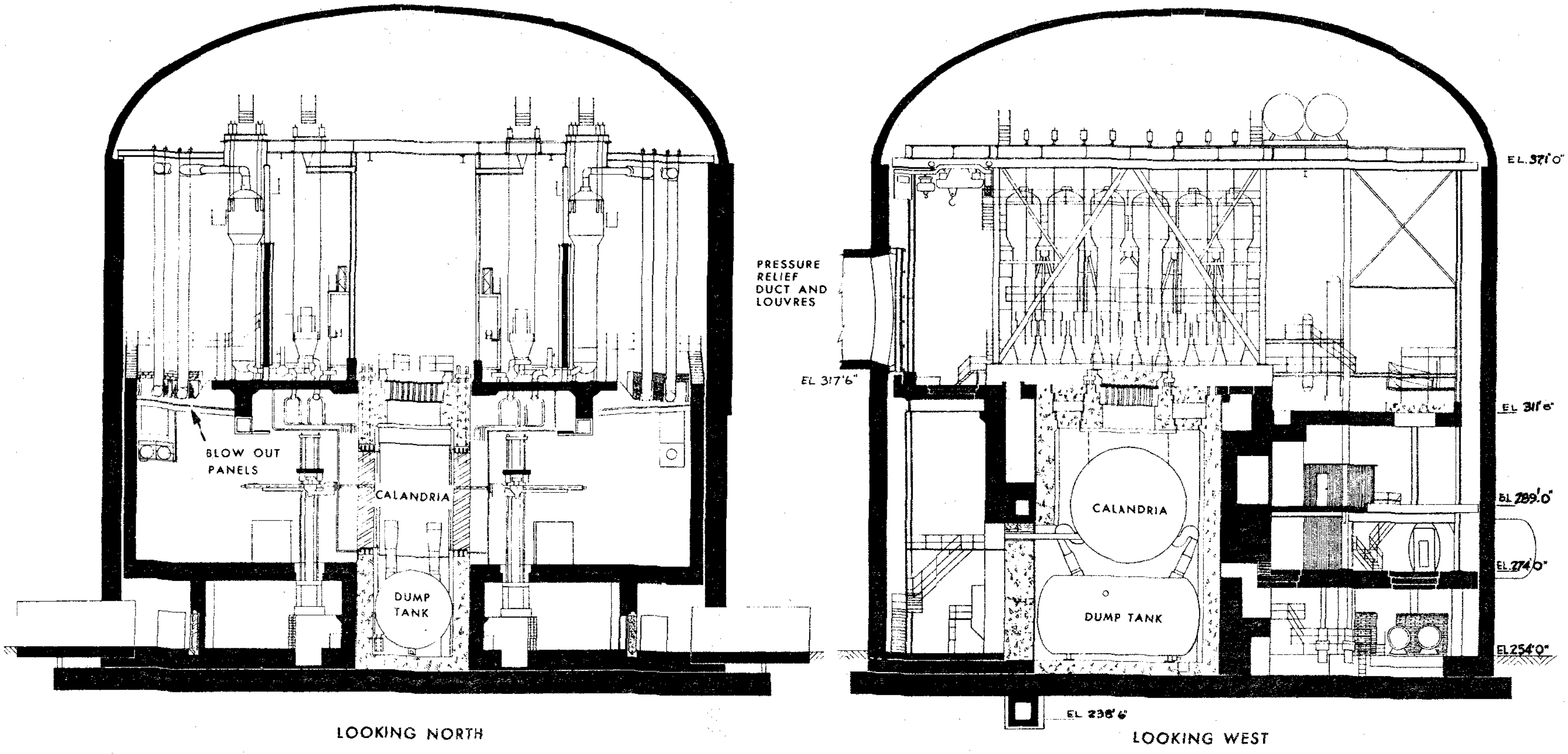


Figure 9 Pickering G.S. Reactor Building - Elevation

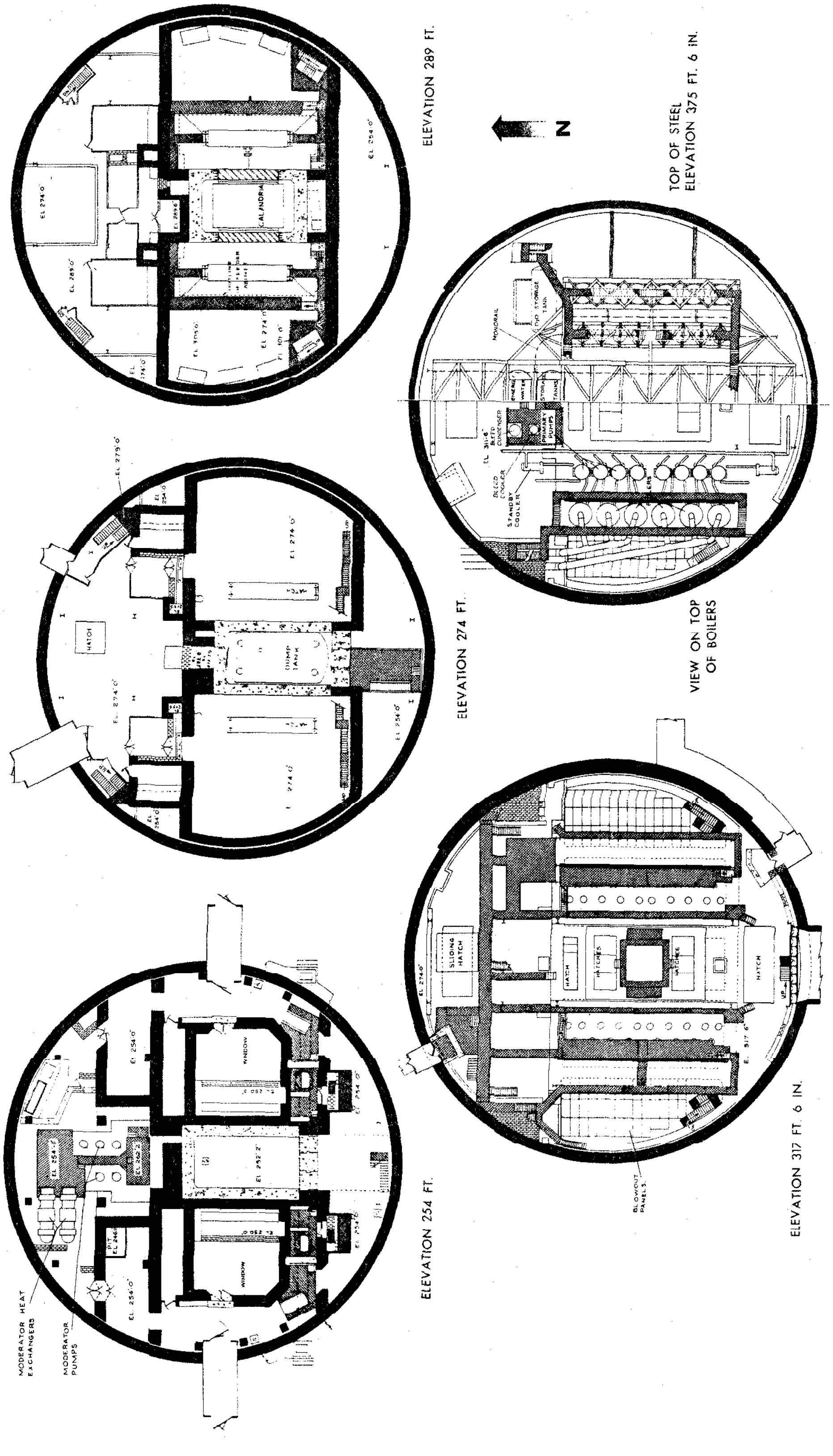


Figure 10 Pickering G.S. Reactor Building - Plan

(5) There is now a twin box structure evident in the layout requirements and this complex is designed to stand clear of the perimeter wall and to support the boiler/pump/header assembly by means of its own structure and the steelwork carried above. Figures 9 and 10. The complete complex structure of walls and boiler room floors is designed for all necessary loads including steam pipe anchorage. The boiler/pump/header system support system is designed to allow for movement due to thermal expansion of the system and its components and from load deflections, including those due to major accident and earthquake loads.

(6) The calandria, together with its end shields and the dump tank, is contained in and supported by an independent concrete vault structure set within the main internal concrete box frame, Figure 11. This inner vault is made of ilmenite or similar heavy aggregate concrete to provide shielding. It has a density of 220 lb/ft^3 compared with 150 lb/ft^3 for ordinary concrete so that wall thickness can be two-thirds of that otherwise required. The vault structure may be furnished with a system of water cooling pipes to limit the effects of radiation induced heating on the concrete.

The problems of installing these extremely large components will be dealt with in another lecture, but a few figures may be of interest here in considering the scale of the work.

From the figures in the table, Figure 12, and the dimensions of the building overall, it is evident that seismic considerations are very important in the whole plant design. AECL has made extensive studies of this problem and has been responsible for recommendations to the plant and building designers to ensure that the CANDU plants built have been in line with the latest international practices.

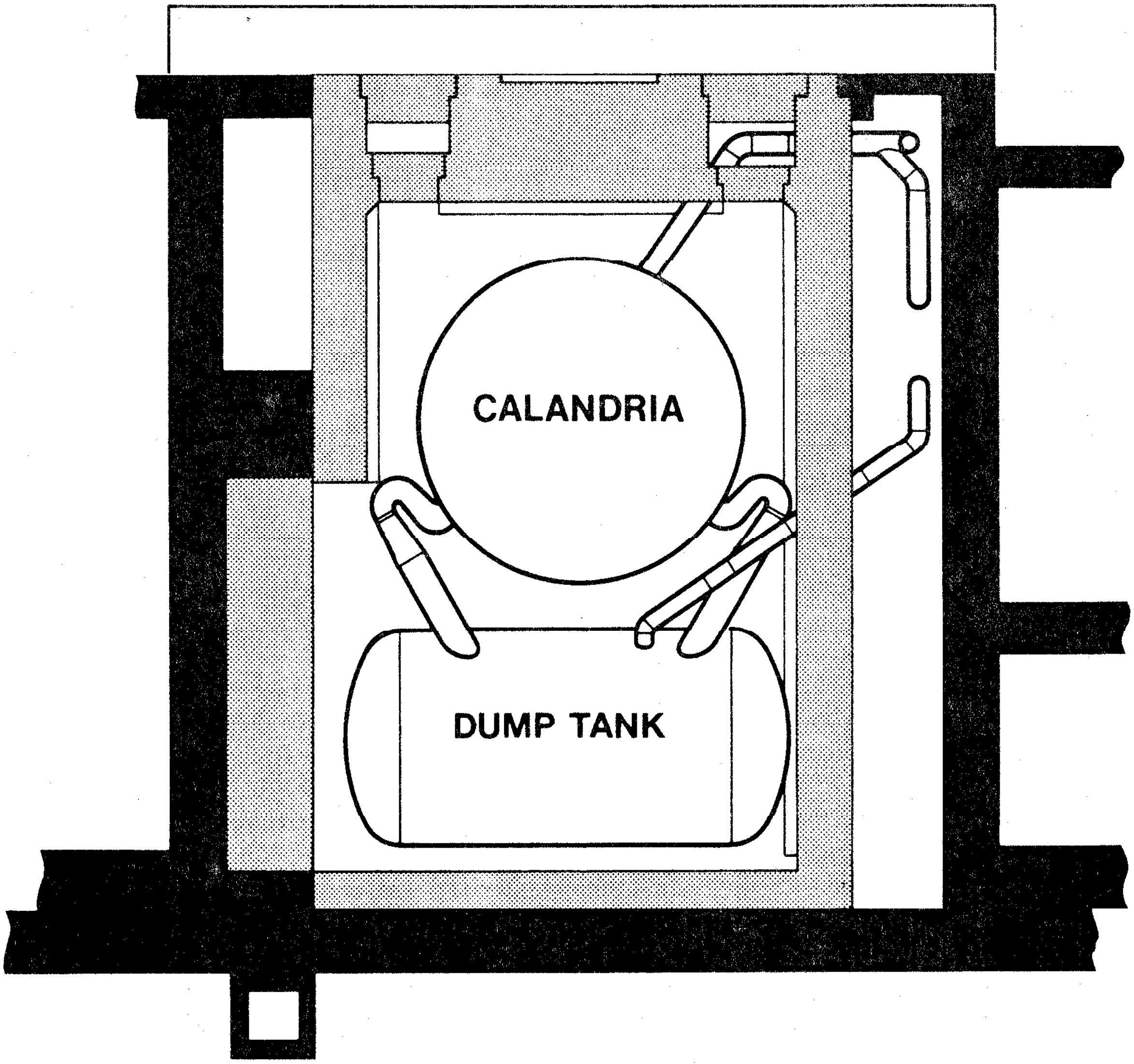


Figure 11 Pickering G.S. - Calandria Vault

	Length	Width	Height	Weight (tons)		Remarks
				Empty	Filled with D_2O	
DOUGLAS POINT						
Reactor Building	130 ft diameter		163 ft top of dome			4 ft thick wall
Calandria Vault	29 ft 9 in	18 ft 3 in	55 ft 4 in			
Temporary Wall Opening	-	24 ft	30 ft			
Calandria	16 ft 10 in	19 ft 10 in diameter		56	200	
Dump Tank	26 ft 2½ in	16 ft 8 in	10 ft 5 in	60	227	
End Shield	3 ft 8 in	16 ft-9½ in diameter		117		2 required
PICKERING						
Reactor Building	140 ft diameter		162 ft 9 in			4 ft thick wall
Calandria Vault	35 ft 2 in	19 ft 6 in	54 ft 10 in			
Temporary Wall Opening	-	24 ft	30 ft			
Calandria & Thermal Shields	19 ft 6 in	26 ft 6½ in diameter		174	466	
Dump Tank	36 ft 4 in	18 ft 3 in diameter		37.5		
End Shield	3 ft 9½ in	22 ft 9 in diameter		246		2 required
Boilers	8 ft 2 in diameter		46 ft 7 in	92.5	97.5	12 required
BRUCE						
Reactor Building	106 ft	92 ft	168 ft 4 in			6 ft thick walls
Shield Tank (i.e. Calandria Vault)	26 ft 6 in	49 ft	55 ft 6 in	607 shipped as a unit	2964 Including Shield tank extension Shielding Moderator	
Calandria	19 ft 6 in	28 ft diameter				
End Shield	3 ft 4 in	30 ft diameter				2 required
Boiler	8 ft 4 in diameter		43 ft 3 in	240 installed		8 required
Main Pump & Motor			35 ft	73 installed		

Figure 12 Major Building and Component Dimensions

Another important factor in the building design is the correct handling of building pressures in the event of a major accident. For the Pickering building, maximum accident breaks are postulated at a header in the vault or in the boiler room. Break-out panels are arranged as, for example, in the fuelling machine vault room roof, to limit local pressure buildup beyond the design pressures of internal walls and floors and to guide the flow of steam and air to the pressure relief panels in the boiler room wall. The roof panels in the unaffected vault blow inwards as an additional measure to equalize the pressure. Local pressures on the perimeter wall are limited by panels allowing blowdown for equalization below the boiler room floor into the accessible areas which surround the central vault block.

In the normal way these panels are closed to enable the atmosphere of the different areas to be isolated from each other. This enables air-borne contamination and high D_2O vapour atmospheres to be localized or confined.

Fuel handling has been described in other lectures. Here it is important to note the problems arising in connection with building layout and design involved in passing the very active and fragile spent fuel bundles safely out through the containment boundary and into a cooled storage system. If the connection must be open at least part of the time the hydrostatic balance in the storage bay and system must be able to counteract the rise in Reactor Building pressure in the event of a major accident. The entire handling equipment and transfer route must be adequately shielded from accessible areas.

3.2.3 Accessible Areas

All those systems and items of equipment to which access is routinely required for operation, servicing or maintenance are housed in rooms within the accessible area, i.e., rooms which are accessible during reactor operation. In the Pickering arrangement this is all the area outside the centre vault block and below the boiler room floor except for the moderator system space which is not accessible when the reactor is in operation.

3.2.4 Shutdown Area

Apart from the accessible areas, the remainder of the Reactor Building forms a "shutdown" area, containing the reactor and its vault, the heat transport and moderator systems, fuelling machine operating areas and areas for auxiliaries. The calandria vault is permanently inaccessible.

3.2.5 *Access into Reactor Building*

In different plant arrangements one or more equipment and personnel airlocks are provided for use during normal plant operation. The airlock equalizing valve and door operation is sequence-interlocked so that a breach of containment cannot occur. Each door and valve is operable from within the lock and from inside or outside the Reactor Building. The airlocks are generally push button operated, but could also be operated manually in an emergency situation. In some arrangements a simple airlock may also be provided for emergency exit only.

In the particular case of Pickering, entry into the Reactor Building is provided by six airlocks which are located and sized to enable major items of equipment to be removed for maintenance as well as to allow personnel access. Of the six airlocks, two give access to the boiler room, which cannot be entered for work during reactor operation. They can only be used for remote visual inspection at that time from the shielded cubicle inside the boiler room immediately in front of the door.

3.2.6 Maintenance Operations

Crane facilities, location of shielding walls and equipment installation and support details are designed to facilitate removal and servicing of equipment throughout the building.

The main crane of 30 tones capacity provides hook coverage over the central area of the boiler room in the Reactor Building. Monorail systems and lifting points are installed where necessary.

Throughout the building, shielding is provided either by the concrete wall and floor structure inherently or by the addition of concrete blocks, steel plate or lead as convenient and economic. Figure 10 shows an external addition to the perimeter wall of the boiler room. This non-structural feature is to ensure that radiation from the boiler room atmosphere after a major accident does not result in a dose rate which would prevent the plant control room being occupied.

3.2.7 Light and Heavy Water Separation

Downgrading of the heavy water by ordinary light water vapour is reduced to a minimum by designing any light water equipment which must be located in the heavy water area to have a leak-tightness similar to that of the heavy water equipment.

Where it is essential to locate process water system valves close to equipment in the boiler or vault area, only low leakage type connections are used. In addition, where necessary, potential light water leakage sources are located within local sealed light water containment enclosures.

The boiler system and feedwater systems have numerous connections to the steam generator in the boiler area. All such connections are welded and flow regulating valves, whenever possible, are located outside the boiler area.

The atmosphere within the accessible area will normally contain light water vapour and the pressure will be slightly higher than that in the boiler area, so that air infiltration will be from the accessible area into the boiler area.

To minimize the quantity of light water infiltration into the vault and boiler area heavy water atmospheres, all piping, electrical, ventilation and instrumentation penetrations are sealed. Similarly, hatches, shielding and other doors are sealed.

In later plant designs, areas of possible high concentrations of D_2O vapour contamination which may be outside containment are being defined as "confinement" areas and required to have very high atmospheric integrity.

3.2.8 Gentilly

Turning briefly to the Gentilly Reactor Building internals as a different example of how the requirement may be met, the vertical calandria pressure tube arrangement with fuelling carried out from below only leads to several important differences. Fuelling machine maintenance still requires a shielded space, which is shown, but the building diameter is 120 feet compared to 140 feet at Pickering.

Because the boiling process occurs in the reactor and steam separators only are required, the coolant system is simpler. However, the steam now contains some activity as it goes from the reactor to the turbine and the latter must be shielded together with the steam pipes. Neither may be approached during operation.

The same problems of earthquake design, spent fuel discharge, local shielding, accessible areas, perimeter wall penetration and access arise in this building as at Pickering.

3.3 Service Building

Outside the Reactor Building the Service Building has a number of very important functions. It normally houses decontamination facilities, active and inactive maintenance shops, stores, showers and change rooms, laboratories, and it may contain spent fuel handling and storage facilities as well as active waste management systems and equipment.

For example, using the Douglas Point case, the building is laid out to facilitate the movement of personnel and material and limit the risk of the spread of contamination. It should be noted that this building was intended to serve two reactor buildings, one at each side. Experience since this building was brought into service has shown that very much larger areas for the servicing of major components are a very good investment, and in the Pickering Service Building, which does not contain spent fuel facilities, the dimensions are much larger.

The service space requirements do not, of course, increase with the number of units, as service maintenance peaks are normally spread over the year.

3.4 Spent Fuel Storage

The spent fuel storage bay is a large enough element of the plant facilities that it is worth specific mention.

The storage bay is essentially a safe, long term, underwater storage for spent fuel. It may be large enough to hold all fuel discharged during the life of the plant as at Douglas Point or, as in later plants, with enough space to allow the fuel to be held only until its activity and heat generation has decayed to a safe level for shipping elsewhere. The bay provides water to give a clear depth of 13 feet approximately above the highest stored fuel bundle. The demineralized water used is cooled to remove decay heat and purified to limit the contamination in it which may arise from possible leaks in fuel.

There are three areas in the bay with distinct functions:

(1) The receiving and inspection area with facilities for canning damaged bundles.

(2) The storage area.

(3) The shipping and flask handling area.

The wall and floor surface must be bright and reflective as well as durable. As complete and permanent leak tightness cannot be assured an external drainage collection system must be provided.

It has become evident that a free standing bay where the structure can be inspected over the whole outer surface is probably the most satisfactory. Some controversy exists regarding the overall economics of bay structure and liners. Both fibreglass reinforced epoxy and stainless steel sheets have been used for liners up to the present.

3.5 Other Structures

The other structures on the site, in addition to administration offices, etc., can be accounted for briefly.

The normal power plant facilities of water treatment building, pumphouse, transformer enclosures, standby power supplies, etc., are of course necessary. In some cases, as for standby power, the requirement is more stringent for a nuclear plant and therefore the equipment is more extensive. For example at Pickering there are six gas turbines of 5 MWe each.

It is generally convenient and economical to have a D_2O upgrading plant on the site.

With negative pressure containment the Vacuum Building is a significant feature, together with the connecting ductwork, unless, as at Bruce, this is buried below grade. There is not enough time in this lecture to review the structural design and arrangement of the negative pressure containment system. Its functioning is discussed in the lecture on Accident Analysis.

The problems arising with more than one unit have been touched upon previously. There are undoubtedly economics in the combining of service facilities and the effective employment of staff, but the system considerations of unit size, etc., are outside the scope of this lecture.

4. RADIATION EXPOSURE MANAGEMENT

4.1 General Approach

In the first part of this lecture there have been a number of references to building features concerned with safety, both of the public and plant personnel. As to safety from radiation exposure in particular, Lecture No. 2 discussed the general topic of radiation, the terminology used, its measurement and the biological aspects to be considered.

The purpose of the remainder of this lecture is to bring together those aspects of the plant design and operation which provide routine radiation protection for the public and the plant staff during day-to-day operation.

Major accidents are dealt with in the forthcoming lecture on Accident Analysis.

Exposure of the surrounding population is limited by exclusion from the plant area and by preventing, in accordance with AECB requirements, any habitation nearer than 3000 feet. The release of all effluents, liquid and gaseous, which might conceivably carry significant activity is monitored and controlled. Active solids are disposed of in a form which prevents release of activity. Thus, any activity which may reach the public through the air or in water can be maintained below permissible concentration levels.

Exposure of plant personnel to radiation hazards is limited by shielding and by control of access to areas of high activity or of possible contamination. In addition, protective clothing, air masks and decontamination facilities are available for use when required.

The considerations involved in routine radiation protection may be divided under two basic headings:

(1) Those aspects relating to protection from direct radiation, i.e., layout, shielding, area radiation monitoring, access routes and access control.

(2) Those aspects relating to active contamination in all forms: waste management, zoning, ventilation, decontamination, protective clothing.

The principles underlying the approach of the designers in providing radiation protection for a nuclear facility of any kind are:

(1) Segregation or isolation of sources and of radiation as much as possible.

(2) Shielding by distance and by use of dense materials.

(3) Control of exposure time and use of activity decay.

(4) Removal of contamination and dispersal or remote storage of the resulting active waste products.

(5) Supply of clothing and clean air for workers.

Standards of exposure dosages are based on those published by the International Commission on Radiation Protection (ICRP) and adopted by the AECB, and are used together with any additional provisions set up by the plant owner. The objective of the designers is to provide a plant such that workers using normal procedures will not receive a total exposure in excess of the allowable values (Figure 13).

The designer also must assume that the facility will be run to a set of operating rules and procedures. The basic document here would be similar to:

Hydro-Quebec - Directives de Sante et Normes de Radioprotection pour les Travailleurs de l'Energie Nucleaire

Ontario Hydro - Radiation Protection Regulations

This is discussed in more detail later in the section on Health Physics.

ORGAN	ANNUAL DOSE LIMITS
Whole-Body, Gonads, Red Bone Marrow	0.5 rem
Skin, Bone, Thyroid	3 rem (1.5 rem to thyroid of children up to 16 years)
Other Single Organs	1.5 rem
Extremities	7.5 rem

Figure 13 Basic Recommended Exposure Limits for Members of the Public

(Equal to one-tenth of Radiation Worker Dose Limits)

4.2 Layout

Within the normal economic limitations and any special requirement such as of minimum heavy water hold-up, the general plan of a reactor building is determined by the layout necessary for the systems and equipment as has been described in the first part of this lecture.

The interior of the building is then logically divided into three main areas according to the radiation fields which are expected (see Figure 14).

(1) "Accessible Areas" which may be entered at any time and where the radioactive field is in the range of 1 to 10 mR/hr. These are typically at grade level and on the two floors above, but outside the vaults.

(2) "Shutdown Areas" which may only be entered when the reactor is shut down and where the field during operation would be generally prohibitive. These are typically fuelling machine vaults, moderator equipment rooms and the boiler room floor and above.

(3) "Permanently Closed Areas", specifically the calandria vault.

4.3 Shielding

A general set of allowable radiation levels based on the regulations and adjusted for occupancy is adopted for areas throughout the plant. In the case of Douglas Point, as an example, the shielding was designed to give the area radiation levels shown in the following table and Figure 15.

Region	Design Radiation Level
Administration Building	0.25 mr/hr (=0.5 r/yr)
Turbine Building	0.25 mr/hr
Control Room	0.25 mr/hr
Service Building	0.25 mr/hr
South Accessible Area in Reactor Building	1.0 mr/hr
North Accessible Area in Reactor Building	5.0 mr/hr
Fuelling Machine Vaults (Reactor Shutdown)	50 mr/hr
Steam Generator Area (Reactor Shutdown)	50 mr/hr

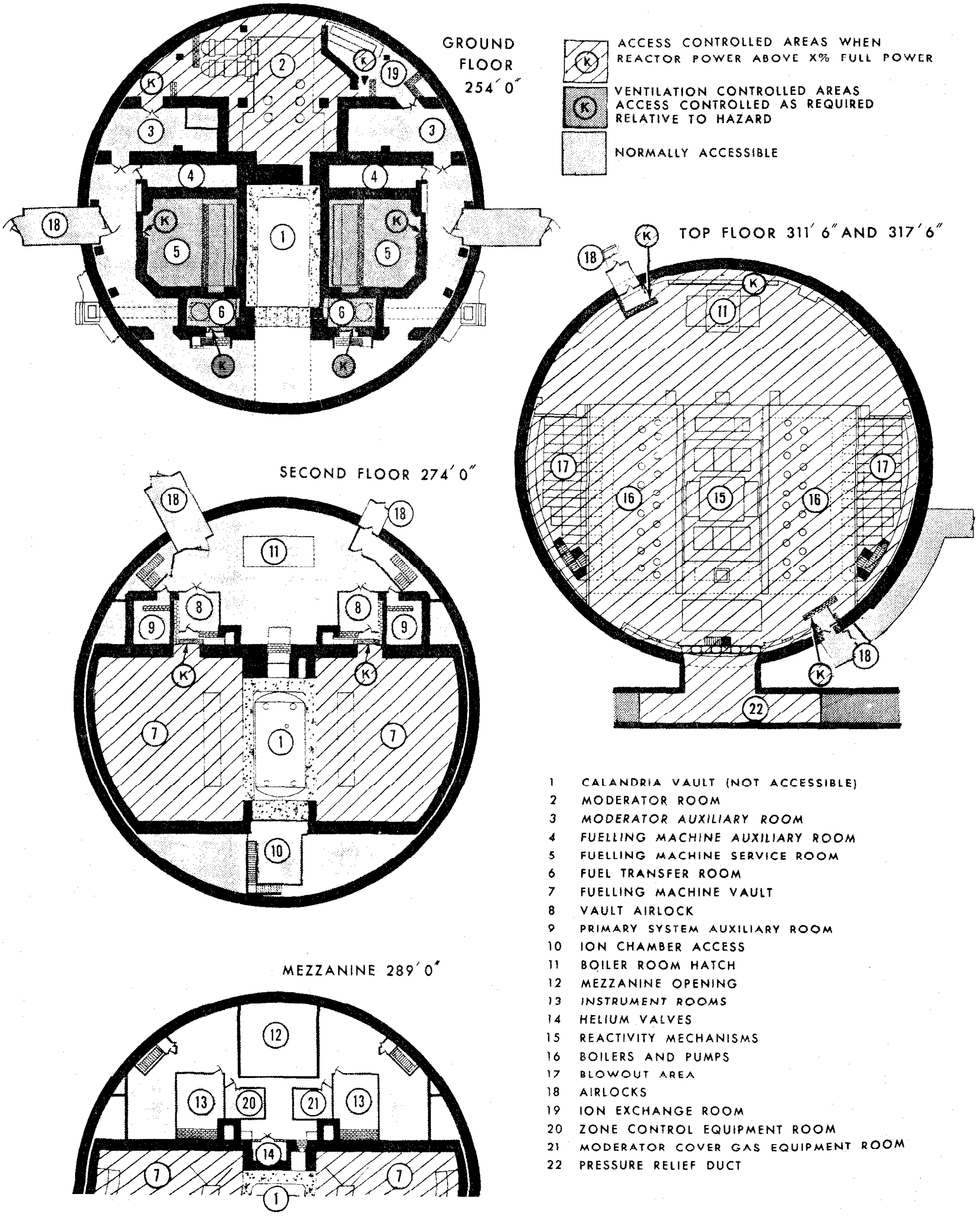
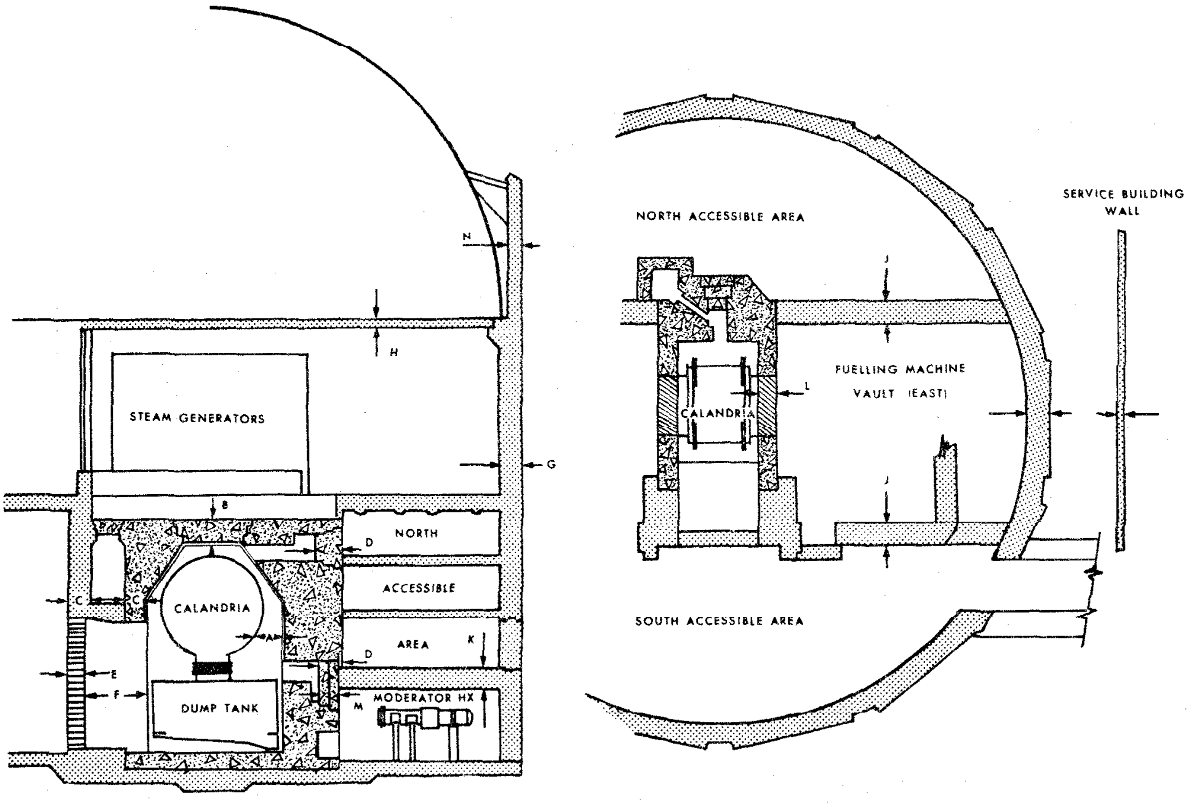


Figure 14 Pickering G.S. - Reactor Building
Access Control Diagram



SECTION	NAME	MATERIAL	THICKNESS
A	THERMAL SHIELD	STEEL	4¼in
B	TOP SHIELD	ILMENITE CONCRETE	4ft 6in
C	SIDE SHIELD	ILMENITE CONCRETE AND ORDINARY CONCRETE	4ft 6in 4ft 6in
D	SIDE SHIELD PLUG	ILMENITE CONCRETE	6ft 6in
E	SIDE SHIELD	ILMENITE CONCRETE	2ft 8in
F	SIDE SHIELD	STEEL TANK FILLED WITH WATER	13ft 6in
G	PRIMARY COOLANT SHIELD	ORDINARY CONCRETE	4ft
H	PRIMARY COOLANT SHIELD	ORDINARY CONCRETE	1ft 6in
I	PRIMARY COOLANT SHIELD	ORDINARY CONCRETE	5ft 4in
J	PRIMARY COOLANT SHIELD	ORDINARY CONCRETE	4ft 6in
K	MODERATOR EQUIPMENT SHIELD	ORDINARY CONCRETE	4ft
L	END SHIELD	STEEL AND WATER	3ft 8in
M	SIDE SHIELD PLUG	ILMENITE CONCRETE	4ft6in
N	PARAPET WALL	ORDINARY CONCRETE	2ft

Figure 15 Shielding

In some areas structural concrete provides shielding against radiation. The minimum requirement in such cases was the thickness of concrete needed for shielding, which generally was greater than the structural requirements.

The Reactor Building outer wall at Douglas Point is nominally four feet thick normal concrete. This thickness is required for shielding areas outside the building from radiation originating in the boiler room area and the fuelling machine vaults; elsewhere (about half the wall surface) the thickness is much more than adequate for shielding. The wall was made a uniform circumferential thickness for structural reasons.

The upper part of the outer wall (parapet wall) is two feet thick normal concrete, and is designed to attenuate radiation from the dome out to the station area.

The internal shielding was designed to produce an acceptable radiation level in the accessible areas during reactor operation. Shielding is provided by the wall around the reactor vault and by the floor at elevation 590 feet above the basement.

The boiler room floor at elevation 627, above the north and south accessible areas provides shielding from the boiler room.

The north stairwell/elevator shaft is shielded above and below the north accessible areas, and the south stairwell is shielded above the south accessible area, in order to restrict radiation scatter through the stairwells into these areas.

The internal shielding also reduces the radiation to the dome. Floor elevation 665 and the boiler room south cross wall provide some shielding around the boilers and reduce the field at the dome and hence outward scatter from it. It was not considered necessary, however, to achieve accessible area radiation levels immediately outside the dome.

Shielding of the calandria is also provided to allow access to the fuelling machine vaults when the reactor is shut down. The east and west walls of the calandria vault and the end shields were designed for this purpose.

To meet shielding requirements the floor thickness in the Reactor Building ranges from 1 ft 6 in in the boiler room roof to 4 feet over the moderator room, while internal walls reach 4 ft 6 in around the reactor vault.

Hatches through shielding floors are, in general, of the same total thickness as the floor. Exceptions are the two hatchways in the four foot thick floor of the moderator servicing area at elevation 590 which are three feet thick. This thickness was considered adequate in view of their geometrical relationship to the radiation sources in the moderator room and material handling problems were eased by making them this thickness.

Removable heavy concrete shield blocks have been provided at a number of positions in the shielding complex north of the north cross wall on the west side of the building, and north of the upper and lower removable shield plugs in the calandria vault.

Local surveys during commissioning and early operation are carried out to define areas where radiation from process system components is higher than originally calculated. As a result additional shielding, i.e., concrete or lead block walls, may be added as necessary.

4.4 Area Monitoring

In areas where radiation fields may increase in the Reactor Building, the active parts of the Service Building, the control room or the plant general area, monitors are placed at various locations.

Each monitor would typically have two alarm levels. The lower level is adjustable and is set just above ambient, far enough to warn of a significant change without acting on minor variations. The upper alarm is set at the maximum allowable level of exposure for the period of time required for evacuation of the area (for the area when workers are present). The two levels of alarm have separate annunciator windows in the control room and they each actuate an intermittent buzzer and flashing light signal. The lower alarm level has a slow rate and the higher level a faster rate. The alarms from monitors in "shutdown" areas of the Reactor Building are cut out when the reactor is operating and the access routes are locked as described in the next section.

Portable and survey monitors are provided for use in places where the fixed monitors are not sufficient for the work in hand.

There is an activity monitor with recording and alarm facilities kept in the control centre as a check on background levels or after-accident levels in this area. The alarm on this instrument operates at 10 mr/hr.

Evacuation from any area of the plant can be called for by the operator in the control centre using the public address network.

4.5 Access Control and Routing (Figure 14)

Radiation fields in the accessible areas of the Reactor Building will normally be such that entry to them can be permitted at all times. Taking Douglas Point as an example, within the Reactor Building, locks have been installed on the elevator controls and the gates or doors which lead to the "shutdown" areas. These cannot be opened without keys which must be brought from the control room.

The keys required cannot be removed from the control room panel without actuating the reactor setback circuit, so that no one can enter the "shutdown" area unless the reactor neutron flux is below 0.1% of full power flux.

The Access Control Interlock system, which incorporates these keys, is designed to ensure also that the reactor neutron flux cannot rise above 0.1 percent of full power flux whenever anyone is in the shutdown area. The keys can only be removed when the exit route is closed and locked.

When any of the access control interlock doors or gates are opened by use of a key brought from the control room, personal padlocks or tags are used to hold the route open until the persons concerned have come out again. The condition of any access control doors or gates and the elevator positions are shown on a panel in the control room. It is possible to escape from shutdown areas, even when the barriers are closed, by climbing over any access control gate or by use of an emergency handle provided on access control doors. At Pickering and Bruce the fuelling machines can give rise to changes in local fields and their movements are incorporated into the Access Control System.

The travel routes through the building are reviewed at various stages of design to ensure ease of movement and safety for the users whether going about normal tasks or escaping from any hazards. The walkways, ladders and stairways conform to normal good practice and the requirements of the appropriate codes and competent authorities.

Doors open towards the escape direction so that minimum exposure times during escape travel can be expected. In the Douglas Point layout the Reactor Building stairways provide refuge from hazards occurring in a particular area and provide closed routes to the airlocks.

Waiting lobbies are provided at the airlock entrances in the Reactor Building. They are provided with emergency showers and telephones. The lobbies were provided for use during escape following a major accident when delay might occur due to traffic at the airlocks.

They can also be useful as local contamination control stations. For Pickering the additional airlocks fitted led to the elimination of long vertical escape routes within the Reactor Building.

In areas where access should be limited but observations are needed, facilities for television viewing are fitted. The fuelling machine vaults at Douglas Point have shielded windows from the accessible areas on each side. The windows provide shielding equivalent to the concrete wall enclosing them. In other plants periscopes have also been fitted where convenient.

4.6 Contamination Control - Zoning (Figure 16)

A plant is generally divided into three zones according to the potential contamination in each area. The zones are defined as follows:

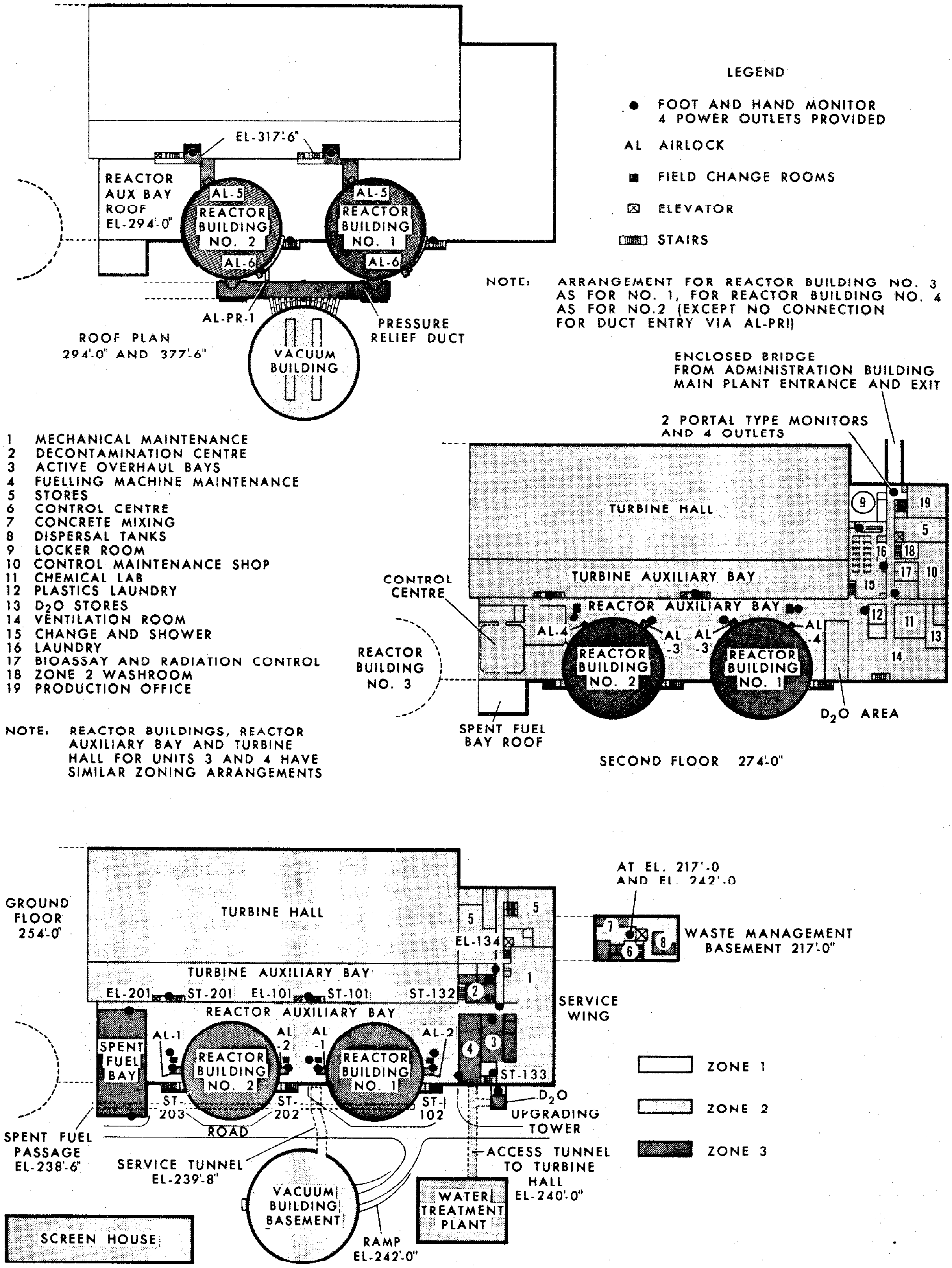
Zone 1 - This zone contains no radioactive equipment and is normally free of contamination.

Zone 2 - This zone contains a minimum of radioactive equipment and normally should not be contaminated. However, some contamination will probably get into this area with the movement of personnel, equipment and/or tools. Contamination will be cleaned up as soon as discovered, or suitably controlled.

Zone 3 - This zone contains the main sources of contamination. It includes the Reactor Buildings, the decontamination centres, the active shops, D_2O handling areas, new fuel handling areas, the spent fuel bay, laundry facilities, the waste management areas. The sources of contamination will be localized and under control in this zone but the existence of contamination in parts of it will be normal.

Normal entry to, and exit from, the station is via the Zone 1 administration area or the locker room area.

Within Zones 2 and 3, airborne contamination is dealt with by adjustment of ventilation flows, and by use of local exhaust connections. These may be accompanied by temporary local isolation "tents" made



LEGEND

- ● FOOT AND HAND MONITOR 4 POWER OUTLETS PROVIDED
- AL AIRLOCK
- ■ FIELD CHANGE ROOMS
- ☒ ELEVATOR
- ▥ STAIRS

NOTE: ARRANGEMENT FOR REACTOR BUILDING NO. 3 AS FOR NO. 1, FOR REACTOR BUILDING NO. 4 AS FOR NO. 2 (EXCEPT NO CONNECTION FOR DUCT ENTRY VIA AL-PR1)

1 MECHANICAL MAINTENANCE
2 DECONTAMINATION CENTRE
3 ACTIVE OVERHAUL BAYS
4 FUELLING MACHINE MAINTENANCE
5 STORES
6 CONTROL CENTRE
7 CONCRETE MIXING
8 DISPERSAL TANKS
9 LOCKER ROOM
10 CONTROL MAINTENANCE SHOP
11 CHEMICAL LAB
12 PLASTICS LAUNDRY
13 D_2O STORES
14 VENTILATION ROOM
15 CHANGE AND SHOWER
16 LAUNDRY
17 BIOASSAY AND RADIATION CONTROL
18 ZONE 2 WASHROOM
19 PRODUCTION OFFICE

NOTE: REACTOR BUILDINGS, REACTOR AUXILIARY BAY AND TURBINE HALL FOR UNITS 3 AND 4 HAVE SIMILAR ZONING ARRANGEMENTS

- ☐ ZONE 1
- ▨ ZONE 2
- ■ ZONE 3

Figure 16 Pickering G.S. - Plant Zoning Arrangement of plastic sheet if necessary. Ventilation arrangements are designed so that any transfer of atmosphere between different areas due to pressure difference will go from the potentially less to the potentially more contaminated area.

Physical barriers, e.g. railings, are used, as well as procedural controls, to direct the movement of contaminated material or persons from contaminated to clean zones.

To assist in control, contamination monitors (friskers) and hand and foot monitors are provided at each interzone transit point. In addition, rubber stations to limit the spread of floor contamination and protective clothing change facilities are also provided where required.

4.7 Protective Clothing

The protective clothing arrangements involve the provision of a breathing air system, air masks and full plastic suits for access to areas where tritium or other airborne contamination or toxic atmosphere are expected. The air system is designed to be highly reliable and safe in use. The mask and suit patterns used vary according to the degree of contamination, the work location, the need for communications, and the economics of decontamination.

The wearing of suits reduces the need for atmosphere purge in an area prior to entry. It does not, of course, provide protection against airborne gamma radiation as for example from Argon-41. Purging to eliminate the radiation hazard from Argon-41 would only be necessary if it was not possible to wait for it to decay sufficiently. Such purging may cause substantial heavy water losses.

In full suits with cooling, men can work in comfort and therefore faster and so limit exposure to direct radiation. They can avoid, or greatly reduce, absorption of atmospheric contaminants, particularly tritium, and they can avoid contact with contaminated surfaces. A suit may be air cooled and have a built-in telephone system if necessary.

Workers in conditions where the radiation field is high must be kept in view if possible, and although exposure of others must be limited the access arrangements allow a back-up or "buddy" system and the communications arrangements allow constant contact to be maintained.

4.8 Decontamination

Decontamination is carried out to reduce hazards due to activity in the form of loose dust or surface contamination on equipment to be maintained or, where necessary, to facilitate access or the handling of components. Decontamination is therefore an essential part of maintenance work in a nuclear power plant.

Facilities for the removal of contamination are provided and consist of arrangements for:

(i) the handling of large or highly contaminated equipment in situ and the removal of contamination from the equipment or from building structures;

(ii) the handling and decontamination of equipment and supplies generally at a central location;

(iii) routine decontamination of plant clothing; and

(iv) personnel decontamination.

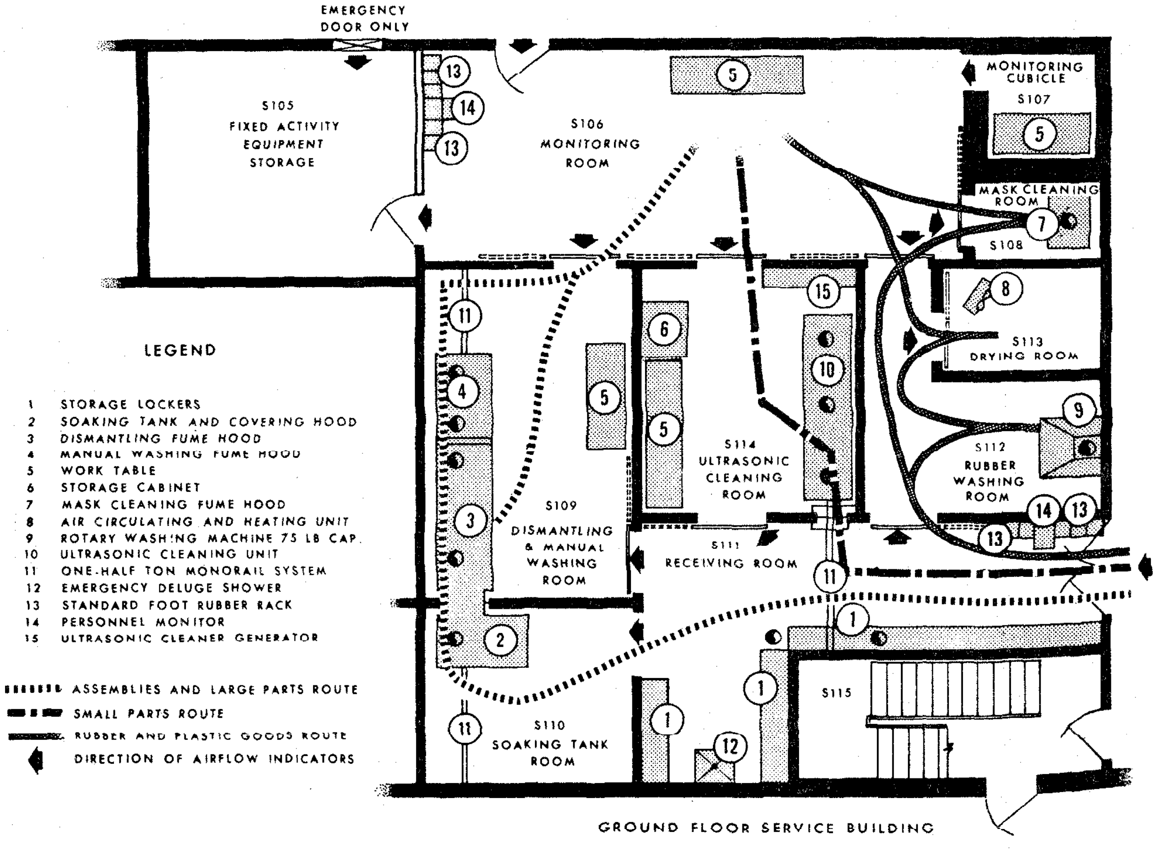


Figure 17 Decontamination Centre

4.8.1 Decontamination Centre (Figure 17)

The decontamination centre, which is in the Service Building, provides facilities such as chemical treatment, steam cleaning and ultrasonic equipment for decontaminating disassembled equipment parts and tools of all types and sizes, including rubber and plastic goods. Both the space provided and the equipment capacities must be adequate to handle the work load for a scheduled reactor shutdown combined with major scheduled maintenance jobs.

The arrangement of rooms, the equipment and the ventilating air system in the decontamination centre are intended to prevent recontamination or the accidental transfer of contamination outside the area. This requires that all material to be cleaned moves in one direction.

4.8.2 Clothing and Personnel Decontamination (Figure 18)

The facilities provided to clean plant clothing and to avoid contamination of street clothing consist of change rooms, showers and locker rooms, and a cotton goods laundry and clothing crib.

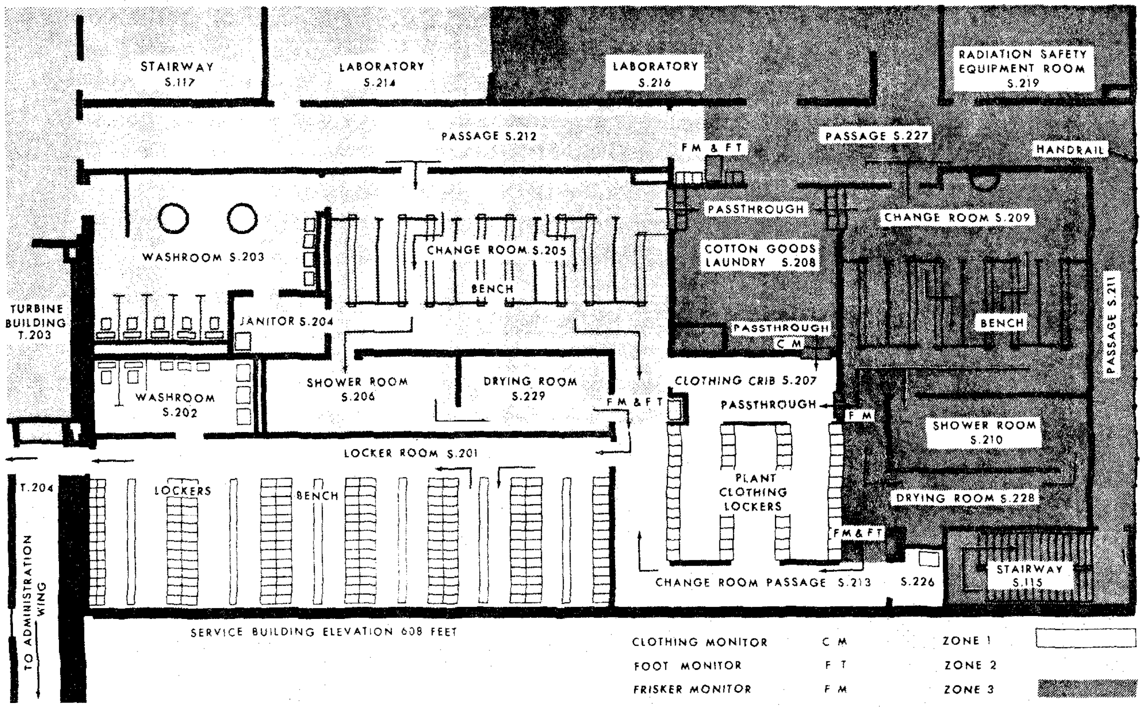


Figure 18 Change Rooms and Cotton Goods Laundry

Emergency personnel deluge showers are installed as necessary in the plant. They have a high rate of water flow and are designed for fast removal of major contamination on clothing or in direct contact with the skin.

4.9 Ventilation

An essential requirement of the ventilating air flow is the correct organization of interzone flow. In general, air is introduced at locations of low radioactivity level or where personnel may be located, and is exhausted from areas of higher radioactivity which are normally inaccessible.

Considerable local recirculation exists within certain rooms or areas in the building due to the action of fans in heaters and coolers. Flow between zones goes through open passages, doors and some ducted connections. In most places, it results from pressure differentials maintained in the various zones by adjusting dampers in the ventilating system, but in some locations the flow is assisted by local fans.

Local ventilating exhaust connections are provided in a number of areas, accessible during shutdown, where it is felt that contamination or sources of radioactivity might exist at some time during the station life. These connections are normally closed, but are designed to permit the area to be exhausted at more than the normal rate. Flexible hoses may be attached to assist in localizing the contamination if desired.

5. EXPOSURE CONTROL PROGRAM

The measures described for the protection of the individual worker are reviewed during the design phase of a project in the Radiation Exposure Control Program which was referred to briefly in Lecture No. 6. This program is used to provide an early indication of those systems or components which require specific attention to limit their radiation effects during operation.

The program was introduced when it became apparent that the use of local field targets and local contamination limits during the design phase were not sufficiently detailed to ensure satisfactory control of operational radiation exposure at the plant. This control is particularly important because of the extra staff costs which may be incurred if individual exposure dose limits are not to be exceeded.

The program consists of four parts:

(a) Prediction

The Prediction stage is closely associated with the initial plant layout work and consists of preliminary estimates of operating plant exposure.

(b) Total Station Dose

The function of the total station dose is to provide a series of exposure targets for systems and components. The term "Budget" is used to describe the dose allocation process and documentation. Because average individual doses and station complement figures may change, the Budget is initially apportioned on a percentage basis. The target value of man-rem (Total Budget Dose) is determined by the size of the proposed station staff and the average annual radiation dose to an individual. The unit of man-rem is employed throughout the program and represents the exposure of one man in a field of 1 R/hr for 1 hour.

(c) Estimate Review

The Estimate Review stage consists of a series of meetings taking system by system with the designers to establish the probable exposure required at maturity for the servicing of all significant items. Remedial action where required is agreed to if possible at the meeting. For convenience this phase of the Program has come to be referred to as "Audit".

(d) Follow Up

The Follow-Up phase, which may include meetings to revise dose estimates or to take note of design changes, may continue on into the commissioning stage of the plant. During this phase feedback to designers takes place and detailed procedures can be developed to give the necessary exposure reduction.

5.1 Program Ground Rules

To help both in budget preparation and in maintaining consistency between the budget and the subsequent review audits, certain guidelines and ground rules have been established.

(1) Only the dose received by operators and maintainers is considered.

(2) Plant maturity conditions are assumed to exist.

(3) Events other than those scheduled or occurring during the normal running of the station are not considered.

(4) Allocation is a yearly average. Consequently it is assumed that because some tasks are performed less frequently than once per year, some exchange of dose between systems over the years will occur if maximum utilization of available man-rem is to be achieved.

(5) The dose assigned to any system includes all duties, both mechanical and control, associated with that system, such as inspection, adjustment, removal, overhaul, refitting, search and survey, decontamination and cleanup.

(6) Maintenance work is considered to include servicing, maintenance, overhaul and inspection functions.

(7) Operations include regular operational duties and those duties directly concerned with the disposal of waste products resulting from reactor operation.

5.2 Exposure Dose Factors

The dose received in performing a particular task is dependent on certain factors:

(1) The number of components upon which the particular task has to be performed.

(2) The frequency of the task.

(3) The time required to perform the task.

(4) The radiation field in which the task is performed.

Reduction of any of these will reduce the dose received, and the designer may follow any or all to reduce the exposure. In fact, if any one factor equals zero, the exposure problem is eliminated.

During the review meetings on Bruce Generating Station various approaches for reducing man-rem exposure have been proposed. The following is a list of approaches in order of their effectiveness.

(1) Stop adding additional equipment.

(2) Eliminate equipment.

(3) Simplify equipment for the system.

(4) Relocate equipment in a lower radiation field.

(5) Provide better chemical control and purification.

(6) Ensure a longer time interval between maintenance periods by providing more reliable equipment.

(7) Arrange for quick removal of equipment for shop maintenance.

(8) Arrange for shorter time required for in situ maintenance.

(9) Provide more space between equipment.

(10) Provide shielding.

These recommendations are discussed with the designers and with Operations personnel both during the meeting and during the follow-up process. They may appear to be elementary or self-evident but it has been found valuable to emphasize them regularly.

Note that shielding is the last item on the list. The addition of shielding, which can involve structural and space problems, may sometimes be unavoidable, but it is to some extent the last resort. The best solution is to place great emphasis on equipment reliability and on system chemical control.

In any project the main concern is always to identify the serious problems soon enough. Design modifications which require a substantial reworking may have unacceptable effects on schedules. The best remedy to this problem is to hold preliminary audits on systems which have proved to be major exposure contributors in other stations.

6. IN-SERVICE INSPECTION

Recently attention has been directed to provide assurance that major accidents do not occur in a nuclear plant because of undetected deterioration. A section of the ASME Boiler Code has been issued - specifically applicable to U.S. reactors but bringing out some of the principles involved. This subject was touched upon in Lecture No. 6 but is raised here because the inspections which may be called for (it should be emphasized that in Canada the requirements are still being developed) will involve exposure for plant staff or any special agency inspectors who may be employed. The exposure involved must be limited as much as possible by attention to system layout, the introduction of remote viewing devices, etc. There seems to be no doubt that this requirement will be defined and enforced in all future nuclear plants.

7. HEALTH PHYSICS

The radiation exposure control in an operating nuclear plant is the responsibility of all concerned, but it may be appropriate here to outline the manner in which Ontario Hydro and Hydro Quebec have organized themselves in this regard. Their practices bear a strong resemblance to those of most utilities in the field.

All personnel designated to work at the station receive some radiation safety training and those who are designated "Atomic Energy Workers" are checked medically in addition. This category, as defined by the ICRP or the AECB, is permitted 10 times the exposure than that which is permitted for the public.

The normal practice is for all personnel to wear a badge which records the integrated external dose which the wearer has received. A colour code on the badge is used to indicate the level of training received and hence the degree of access permitted to the wearer.

In addition, internal exposure due to the inhalation or absorption of tritium and other radionuclides is checked regularly.

Additional dosimeters are worn by personnel entering high radiation areas. Like most aspects of safety, individual training and responsibility is vital.

The utility has a Health Physics Department within the headquarters Medical Division. It has the responsibility of preparing the Radiation

Protection Regulations in co-operation with the Operating Division for issue under the authority of the General Manager.

The Health Physics Department furnishes one or more professional health physicists to the station as consultants and to advise the Station Superintendent in all matters where specialized radiation expertise is required or where special studies may be called for. The main area of concern for the Health Physics staff in the radiation protection program includes such items as personnel dosimetry, bio-assay and environmental monitoring.

The Radiation Protection Regulations form the basis for more detailed station procedures as prepared by the station Health Physicist. These latter are issued by the station Radiation Control Supervisor, who is a senior member of the Operations staff with responsibility for day-to-day radiation protection equipment and procedures within the plant and for all local training. It is his responsibility or that of his staff to conduct training and examinations on specific station procedures and equipment leading to the badge qualifications governing degrees of personal access within the plant. The Health Physicist provides instruction on science fundamentals in such courses.

Day-to-day operations of the plant involve continuous checks of exposure received and the Radiation Control Supervisor ensures that the correct procedures are followed and the necessary records kept. Periodic reports are required for submission to the AECB.

A typical station radiation protection procedure would include general instructions on the following lines:

"Complete dose limits are given in the Radiation Protection Regulations. Annual dose is calculated for an Equivalent Calendar Year (ECY) which commences on the 1st of January, April, July or October, as allocated by the Data Clerk when an individual first joins Nuclear Operations. *The basic ECY dose limit is 5 rem for the gonads or whole body, 15 rem for the lens of the eye and 75 rem for the extremities.* A further limitation is based on each quarter of an ECY, where the whole body limit, for example, is 3 rem.

"Authorization is needed from the Health Physicist to exceed the 5 rem/ ECY limit, excepting in certain emergency cases. There are situations where the limit may be extended to 12 rem.

"In order to regulate the distribution of an individual's dose in time, a formal notification must be made by the individual or his supervisor, if it is desired to exceed 400 mrem in any 2-week film period. This is not a dose limit and no permission is needed. The form "Notification of Planned Exposure" must be completed and sent to the Data Clerk.

"If the Data Clerk receives any film dosimeter results exceeding 400 mrem, for which one of these forms was not submitted, he will initiate an investigation. The form must be submitted before the exposure, of course, and an entry made to indicate this in the Radiological Log.

"Internal exposure (chiefly for tritium uptake) is controlled by bioassay results. A tritium result of 28 Ci/litre (urine) is regarded as one maximum permissible body burden; (mpbb). A person having 1 mpbb but less than 2 mpbb's, will be in the CAUTION category until results show the level to be below 0.5 mpbb's. More than 2 mpbb's will be regarded as the REMOVAL category, again until results show the level to be below 0.5 mpbb's. In the Caution Category every attempt will be made to prevent further tritium uptake. In the Removal Category an individual may not carry out work involving exposure to tritium without authorization from the Health Physicist.

"Film badge dosimeters are evaluated every two weeks and the results are used to form the official record of personnel dose."

Film dosimetry badges are the property of the National Department of Health and Welfare, and film packs are supplied routinely by them for insertion. The Department also evaluates the films and supplies the station with the dose results. Beside film packs, the dosimetry badge has compartments for devices to permit a wide range of dose assessment that can be evaluated after emergencies or accidental exposures.

Employees collect a film dosimetry badge with identification photograph on arrival, from racks in the main lobby. They must be returned there on leaving the station. Visitors are issued an equivalent badge.

8. ACTIVE WASTE MANAGEMENT

8.1 General

Facilities are provided for safe permanent storage, or for safe disposal, of all radioactive gaseous, liquid and solid wastes. The equipment, tankage and facilities for handling liquid and solid wastes, are flexible enough to cope with the anticipated increase in waste volume and activity during periods of major maintenance work or adverse reactor operation. Potentially active gaseous wastes must pass activity monitors before being released to the atmosphere. If these gases contain an unacceptable level of activity they are filtered through absolute and/or iodine filters before being discharged.

The design and operation of the active waste disposal facilities are governed by the Derived Release Limits which are explained later.

Several basic treatment processes may be used in a particular plant for the management of these wastes depending upon the type and activity. These processes may include:

(a) Holding for natural decay of the radioactive isotopes.

(b) Dilution and release of liquid and gaseous active wastes in the respective plant effluent streams.

(c) Ion exchange and/or filtration to remove the radioactive materials.

(d) *Reduction in volume by incineration, evaporation, or baling.*

(e) Solidification of liquids in concrete or other solid material.

(f) Permanent containment and storage of solids in underground facilities within the plant buildings.

(g) Transport of solid wastes to burial areas.

As an example Figure 19 shows the liquid waste management system at Pickering presently in operation. The way in which separate categories are treated can be seen. In this case they comprise processes (a) and (b) above. The treatment and control depend upon the sampling and monitoring arrangements shown.

Another example which shows the arrangements for sampling and monitoring in the case of active gaseous effluent is shown in Figure 20.

8.2 Standards for Activity Release to the Environment

It has been found from experience at sites in Canada that the AECB Guidelines, when applied to a site with a comparatively sparse population distribution, lead to the release criteria for liquid and gaseous effluents being governed by the permissible dose to the individual at the plant boundary. The integrated population dose as limited by the

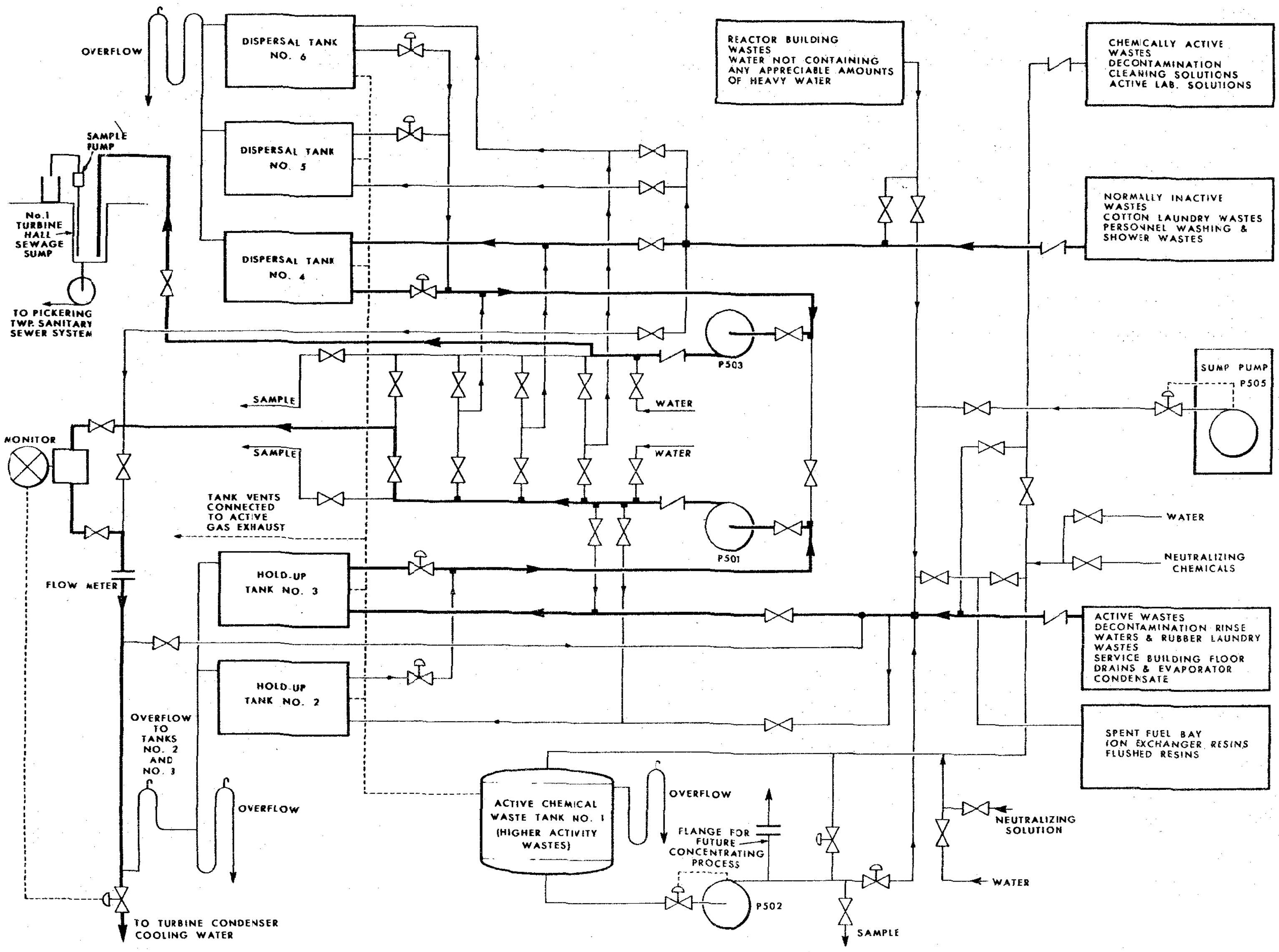


Figure 19 Radioactive Liquid Waste Management Simplified Flow Sheet

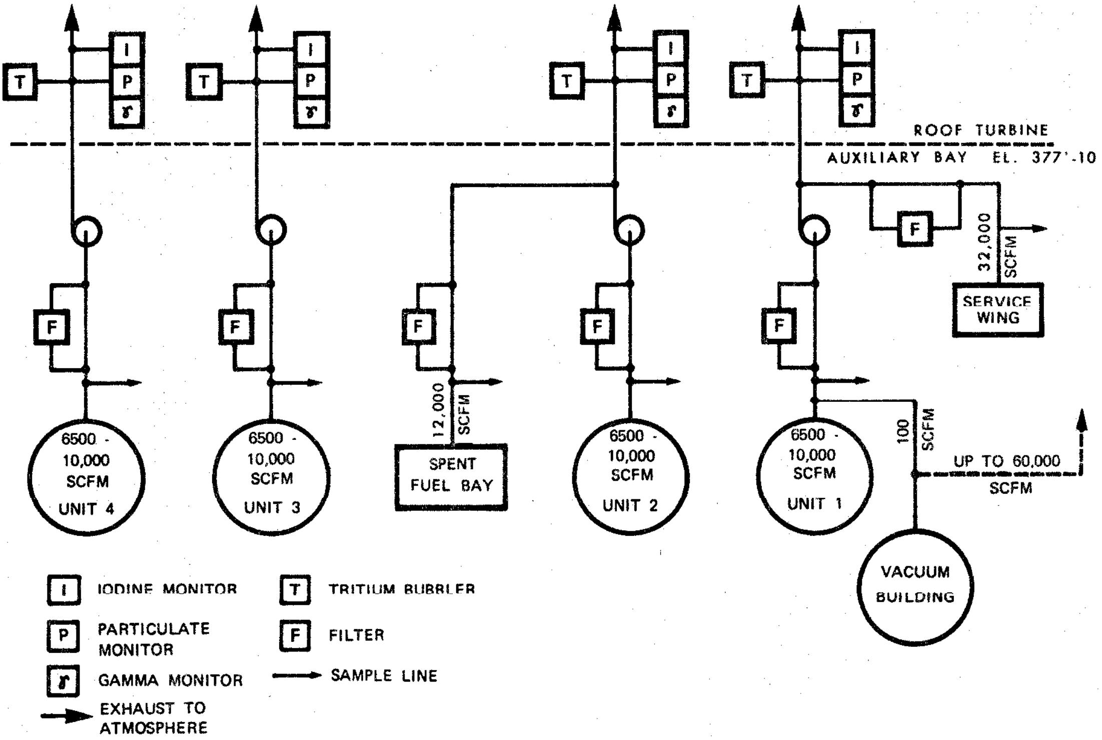


Figure 20 Ventilation Exhaust Duct Monitoring

Guidelines, either for accidents or routine operation, has been found to have an overriding effect on the release criteria only in areas of very high population. The following account of the derivation of permissible releases is concerned, therefore, with the dose to the individual at the boundary.

A set of operating procedures is developed to cover monitoring and control of active effluents. For this, it is essential to have approved Derived Release Limits to which actual releases as measured can be related. These limits result from Derived Working Limits or Maximum Permissible Concentrations which, in turn, are based on dose limits for individual members of the public at the site boundary. For normal operations, the dose limits chosen are the lower of those recommended by the International Commission on Radiation Protection or by the Atomic Energy Control Board.

The Derived Working Limits are given in units of activity per unit volume, e.g. curies per cubic metre, and the Derived Release Limits in units of activity per unit time, e.g. curies per hour.

The derivation of DWL's and hence DRL's both for airborne and waterborne effluents is based on methods which have been presented to the AECB for application to specific CANDU reactor plant sites. They are believed to be conservative. The actual values are based, however, on specific critical population groups and on release at specific sites, and would be re-evaluated during the design phase of any new plant.

The DRL's are not considered as design targets, but rather the maximum limits which must not be exceeded in operation. The ICRP recommendation of keeping all exposures as low as practicable is followed. Plant design is predicated on the principle that one-tenth of DRL figures should not be exceeded in normal operation, although some peaking is acceptable.

All active or potentially active gases, vapours or airborne particulates which occur in a station are monitored and filtered, and held up if necessary, prior to release to the atmosphere. Effluent monitors are used to ensure that the limits of permissible release are not exceeded.

Derived Release Limits for gaseous effluents are determined from the Maximum Permissible Concentrations in air (MPC_a) or Derived Working Limits taken at the site boundary, and the mean dilution factor, K_a, which has units of time against volume and is chiefly dependent upon release height.

In practice, K_a has been found to be relatively insensitive to geographical location. For conditions in Southern Ontario the application of dilution factors as proposed by F. Pasquill based on studies in the U.K. has been considered acceptable.

It is to be expected that this would also be satisfactory as a first approximation for any probable location in Canada.

The averaging period for gaseous effluent concentrations would be one week. Provision must also be made for short term releases at a rate higher than the maximum permissible average rate by permitting up to 20% of the maximum permissible dose for an individual to be received from such short term releases. This, of course, necessitates a reduction in the maximum permissible average boundary concentrations that may result from the other routine continuous releases.

Since the short term releases may happen to coincide with poor dispersal conditions in the atmosphere, the dilution factor K_a assumed in determining the maximum short term release rate is taken as twenty times more conservative than that used for the average meteorological conditions.

The proposed Derived Release Limits on gaseous activity for a site are tabulated in the formal presentation on safety to the AECB. The effective discharge height used in the calculations is confirmed by trials during plant commissioning.

A more conservative approach is taken for the evaluation of the effect on the public of postulated major accidental releases from the plant. The dilution factor for a release under these conditions is taken to be that for the atmospheric condition termed Pasquill F which represents a very stable inversion. The release is assumed to occur at ground level but with an initial dilution due to turbulence in the building lee. These analyses are described in another lecture and form part of the formal submission to the AECB as part of the licencing process.

The Derived Release Limits for liquid effluents are selected such that the Maximum Permissible Concentration for Fresh Water, MPC_{fw}, or Derived Working Limits are not exceeded in the cooling water discharge flow. The DRL's are expressed in terms of Curies per month, the averaging period being taken as one month, although the basic ICRP recommendation relates to a period of one year.

Since the primary route for release of radioactive liquid wastes is into the condenser cooling water (CCW), the DRL's as well as the permissible instantaneous release rates that may be established for internal administrative control would vary as a function of the number of CCW pumps in operation during the period under consideration.

The maximum effluent concentration averaged over short periods of a few days should not exceed 10 times the MPC_{fw} value.

In determining the DRL's for active liquid waste, the following principles are followed:

(1) DRL's will be based on the more restrictive critical path via fish consumption.

(2) No allowance will be made for dilution in the water body.

(3) No allowance will be made for removal of radioactivity in silts and bottom sediments.

Although Derived Release Limits are determined separately for gaseous and liquid releases, the possibility of simultaneous exposure from the two routes cannot be excluded. Effluent and environmental monitoring will ensure that

$$\frac{\text{Air Concentration}}{\text{MPC}_a} + \frac{\text{Water Concentration}}{\text{MPC}_{fw}} \leq 1$$

Correlations between such effluent and environmental measurements may be the basis for subsequent adjustments in the derived release levels and the plant design will have sufficient flexibility to allow for this.

9. ENVIRONMENTAL SURVEILLANCE (Figure 21)

Beyond the site boundary, monitoring and sampling of the environment is primarily the responsibility of governmental agencies with whom the question is discussed at an early stage in site selection. The utility health physics staff carry out a program on the lines shown in Figure 21 while the other agencies integrate local surveillance into nationwide programs.

On-site or boundary environmental measurements include typically, quarterly integrated gamma doses, average tritium air concentration, precipitation activity, and outfall and ground water activity.

Perimeter monitors are provided for ambient gamma monitoring on the station property.

Meteorological equipment is provided at the plant to assist in environmental surveillance and in-plant routine and emergency considerations of airborne effluent discharge.

9.1 CANDU and the Environment

There is not enough time for a detailed recital of the pros and cons of a nuclear plant with regard to its influence on the environment. However, a few points can be mentioned.

The active effluents from a nuclear plant can all be identified and kept under complete control.

Releases outside the plant can be and are maintained well below international standards set by the best informed people in the field. These standards are in themselves extremely conservative.

Apart from this, there is no evidence that small amounts of radiation are harmful and mankind has always lived with radiation. Designers are prepared, however, if there were any new and justified public concern, to reduce effluent levels further. At present this does not seem economically or socially justified. I would recommend a re-reading of Lecture No. 2 in this connection.

At the present stage of technology thermal effects are perhaps a little more significant from a nuclear than a coal or oil fired plant. But in spite of the ecologist's concern, which I personally share in many respects, these effects are not necessarily bad, particularly in Canada. I like the term "thermal enhancement". We do know that the fishing is better at the plant outfalls which may even be used by the government hatcheries for stocking purposes.

The space requirements of a nuclear plant are considerably less than those for a coal plant of comparable output. An oil plant, although closer to the same size, needs a wharf and tankage and brings the risk of spills which are very much in the mind of ecologists.

Non-active liquid or gaseous effluents are nothing more than those of any large institution, and they can readily be kept within local by-law requirements.

As to appearance, a nuclear plant can be a very acceptable component of a modern man-made landscape. It is customary to make a serious effort to study the visual impact and, while the architects sometimes grumble about the limitations on their control, they will admit that good functional engineering can produce a good looking group of buildings. The public certainly comes to visit the existing plants in ever increasing numbers.

SAMPLE	FREQUENCY	SAMPLING LOCATION	ANALYSES	WHERE ANALYSED
AIR: (a) Inhalation	Continuous Monthly TLD[1]	Not more than 5 molecular sieve samplers at station boundary	H-3	Health Physics Central Lab
(b) Immersion	TLD dosimeters changed quarterly	Several at about 1, 5 and 15 km from station	Integrated quarterly gamma dose	Health Physics Central Lab
	Integrating dose rate meter	At one suitable TLD site	Integrated quarterly gamma dose	Station Health Physics Group
PRECIPITATION	Quarterly composite of site buckets	About 5 precipitation buckets at station boundary and 1 at a reference background location	H-3 Gross β	Health Physics Central Lab
MILK	Monthly in summer (April to October)	Composite of not more than 3 farms within 10 km of station	I-131 H-3	Station Health Physics Group Central Health Physics Lab
WATER: (a) Surface Water	Weekly composite	Station circulating water effluent	Gross β	Station Chemical Control Lab
	Quarterly composite	Station circulating water effluent	H-3, specific radionuclides	Health Physics Central Lab
(b) Drinking Water	Semi-annual composite	Municipal pumphouse if within 10 km of station	H-3; Gross β, (specific radionuclides if 10^{-7} Ci/ml Gross β activity)	Health Physics Central Lab
FISH	Twice a year	Near station outfall	Gamma spectrometric analysis	Health Physics Central Lab

[1] Thermoluminescence Dosimetry

Figure 21 Routine Environmental Monitoring Program