Canadian Fusion Fuels
Technology Project

ITER SAFETY TASK NID-10A: CANDU OCCUPATIONAL EXPOSURE EXPERIENCE: ORE FOR ITER FUEL CYCLE & COOLING SYSTEMS

CFFTP G-9509
February, 1995

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Ontario Hydro Nuclear
Nuclear Technologies Services

CFFTP GENERAL

The Canadian Fusion Fuels Technology Project represents part of Canada's overall effort in fusion energy research. The focus for CFFTP is tritium technology and remote handling. The Project is funded by the Government of Canada and Ontario Hydro Technologies. Ontario Hydro Technologies administers the Project.

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This report contains information on TRITIUM Occupational Exposure (Internal Dose) from typical CANDU Nuclear Generating Stations. In addition to dose, airborne tritium levels are provided, as these strongly influence operational exposure.

The exposure dose data presented in this report cover a period of five years of operation and maintenance experience from four CANDU Reactors and are considered representative of other CANDU reactors. The data are broken down according to occupational function (Operators, Maintenance and Support Service etc.).

The referenced systems are mainly centered on CANDU Heat Transport System, Moderator System, Tritium Removal Facility and Heavy Water (D2O) Upgrading System. These systems contain the bulk part of tritium contamination in the CANDU Reactor.

Because of certain similarities between ITER and CANDU systems, this data can be used as the most relevant TRITIUM OCCUPATIONAL DOSE information for ITER COOLING and FUEL CYCLE systems dose assessment purpose, if similar design and operation principles as described in the report are adopted.

1.0 INTRODUCTION

This report presents a collective Occupational Exposure Dose to personnel, working at the commercial CANDU plants over a period of five years. The Occupational Exposure Dose may occur in many ways. The dose discussed in this report is INTERNAL DOSE, defined as the dose incurred from beta radiation exposure via tritium inhalation or ingestion, and does not include EXTERNAL DOSE, which is the sum of gamma and neutron exposure.

The INTERNAL DOSE exposure is mainly due to tritium radiation, which is found in the operational environment. The exposure could be partly because of:

- System Characteristic,
- Confinement limitation,
- Equipment leak-tightness,
- Environment Control,
- Operational Practice and
- Maintenance Frequency

It is expected that the doses may vary from year to year, depending on the length and frequency of the maintenance outages, and the nature of the work performed during these outages. However, one can get a good picture of the overall tritium exposure dose associated with the operation of a similar system.

The INTERNAL DOSE is mainly attributed to the CANDU Reactor Pressurized Heat Transport and Moderator Systems. The Tritium Removal Facility and the D_2O Upgrader System also contributes to the workers' dosage.

To provide the reader with a better understanding of the systems involved, a brief description of the overall systems is provided below.

2.0 OVERALL SYSTEM DESCRIPTIONS

2.1.1 CANDU Heat Transport Systems

The heart of the CANDU Reactor is the Calandria Assembly. It contains the Main Shell, Sub-Shell, Fuelling-Machine Tubes, Feeders, Calandria Tubes, Moderator Inlet/Outlet, Reactivity Control Units, etc. This massive piece of equipment is enclosed in a prestressed concrete vault. The two major circulation systems that keep the Reactor in operation are Pressurized Heat Transport (PHT) and Moderator systems.

The major components associated with the PHT system are:

- Inlet/Outlet headers,
- Steam Generators,
- Preheaters,
- Circulation Pumps,
- Reactor,
- Expansion Tank,
- Maintenance/Shutdown Cooling Pumps and Preheaters.
- Feed, Bleed and Relief Equipment.

2.1.2 CANDU Power Cycle

The Heat Transport System circulates pressurized heavy water through the Reactor fuel channels to remove heat produced by the fission of uranium fuel. Heavy Water in this case is used for the Heat Transport medium because it is the most efficient liquid coolant from the standpoint of neutron economy. The heat is carried by the Reactor coolant to the steam generator, where it is transferred to natural water to form steam. The steam is subsequently used to drive the turbine-generator.

2.1.3 Heat Transport Circuits

There are two main circuits providing bi-directional flow through the Reactor core, such that the flow is in opposite directions in adjacent channels. Major components found in each circuit are; two (2) pumps and preheaters, four (4) steam generators, two (2) inlet and outlet headers, and Pressure relief protection.

The outer zone of the Reactor is fed directly from the circulating pumps, which draw its D2O coolant from the steam generators. The inner zone channels are fed by D2O coolant, which passes from the pumps through preheaters, that sub-cool the D2O coolant prior to entering the inner zone channels. The preheaters are used to heat the feedwater, supplying the steam generators. Half of the inner coolant, passes through the preheaters, while the remaining 50 percent by-passes the preheaters. This is done to achieve the optimum channels discharge temperatures at full power operation.

The outlet feeders from both zones at each of the Reactor, are connected to a Rector outlet header. Each outlet header is connected to four (4) steam generators. The outlet header pressure is controlled to 9.18 MPa(a) at 100 percent power (Figure. 1-1).

2.1.4 Heat Transport Pumps

The four Heat Transport (PHT) pumps are vertical, single suction, double volute, centrifugal pumps. The motor is a vertical water/air cooled squirrel cage induction type. A cutaway view of the pump/motor assembly is shown in (Figure. 1-2). The pumps are located at each end of the Reactor, with motors and seals accessible from outside the containment envelope. A bellows type seal connects the top of the pump casing to the containment housing (Figure. 1-3).

To prevent leakage during both operation and equipment failure, double mechanical seals backed up by tertiary axial and segmented graphite bushings are provided as shown in (Figure. 1-4).

This provision reduces personnel dose during maintenance of the pumps.

2.1.5 Feeders, Headers and Piping

The feeders at each end of the Reactor run from the fuel channels vertically up the face of the Reactor, then horizontally across and above the fuelling machine area to the Reactor headers.

There is an outlet header at each end of the reactor. The headers conduct the flow of primary coolant from the outlet feeders to the steam generators. Each outlet header is connected to four steam generators, with connection between each steam generator and its associated header.

The two Reactor inlet headers for the inner zone and outer zone, located at each end of the Reactor core are housed in an insulated cabinet.

There are no isolation valves provided on the PHT circuit, except on the Reactor Shutdown Cooling System. This is to minimize personnel exposure dose during maintenance.

2.1.6 Preheaters and Steam Generators

Eight steam generators complete with steam drum are used for transferring heat from the heavy water coolant on the steam generator primary side to its secondary side.

A cutaway view of steam generator fitted with vertical U-Tubes bundles inside the shell, and connected to a common steam drum equipped with steam separator is shown in (Figure. 1-5).

A cutaway view of preheater used to raise the temperature of and boil the feedwater on the steam generator secondary side is shown in (Figure. 1-6)

2.1.7 Shutdown Cooling System

The Shutdown Cooling Circuit is designed to cool the HT system from 177°C to 54°C, and to hold it at the latter temperature for an indefinite time. The system utilizes the preheaters and main HT pumps to transfer heat from the HT system coolant to a demineralized water recirculation loop.

The Shutdown Cooling System consists of two 50 percent demineralized water-to-service water heat exchangers and two 100 percent circulation pumps (Figure. 1-7).

2.1.8 Maintenance Cooling System

The Maintenance Cooling System is normally used to cool down the HT system to 35°C from 54°C during shutdown for maintenance.

Maintenance of major components (steam generators, pumps, valves) requires that the HT system be depressurized, drained to header level and kept at 35°C. The Maintenance system is located outside the containment except the isolation valves. The valves are always closed when the Reactor is operating.

The Maintenance Cooling System consists of a one-loop circuit, containing a heat exchanger and two pumps connected between the reactor inlet and outlet headers (Figure. 1-7).

2.1.9 Moderator System

The Moderator System is used to slow down the high-energy fission neutrons to thermal energies. Heat is generated in the Moderator by neutrons as they slow down. The heat generated in the Moderator is removed by the Moderator Circulation System.

The Moderator Circulation System is made up of two halves. Each consists of a pump and heat exchanger, feeding a common supply header and drawing heavy water from the calandria. Cross-ties upstream and downstream of the main pumps are provided to permit operation of either of the 100 percent capacity pumps during maintenance.

Auxiliary pumps are also provided in the Moderator System to supply cooling flow to the calandria under abnormal or accident operating conditions (Figure 1-8).

2.1.10 Other Associated Systems

Associated with the Heat Transport and Moderator Systems, there are many other auxiliary systems, such as Pressurizer, Feed, Bleed and Relief Systems, Purification System, D2O Sampling and Collection Systems, D2O Storage and Cleanup Systems, and Leakage Detection System etc. These associated systems will not be dealt with in this report.

2.2 Tritium Removal Facility (TRF)

The TRF is designed to remove tritium from heavy water, which is used for cooling the CANDU Reactors and its Heat Transport System during power generation.

The TRF is designed to handle a flowrate of 360 kg/h of tritiated heavy water, with feedwater tritium concentration ranging from 3.4 Ci/kg to 34 Ci/kg (0.13 -1.3 TBq/kg). The heavy water product processed from the TRF will have a tritium concentration of about 0.95 Ci/kg (0.04 TBq/kg) during initial operations, and about 0.28 Ci/kg (0.01 TBq/kg) when steady state operations have been attained.

The TRF consists of three major process operations:

(a) Vapour Phase Catalytic Exchange (VPCE) cascade operation, in which tritiated heavy water vapour (DTO) is depleted of tritium (T_2) by means of a catalytic exchange of tritium (T_2) between deuterium gas (D_2) and DTO: (DTO [v] + D_2 [g] $\rightleftarrows$ DT [g] + D_2O [v]).

(b) Cryogenic Distillation operation, where isotope separation of D_2/DT into D_2 and T_2 by low temperature distillation takes place.

(c) Tritium Immobilization and Handling operation, in which >99% pure tritium taken from the final High Tritium Column of the Cryogenic Distillation operation is immobilized in the Tritium Immobilization Containers for storage.

A schematic of the TRF is shown in Figure 2-6.

2.2.1 Feed Treatment System (FTS)

The Feed Treatment System (FTS) is the very front end process. It transfers the tritiated heavy water from the feed storage tanks by two canned motor pumps into a degassing column. Dissolved gases, mainly air or cover gas, are released via a cold trap into the stack.

The heavy water flows into the feed evaporator, where non-volatile impurities are retained. While part of the vapour is fed back to the degassing column as stripping gas, the main vapour stream from the evaporator is condensed back into liquid state after passing through a condenser and a cooler. The feedwater then flows through a charcoal-filled feed adsorber for removal of any trace amounts of volatile impurities and through a micro filter for trapping of any charcoal or other particles. The purified heavy water is then collected in an intermediate storage tank for feeding the VPCE operation.

2.2.2 Vapour Phase Catalytic Exchange (VPCE)

There are eight stages in the VPCE, each consisting of an evaporator, a superheater, a catalyst bed and a condenser/separator. As the tritiated heavy water vapour and deuterium gas (D_2) pass through the cascade, the D_2 gas stream becomes enriched in tritium by the following isotope exchange reaction at 200°C: ($DTO\ [v] + D_2\ [g] \rightleftarrows DT\ [g] + D_2O\ [v]$).

When the tritiated heavy water from the FTS storage tank is pumped into the first VPCE stage for evaporation, the following cascaded process occurs:

(a) The tritiated heavy water is vaporized and mixed with cold deuterium gas stream (D_2/DT) from the second (next) stage.

(b) The gas/vapour mixture is superheated to 200°C prior to entering the catalyst bed, where isotope exchange reaction takes place:

$$(DTO\ [v] + D_2\ [g] \rightleftarrows DT\ [g] + D_2O\ [v]).$$

(c) The D_2/DT gas is then separated from the heavy water vapour in the condenser for the present stage.

(d) The tritium-depleted heavy water flows to the evaporator of the next stage, and the partially tritium enriched gas (D_2/DT) goes to the previous stage.

(e) The D_2 gas and DTO vapour flows are counter-current across the cascade, but co-current within each stage.

Two liquid ring compressors are used to drive the flow of deuterium (D_2) gas between the VPCE cascade process and the cryogenic distillation column. The final detritiated heavy water product from the condenser of the last stage is collected in the TRF product tanks for return shipment to the stations.

2.2.3 Dryer Unit

The Dryer Unit removes any heavy water vapour found in the enriched tritium gas (D_2/DT) stream before allowing it to enter the cryogenic distillation column. This will prevent the cryogenic heat exchangers from icing-up.

The enriched gas is taken from stage No.1 of the VPCE to the Dryer Unit by a pair of liquid ring compressors. The compressors compress the incoming gas to about 220 kPa. After compression, the dewpoint of the gas is reduced by passing it through a water sealed cooler, a chiller and a molecular sieve adsorber. Then it enters the cryogenic distillation system.

The Dryer Unit consists of two adsorbers in parallel, one being on line for drying the incoming gas, while the other is in the regeneration mode. The drying cycle will last for approximately 24 hours before the bed needs to be regenerated, which will take about 16 hours.

2.2.4 Adsorber Unit

The Adsorber Unit (AU), together with the Low-Tritium Distillation (LTD) and High-Tritium Distillation (HTD), forms the cryogenic distillation system.

The Adsorber Unit protects the first cryogenic distillation column from ice particles by removing any traces of oxygen and nitrogen as well as D_2O vapour that may escape from the dryer unit.

The Adsorber Unit consists mainly of four adsorber precoolers, two adsorbers and a distillation precooler. The tritium-rich deuterium gas enters the Low-Tritium Cold-Box (LTCB) and is cooled down by counter-current heat exchange before passing through one of the two parallel adsorber (silica gel) to remove all traces of impurities of O_2, N_2 and D_2O.

Regeneration of an adsorber takes place once a month or when O_2 is detected in the inlet stream, or when the pressure drop across the adsorber unit exceeds the pre-set level, whichever occurs first. A regeneration cycle mainly consists of warm-up, pump-out of desorbed gases, drying with D_2 and cooling with liquid nitrogen.

During regeneration, a pair of precoolers are also de-iced. There is always one duplicated train of precoolers and adsorber bed in service while the other is on regeneration.

2.2.5 Low Tritium Distillation (LTD)

The tritium-rich gas leaving the adsorber enters the Low-Tritium Distillation column (LTC), which is operated at approximately 25°K. The detritiated D_2/DT stream leaving the column is returned to the VPCE.

The LTC is made up of a large column at the top and a small column at the bottom. Decay helium is purged through the column condenser and column head once every few months through the recombiner.

A coldbox (LTCB) is used to encase the LTC equipment for the purposes of providing the required thermal insulation (vacuum) to maintain the cryogenic operating temperature as well as to offer as a double containment to the tritium process equipment. An Expansion Tank is provided to limit the pressure increase in the LTC during its warm-up operations.

Two parallel oil-diffusion pumps and two sliding-vane vacuum pumps are provided to maintain the LTCB vacuum requirement (approx. 10^{-3} Pa).

2.2.6 High Tritium Distillation (HTD)

The High Tritium Distillation Column (HTC) draws the Tritium-enriched deuterium from the bottom of the LTC and feeds to the top of the first columns of the HTC cascade. The HTC is made up of three consecutive columns of decreasing diameter, and a catalytic converter.

The principle of thermosyphoning is used to transfer gas between columns against increasing subsequent column operating pressure. There are no transfer pumps between columns.

The HTC increases the D2/DT separation and converts deuterium-tritide into deuterium and tritium by passing it through a catalytic converter.

The HTC together with condensers and reboilers is operated at approximately 25°K, while the catalytic converter is kept at 300°K. An expansion tank is also provided for the HTC to protect the safety of its components during warm-up operations.

A coldbox (HTCB) is used to encase the HTC equipment for the purposes of providing the required thermal insulation (vacuum) to maintain the cryogenic operating temperature as well as to offer as a double containment to the tritium process equipment.

Two parallel oil diffusion vacuum pumps and two sliding vane vacuum pumps are provided to maintain a vacuum of approximately 10^{-3} Pa inside the coldbox. The exhaust gases from the vacuum pumps are collected in an exhaust holding tank, which may be directed to the Air Cleanup System or to the exhaust stack depending on the hydrogen isotopes concentration recoverable.

2.2.7 Cryogenic Refrigeration System (CRS)

The cryogenic hydrogen refrigeration system (CRS) is used to keep the LTC and HTC distillation temperature at a constant temperature of about 25°K. This system is powered by two 2-stage parallel piston compressors. The compressors compress hydrogen gas at room temperature from 147 kPa to 1044 kPa.

After each compression stage, the hydrogen is cooled down by service water cooler to ambient temperature before entering the CRS cold box. A number of counter-flow heat exchangers are provided inside the cold box to recover some of the cooling effect from the exit hydrogen gases.

Two hydrogen cooling loops are utilized to achieve the desired temperatures inside the cold box. They are the turbine loop and the Joule-Thomson loop. A number of heat exchangers, evaporators, flow control valves and condensers are equipped in the loops to achieve the various cryogenic temperatures needed for LTC and HTC distillation process operations.

A stand-by emergency hydrogen storage tank containing liquid hydrogen is provided for temporary cooling of the HTCB condensers, in the case of malfunction of hydrogen compressors.

A hydrogen expansion tank is provided for the LTC and HTC cryogenic loops to protect the safety of its components during warm-up operations.

2.2.8 Recombiner System (RS)

There are a number of auxiliary systems supporting the above main TRF process systems. These are Recombiner System, Drain and Purge System, Deuterium Make-up System, Liquid Collection System, Liquid and Gas Sampling Systems and Control system.

The provision of the Recombiner System is to allow the reduction of hydrogen isotope inventory by safe, controlled combustion during operation. Some of these inventories are coming from the following sources:

(a) Protium tails from the head of the first column (via Gas Sampling System).

(b) D_2 with traces of N_2 and O_2 coming from regeneration of the adsorber unit in the LTCB (via Drain and Purge System).

(c) HD, D_2, DT mixtures coming from different parts of the installation via Drain and Purge System, due to maintenance work.

(d) Evacuation of the whole D_2 inventory, in the event of a shutdown for major repair work.

Deuterium and protium tails are separately fed into the burner at a constant, preset flow rate, controlled by a separate deuterium and protium flow controller. The whole burner system before start up is purged with O_2 flowing to the stack to prevent any explosive mixture in the system prior to ignition. The hot combustion gases are cooled by heat exchanger coils and the condensate is collected by gravity flow into a heavy water tank.

2.2.9 Drain and Purge System (DPS)

The Drain and Purge System (DPS) is used to transfer process gas or purge gas between systems for maintenance, or preconditioning of equipment. It is also used to allow the transfer of process gas from the nitrogen adsorbers to the recombiner system during regeneration cycle. In addition, the DPS is also be used in the gas sampling systems to remove or purge any lines prior to and after the sampling.

The DPS is made-up of a vacuum pump and two compressors of metal bellow type, with an interstage condenser to trap moisture. The vacuum pump is able to evacuate the system down to a pressure of approximately 10 kPa, while the compressors are capable of discharging the gas to the storage tank at pressure up to 500 kPa.

Any transfer of gases from the DPS to the Recombiner System or to the gas cleanup system will take place only if there is a positive supply pressure above ambient in the tank to prevent potential backflow of oxygen into the DPS.

2.2.10 Deuterium Make-up System (DMS)

Deuterium is generated by electrolysis of heavy water. This is to compensate for the extracted amount of tritium product or deuterium lost during the regeneration of the Adsorber Unit. Also, at the start-up of the TRF, the Deuterium Make-up System (DMS) provides the initial total deuterium inventory. The oxygen generated by the electrolysis is used to feed the recombiner system. The DMS is made up of a standard commercial electrolysis unit.

2.2.11 Liquid Collection System (LCS)

The provision of Liquid Collection System (LCS) is to allow drainage of all equipment, which may contain liquid under ambient conditions. The LCS is located at low point such that all systems can be drained by gravity and collected into a tank. The liquid from the tank can be pumped by a canned motor pump, either through the liquid sampling system back to the heavy water upgrading system or back into the feed tanks.

2.2.12 Sampling Systems (LSS/GSS)

The Liquid and Gas Sampling Systems (LSS/GSS) are needed by the TRF to provide process and safety related information during TRF operation. The sampling may take place continuously or periodically by monitoring the compositions of certain process streams.

The following sampling points are provided:

(a) Liquid Samples

- Feed water from feed tank pumps, return of sample to feed tank.
- Degassed/purified feed water from VPCE feed pump, return of sample to intermediate tank.
- Detritiated product water from VPCE product tank pumps, return of sample to either one of the product tanks.

- Recombiner product from recombiner condensate tank pump, return of sample to recombiner condensate tank. Liquid from collection tank pump, return of sample to collection tank.

The liquid sampling system is enclosed in a cabinet, and contains five sampling pots, sample flow meters, sample pressure gauges, and sample pot drain valves. A relief valve is provided in the sampling pot to protect it from overpressure.

(b) Oxygen Sample

In order to ensure the proper gas composition in the TRF process operation, there are three oxygen trace analyzers monitoring the oxygen content in the following hydrogen and deuterium streams:

- D_2 feed gas from the front-end gas loop, downstream of the N_2 adsorber to the cryogenic distillation (continuous monitoring).
- DMS make-up, D_2 supply to VPCE loop (continuous monitoring).
- Hydrogen in the CRS coolant loop (during warm-up or maintenance).

(c) Moisture Sample

There are two moisture analyzers continuously monitoring the water content in the deuterium and hydrogen gas streams:

- D_2 feed gas from the front-end gas loop, downstream of the Dryer Unit to the cryogenic distillation.
- Hydrogen in the CRS coolant loop from the compressor discharge to CRS cold box.

(d) Hydrogen Detectors in Air

There are two hydrogen detectors provided in the DMS room to monitor continuously of the deuterium concentration present in the room for alarming and switching the DMS off if deuterium is accumulating and being detected in the room air.

(e) Hydrogen Detector in LTCB/HTCB

There is one thermal conductivity type analyzer monitoring continuously on each LTCB and HTCB casing vacuum pump discharged gases for the total content of hydrogen and deuterium.

(f) Tritium Analyzers

There are five tritium analyzers monitoring continuously the tritium concentration in the following deuterium steams, and off gas from coldbox casing vacuum systems:

- D_2 feed gas from the front-end gas loop, downstream of the Dryer Unit to the cryogenic distillation.
- Return of D_2 gas from the cryogenic distillation to the VPCE loop.
- Protium tailings from the cryogenic distillation system to the Recombiner System.
- LTCB discharge gases downstream of the vacuum pumps to the stack.
- HTCB discharge gases downstream of the vacuum pumps to the chronic-release holding tank.

2.2.13 Tritium Immobilization System (TIS)

The primary function of the Tritium Immobilization System (TIS) is to receive and immobilize concentrated tritium extracted from the TRF final High Tritium Column. The immobilized tritium is stored in the form of titanium tritide inside the Immobilized Tritium Container (ITC). Also the TIS can perform filling of tritium sales containers for off-site customer use.

The Tritium Immobilization System consists of dual, independent processing loops each of which includes an assay vessel, an immobilization container, combination gas analyzer/leak detector, heaters, a vacuum/transfer pump set, a uranium-bed, associated tubing, valves, instrumentation and control equipment.

The above two loops of the TIS are contained in separate argon-filled glove-boxes, which act as secondary containment.

The process loop takes the tritium gas from the TRF final High Tritium Column (HTC), and samples it for purity check by the tritium analyzer with an assay vessel capable of loading 1.7 PBq (45 kCi) on each batch operation. Eleven batches are needed to fill (immobilize) in each ITC (approx. 500 kCi).

There is one Air-Lock provided for each process loop to house the ITC. During immobilization, the activated ITC is placed into the Air-Lock and valved onto the TIS fill line. The Air-Lock is then closed and purged with inert gas before allowing circulation of argon gas from the glove-box clean-up system (GBCS). The GBCS also provides argon to the glove box circulation, removing any process heat and tritium gas that may have leaked from the TIS loops.

Recovery of immobilized tritium from any ITC can also be done by the TIS. This is carried out by heating the immobilized ITC to 450-500°C while the vacuum/transfer pump keeps removing the evolved gas and maintains a vacuum in the container. The recovered gas can be stored in the uranium bed.

A common tritium sales containers Air-Lock, which is capable of filling any small quantity of tritium in sales containers for off-site users, is connected to the TIS.

2.2.14 Glove-Box Clean-Up System

The Glove-Box Clean-Up (GBCS) captures and removes tritium which leaks out of the TIS equipment into the argon atmosphere of the TIS glove-boxes or ITC appendages, it. The circulation of the argon through the glove-boxes also removes heat generated by the immobilization process and the TIS equipment.

When the GBCS receives the circulation argon from the glove-boxes or ITC appendages, it first filters through a 4-micron filter to remove any fines before entering the blower, which provides a flowrate of 170 m^3/h (NTP) of argon through the system. The argon then flows through a charcoal trap to remove any hydrocarbon impurities prior to entering a preheater and recombiner, where hydrogen isotopes and oxygen recombine to form oxides (vapour). Then the gas mixture cools down through a condenser, where condensate is drained to a tritiated storage tank. The remaining residual moisture in the gas is removed by passing through a molecular sieve dryer, before going through an oxygen removal bed, where any residual oxygen is removed. The dry, oxygen free and purified argon is then cooled down before returning to the TIS glove-boxes.

Both the moisture removal beds and the oxygen removal beds are regenerable. A common regeneration loop consists of a regeneration blower, a regeneration heater, a regeneration cooler and valving arrangement. This will allow one of the two beds to be isolated for regeneration while keeping the other on service. The tritiated water collected in the cooler drains to a storage tank.

2.2.15 Air Clean-Up System

The Air Clean-Up System (ACS) is provided mainly for cleaning up contaminated air inside the TRF rooms, during and following a tritium spill, which may be caused by equipment leakage, equipment failure or operational errors. Only rooms containing tritium process equipment are connected to the ACS.

The ACS is on standby during Normal Operation, but at any time it shall be ready to be activated immediately at the operator's discretion. When the operator receives a high tritium alarm from room containing tritium process, the operator will close the Building Ventilation System (BVS) dampers and open the ACS dampers to that room. The ACS blower will be started manually, and the contaminated air from the affected room will first pass through a filter assembly to remove any loose particles before entering the ACS blower. Then the air stream flows through a charcoal trap to remove any hydrocarbon impurities prior to entering a preheater and a recombiner. The preheater heats the air stream to 150°C so that hydrogen isotopes and oxygen can recombine effectively in the recombiner to form oxides (vapour). Then the air stream (mixtures) cools down through a condenser, where condensate is drained to a tritiated water storage tank. The remaining residual moisture in the air stream is removed by passing through a dryer containing two molecular sieve beds.

The dryer is regenerable with a common regeneration loop including a regeneration blower, a regeneration heater, a regeneration cooler and valving arrangement. This will allow one bed to be isolated for regeneration while keeping the other bed on service. The tritiated water collected in the cooler drains to a tritiated water storage tank.

2.3 Heavy Water Upgrading System

The heavy water upgrading system is used to restore the quality of Heavy Water to CANDU Reactor grade (99.9%) purity by removing any light water and other impurities, downgraded due to operations. The upgraded product, then is returned to either the CANDU Reactor Moderator or Heat Transport systems;

The heart of the Upgrader is the distillation columns, containing special packing. Under normal operating conditions, a constant D2O concentration profile is maintained in the column. The final product is collected at the bottom of the column, while the light water is rejected at the top. The water to be upgraded is fed into the column as vapour stream.

The Heavy Water Upgrading plant mainly consists of the following:

- The feed storage and ion exchange cleanup system.
- Distillation towers containing special packing, liquid distributors, and other internals.
- The Vacuum system and reboiler, condenser and cold traps.

2.3.1 Feed Storage System

A number of feed storage tanks, each sized up to 2.75 m in diameter by 8 m long are inter-connected to form the feed storage system. They provide the following services:

- Recover any overfill from other tanks.
- Act as a breathing (helium cover gas) tanks when tanks are emptied or filled.
- Serve as incoming weight accounting tools as each tank is mounted on load cells.
- Provide a storage means for columns pumped out during maintenance.

The storage system includes canned pumps for feeding the columns, inter-connecting piping for facilitating operation flexibility, vent condenser for recovering any heavy water vapour, inert gaseous blanketing for preventing ingress of air to the system and relief valves for both under/over pressure protection.

2.3.2 Ion-Exchange Cleanup System

Downgraded heavy water from Heat Transport System, or Moderator System are often contaminated with oil and other soluble, or insoluble impurities. The Cleanup System made up of receiving tanks, filters, oil separators, ion-exchangers and pumps etc., are used to cleanup the downgraded water prior to feeding the Upgrading Facility.

2.3.3 Upgrader

The heart of the heavy water upgrader is the vacuum distillation columns containing special packing, distributors and internals, reboilers, condensers and reflux pumps, etc. The distillation columns upgrade the quality of downgraded heavy water to the concentration and purity required by the CANDU Reactors.

2.3.4 Distillation Columns

The distillation columns operate at about 10 to 30 kPa and about 45°C to 70°C.

During distillation, downgraded heavy water is vaporized by an evaporator before feeding into the column. Light water is removed from the head condenser via the head product cooler, and collected in the head product tank, prior to release to the active waste system.

The final upgraded product taken from the bottom sump, after circulating through an evaporator and a condenser, is collected in the product tanks, or returned to the heavy water storage tanks.

2.3.5 Vacuum and Condenser System

The vacuum system consists of the following:

- Two vacuum pumps,
- One seal water tank,
- One seal water cooler,
- Valves and instruments.

The Vacuum system keeps the feed evaporators, reboiler, columns, vapour crossover line, head product condenser and cold trap at the operating pressure.

3.0 TRITIUM HAZARD FROM OCCUPATIONAL EXPOSURES

Tritium can be present in the work place in airborne form as a gas (HT), a vapour (HTO) or aerosol or tritiated dust; on contaminated equipment and materials; or in contaminated liquids. (Tritium in the form of hydrogen molecules, HT, DT, or T_2 as a gas, or adsorbed on surfaces, is generally written as HT whereas tritium in the form of the oxide, HTO, DTO or T_2O is generally written as HTO). Intake pathways of tritium into the human body are:

(a) Inhalation (HT & HTO)

(b) Skin Uptake

- Diffusion of airborne tritium (mainly HTO) through the intact skin;
- Skin absorption through contact with contaminated surfaces or with contaminated liquids;

(c) Ingestion

The biological hazards of the different forms of tritium can differ significantly. Following intake into the body, HTO mixes uniformly within two to three hours with the body water, and can then diffuse into cells. Tritium gas, on the other hand, is not readily absorbed into the body water or tissue. HT dissolved in body water is rapidly removed from the body. Direct irradiation of lung tissue by inhalation is the main pathway for the HT. Due to the low energy of the tritium beta particles (mean energy 5.7 keV), the radiological hazard of HTO relative to that of HT for equal concentrations in air is 25,000 to 1, for occupational exposure [ICRP30, 1980].

HT can be converted to HTO through oxidation and isotopic exchange mechanisms. Because of the large difference in radiological hazard between HT and HTO, this conversion process is a major consideration in tritium safe handling. A study by Robins et al [1985] has shown that this oxidation is less than several percent per day, although the conversion may be enhanced by temperature, humidity, gas flow, surface type and area.

Tritium may also be present in particulate form such as metal tritides. When inhaled, this particulate may be retained in the lung with a biological elimination half-life of the order of hundreds of days if the material has low solubility. However, the dosimetry is not well established and bioassay is difficult.

3.1 Regulatory Dose Limits

The radiation dose limits for atomic radiation workers and individual members of the public are set in Canada by the Atomic Energy Control Board (AECB) and are given in Table 1 [AECB, 1988]. These limits are based on the recommendations of the International Commission on Radiological Protection (ICRP) and apply to the sum of the doses received via all routes, e.g., airborne, waterborne and direct radiation exposure. The AECB has proposed to reduce the radiation dose limits based on the 1991 recommendations of the ICRP [AECB, 1991].

3.2 Tritium Gas (HT) Exposure

The tritium gas exposure is equivalent to submersion in a radioactive cloud. The radiological hazard associated with such exposure conditions is presented in ICRP-30 [ICRP30, 1980]. The pathways to human are:

(a) External exposure from immersion in a tritium gas;

(b) Internal irradiation of body tissue by the absorbed tritium gas in the tissue;

(c) Direct irradiation of lung tissue by inhalation;

(d) Skin exposure due to permeation of HT and subsequent exchange with tissue molecules and;

(e) Internal irradiation of body tissue due to absorption of HT and subsequent oxidation of HT to HTO.

ICRP-30 considered the direct irradiation of lung tissue to be the major exposure pathway. Using an average lung volume of 0.003 m^3 and lung mass of 1 kg, the resulting Derived Air Concentration (DAC) or Maximum Permissible Concentration in Air (MPCA) is calculated to be 5.6×10^5 μCi/m^3(2.0×10^{10} Bq/m^3). This concentration corresponds to 42 rem (420 mSv) lung dose over a standard working year of 2000 hours [Mohindra, 1987].

However, ICRP-30 did not consider the dose from HTO produced from in vivo oxidation of the small amount of HT absorbed in the body. The effective dose from HTO produced by an vivo oxidation is approximately equal to that from lung irradiation by HT [IAEA, 1991]. This effect suggests a DAC or MPCA value of 2.8×10^5 μCi/m^3 (1×10^{10} Bq/m^3) for elemental tritium. This concentration will result in a lung dose of 21 rem (210 mSv) and 2.5 rem (25 mSv) effective dose equivalent contribution, based on 2000 working hours per year [Mohindra, 1987].

In the current Atomic Energy Control Regulations, the annual lung dose limit for an atomic radiation worker is 15 rem (150 mSv). The DAC derived in the ICRP-30 was adjusted for the AECB lung dose limit and was calculated to 2.0×10^5 μCi/m^3 (7.4×10^9 Bq/m^3) [Mohindra, 1987]. This value has been used for the MPCA of tritium gas conversion.

3.3 Tritium Oxide (HTO) Exposure

To derive tritium oxide intake limits for workers, ICRP-30 recommended a model in which tritiated water is assumed to be distributed uniformly and instantaneously among all soft body tissues at any time following the intake, independently of the routes of entry into the body. Its retention is described by a single exponential with a half-life of 10 days.

Based on this model, the resulting Derived Air Concentration (DAC) is calculated to be about 21 μCi/m^3 (7.7 x 10^5 Bq/m^3) [IAEA, 1991], which corresponds to a whole body dose limit of 5 rem/yr (50 mSv/yr) for an atomic radiation worker. The calculation used a dose conversion factor of 67 rem/Ci (1.81 x 10^{-11} Sv/Bq) for inhalation of HTO, an adult inhalation rate of 0.02 m^3/min, 2000 working hours per year, and a multiplying factor of 1.5 to account for intake by skin absorption. This multiplying factor assumes that the ratio of intake by skin absorption to intake by inhalation is 0.5 for occupational exposures.

A DAC of 20 μCi/m^3 (7.4 x 10^5 Bq/m^3) has been adopted for use at Ontario Hydro [Whillans, 1992]. However, a value of 10 μCi/m^3 (3.7 x 10^5 Bq/m^3) has been used as MPCA for tritium oxide conversion.

3.4 Tritium Surface Contamination (TSC) Exposure

Skin contact with surfaces contaminated by tritiated water (HTO) results in uptakes of HTO into the body, distribution and excretion, the same as for any other form of HTO exposure (See Section 3.3).

Skin contact exposure to surfaces contaminated by elemental tritium, on the other hand, leads to the excretion both in the form of tritiated water and in organic-bound tritium (OBT). The appearance of this activity is significantly delayed with respect to the prompt appearance of activity resulting from skin updates of HTO [Eakins et al, 1970 and 1975]. Moreover, the decay rate of the HTO concentration in urine as a result of tritium surface contamination has a half time in the range of 13 to 16 days, significantly longer than when the update was due to HTO.

More recent experimental work on animals confirmed elevated levels of OBT, especially in skin [Johnson et al, 1988]. During the first day following exposure the skin OBT concentration was at least 20 times higher than that in the liver, and the ratio of OBT to HTO in skin was about 30. The dosimetry of tritium from TSC therefore reduces to estimating the dose to the skin at the point of contact.

Internal Ontario Hydro Standards [Whillans, 1986 and 1989] have been derived for the TSC hazard. A maximum permissible level (MPL) of 500 μCi/m^2 (1.85 x 10^7 Bq/m^2) was set for TSC, based on an average skin uptake fraction of 0.01 and a skin dose factor of 0.17 rem/μCi (4.6 x 10^{-8} Sv per becquerel uptake), and an effected area of 300 cm^2. This limit corresponds to the proposed skin dose limit of 50 rem (500 mSv) per year for an atomic radiation worker [AECB, 1991]. It is based on the conservative assumption that a worker will contact the contaminated surface 10 times per day in each of the 250 working days per year.

4.0 TRITIUM SAFE HANDLING AT STATION

The CANDU Reactors have been in operation since 1960. There were no major tritium spills taken place at the Ontario Hydro Nuclear Generation Facilities during all these years of operations, although numerous repairs and retrofittings were conducted at the site. No personnel were exposed to tritium levels in excess of regulatory limits.

These high performance records are mainly due to proper Tritium Handling Policy and Safety Design Philosophy incorporated into the Facilities through:

(a) Source control to confine and to minimize the spread of tritium in the system;

(b) Contamination and exposure control to minimize exposure to workers.

(c) Tritium Monitor Control to alert workers.

4.1 Source Control

4.1.1 Leaktightness of Process Systems

At the facilities, special emphasis is placed on prevention of leakage by careful selection of equipment design and number of joints. Equipment and valves are chosen with careful consideration to leak-tightness. All process connections are made up of welded joints, whenever possible and practical. The use of elastomer and halogen material gaskets is kept to a minimum.

In general, stainless steels are preferred as construction materials whenever possible, although the PHT and Moderator Systems are made of carbon steel. All heat exchangers are fabricated from inconel or austenite stainless steel.

4.1.2 Tritium Containment

The main airborne activity of concern to the station operation and maintenance staff is tritium. Whenever significant leaks of heavy water occur, the airborne tritium concentration will generally be in excess of the level permitted for continuous breathing. Therefore, all auxiliary systems associated with PHT and Moderator Systems are located mostly within the prestressed concrete containment structure, and the majority of the systems are within the dry vault. Airtight doors are provided in these rooms.

The rooms that house the PHT and Moderator Systems are shown in Figures 2-1 to 2-5.

4.1.3 Tritium Removal from Air

To maintain the atmosphere relatively free of HTO, DTO inside containment, D2O Vapour Recovery Dryers are provided. The dryers are operated around the clock to keep the dew point of the containment always below 16°C.

Any excessive increase of humidity within the containment, due to possible leakage of D2O by failure of equipment, will be detected by its moisture detecting elements in the containment of the reactor building. Also alarm will be sounded in the control room to request follow-up inspection. Repair of leakage will be done promptly following field check. Personnel must wear Protective clothing during repair or maintenance. (Section 4.2.5).

All D2O or HTO vapour adsorbed by the molecular sieve of dryer beds, will be recovered in the condensate tank in liquid form by regeneration of the dryer beds. Automatic adsorption and regeneration cycles are built-in features of the Vapour Recovery Systems.

4.1.4 Purged Ventilation

Prior to maintenance, systems are flushed with inert gas to minimize the occupational exposure due to tritium build-up in the system. The containment is purged with ventilation. Localized ventilation system is also provided in a working area and is effective in reducing tritium hazard to operating personnel and reducing the spread of contamination. For example, ventilated "elephant trunks" can be used for local containment over contaminated equipment.

4.2 Contamination and Exposure Control

All independent workers at the station are trained regarding hazards associated with Tritium. In addition, practices and procedures for controlling the spread of tritium contamination and occupational exposure are followed by all station personnel, entering a radioactive work area. These operating procedures are summarized below:

4.2.1 Zone Control

All containment areas are designated as zone 3, in which most of the radioactive equipment are located. Zone 2 contains a minimum of low level radioactive equipment. Zone 1 is clean area, where administration is conducted. Thus zoning facilitates the location and segregation of systems and equipment, and the control of movement of people and equipment and the spread of contamination. Within the contaminated zone, temporary "rubber areas" are set up to localize areas of particularly high contamination. Tritium smears of personnel and equipment are obtained and analyzed prior to leaving the areas, in order to minimize the risk of spread of tritium surface contamination.

4.2.2 Procedural Control

When any radioactive work is carried out in the station, a Radiological Exposure Permit (REP) is to be completed, prior to issuing a work authorization. This is effective in controlling exposure to the worker by ensuring that the worker is aware of the hazards associated with the work and appropriate actions to be followed.

4.2.3 Tritium Monitoring

Fixed area alarming tritium monitors (FAATM) provide a continuous indication of the gross tritium concentration. They are used primarily:

(a) To warn and thus prevent an individual from receiving an injurious dose, and

(b) To warn of the occurrence of a sudden high radiation hazard as a result of operating circumstances or work being performed.

Portable tritium monitors are used for workplace monitoring, where localized tritium concentrations near process equipment are expected to vary significantly with time during a particular job.

Portable monitors can stay with the individual close to the work area, where localized concentrations may be quite different from the average room air concentrations indicated by fixed area monitors. Two different kinds of tritium monitors are used:

(a) Scintrex Tritium Survey Meter is used to measure the airborne tritium concentration. In order to differentiate between tritium gas and oxide, the meter must be run first without and then with a silica gel cartridge attached. The meter is compensated for gamma up to about 5 mR/h with accuracy about ± 20% of tritium concentrations above 5 MPCA. The meter is capable of reading 2 x 10^6 MPCA of tritium oxide and 100 MPCA of HT.

(b) Triton Portable tritium in Air Monitor is used to measure the airborne tritium concentration (MPCA) and changes in the concentration. An alarm circuit is provided. This monitor cannot differentiate between tritium gas and tritium oxide. Gamma compensation is provided up to about 5 mR/h. The monitor is capable of measuring tritium concentration between 0 to 1,000,000 mCi/m^3 with accuracy ± 20% of full scale.

Measurement of tritium oxide is provided by the tritium collector with an accuracy ± 5%. The collector traps tritium oxide from the air in a standard scintillation vial.

Tritium surface contamination is measured effectively by using a poly foam smear and counted with a scintillation counter.

Procedural steps are to be followed by all personnel when taking tritium measurements.

4.2.4 Dosimetric Control

Urine bioassay measurements not only provide data for the official internal dose record (compliance dosimetry) but are also used for internal dose control. Urine samples are required by all station personnel:

(a) Prior to performing radioactive work in station.

(b) Approximately 24 hours after exposure to tritium surface contamination.

(c) Approximately 4 hours after a known or suspected exposure to tritium oxide or tritium gas.

(d) Routinely.

Procedural steps are established for assessing and assigning lung and skin doses to personnel resulting from exposures to Tritium gas and/or Tritium-contaminated surfaces [Presley, 1989].

4.2.5 Personnel Protective Clothing

Basic protective clothing for the station Tritium hazard areas is cotton coverall. All personnel entering the area, including those in radiation area clothing, must wear disposable coveralls, gloves and booties. Any persons operating glove-box should smear the inside of the gloves attachment of the glove-box to ensure no tritium surface contamination is present.

The following protective equipment are required depending the type and level of tritium hazard:

(1) Tritium Surface Contamination (TSC)

a) For TSC $\geq$ 1 μCi/m^2, double gloves, disposable Tyvek coveralls and booties (over basic protective clothing) are required. Respiratory protection may be needed depending on the airborne tritium levels.

b) For TSC $\geq$ 50 μCi/m^2, double gloves, disposable Tyvek coveralls, booties and respiratory protection (Ram's horn and hood, air mask) are required.

c) For TSC $\geq$ 500 μCi/m^2, disposable plastic suits (MK IV suit and oversuit) are required.

(2) Tritium Gas

a) For tritium gas $\geq$ 1500 μCi/m^3, respiratory protection (air mask, Ram's horn and hood) is required.

b) For tritium gas $\geq$ 15000 μCi/m^3, plastic suits (disposable or Mk IV) are required.

Procedures for dressing into and undressing from the disposable air vest suit are provided.

Plastic suits (MK IV) must be worn when entering rooms, where high tritium exposure is expected during maintenance. Breathing air respiratory equipment must be used.

4.2.6 Personnel and Equipment Decontamination

Following a significant acute HTO exposure, the committed dose to the worker can be reduced by prompt showering after exposure and by increasing the normal water intake rate. A personal decontamination facility has been setup in stations. There is a shower as well as a sink for decontamination purposes. Procedures have been established to decontaminate the affected area.

Any material which is found contaminated with tritium surface contamination are to be decontaminated in the fume hood or temporary decontamination tent in a designated area. Procedures have to be followed to decontaminate equipment with surface contamination.

5.0 TRITIUM EXPOSURE

Tritium hazards at the station may result from:

a) Chronic leakage from process systems and equipment;

b) Acute leakage or spills due to equipment failure and/or human error;

c) Tritium contamination from maintenance and repair activities.

During these years of operation, no major leakage or spills have occurred. Tritium exposures were limited to chronic leakage from process systems and equipment, and from maintenance and repair activities. No tritium lung and skin doses were detected and recorded during maintenance and repair activities.

5.1 Tritium Airborne Levels

During normal operation, airborne tritium room concentrations are influenced by the chronic releases from process systems and equipment, the D2O Vapour Recovery Dryer performance and the ventilation rate in the room. Airborne HTO and HT concentrations are measured routinely in several locations within the Reactor Building and the Common Service Areas (Table 2). These concentrations are obtained largely by tritium collector (accuracy of ± 5%) and Scintrex Tritium Survey Meter (accuracy ± 20%). These data summarized covering a period of five years (1989-1993). The average concentrations reflect the normal operating condition and the maximum concentrations are due to maintenance and repair activities.

Normally, each station has Tritium Hazard Level Targets set as shown in Table 6.

5.2 Tritium Surface Contamination

Tritium surface contamination has been monitored regularly in the heavy water management areas for many years. A review of data covering all the areas monitored for the past 5 years (1989-1993) shown in Table 7 indicates that no single measurement was above 1 microcurie per square metre.

5.3 Tritium Occupational Exposure Dose Data

The Tritium Occupational Exposure data are presented in a summary form in Table 3. This table summarizes five years worth of data collected for each class of worker and reported by the stations on a monthly basis. The following illustrates how the data are compiled. The number of people assigned to each occupational group may vary from quarter to quarter, depending on work loads. For example, there are about 280 operators at the plant, but each month a number of them, say one quarter or one third, are assigned for duty in areas where they will receive a dose. Operating staff are rotated in their duties in such a fashion to ensure that no one individual receives a dose significantly greater then the average for the group. The dose data shown in Table 8 represents average worker dose, since doses for individual workers are confidential.

5.4 Dose Distribution Based On Work Nature

The exact activities of maintenance or repair work performed and attributed to Dose Distribution are sometimes difficult and time consuming to determine, particularly when workers are assigned to multiple tasks in work groups. However, estimated dose exposure ranges shown in Table 3 can be used for each operating groups, performing their normal duties.

5.5 The Normal Duties

The normal duties of each operating group are generally defined as below:

(1) Operators

Operators are normally responsible for the attendance of systems' operation. They perform various operating functions according to the need of the systems, such as:

- Checking and monitoring system Temperature, Pressure, Level, Flow Conditions etc.,
- Purging, loading, unloading or performing any other operations,
- Making visual check on valves, gauges, pumps, heat exchangers, etc.,
- Reporting any failure on operating equipment,
- Providing input for equipment maintenance, repairs or system outage, etc.

(2) Maintenance

Planned and unplanned outage work is a major part of the maintenance activities.

Typical maintenance work are as follows:

- Replace valve diaphragm, seats and stem packing to ensure no leakage.
- Replace or plug leaking heat exchanger tubes.
- Install new seals on pumps, blowers, airlock door seals, etc.,
- Replace failed motors, heaters, plugged filters, plugged drain valves, etc.,
- Replace leaking gaskets on isolation valves, relief valves or instrument gauges,
- Overhaul equipment,
- Perform periodic inspection on equipment.

The normal routine operating dose exposure is estimated to be between 0 - 0.05 mSv/person/annum. Similar magnitude can also be applied to maintenance.

The dose exposure could be higher if major system outage takes place, or involves accident spill.

5.6 Dose Attribution Based On Systems

The total internal dose received by each of the above operating groups are obtained from these major systems - Heat Transport System, Moderator System and Heavy Water Detritiation System. However, dose is not specifically collected and recorded on the basis of the system that produced it, but on the basis of the operation performed. This is due to the following reasons:

1) Staff could be assigned to work on all systems.

2) Cross contamination between systems could take place during systems outage.

3) For statutory reporting reasons, stations are mainly interested in recording accumulated annual dosage.

4) It would be very costly to administer individual system dosage.

For ITER estimating purpose, one could use the break down of the total internal dosage attributed to these systems as shown in Table 5. One would note that most of the dose is attributed to the Heat Transport System, even though the Heat Transport System concentration is 20 to 30 times less than in the Moderator. This is mainly due to:

(1) There are more components in the HT system,
(2) There are more service done in the HT system,
(3) The Moderator is more leaktight than the HT system.,
(4) HT operates at 10 MPa, while Moderator at 0.7 MPa,
(5) HT operates at 300^0 C while Moderator at 60^0 C.

5.7 ITER Dose Exposure Reference

For ITER to make use of this dose exposure as design estimation (consideration) for Shield/Blanket Cooling System and Divertor Cooling System, and Fuel Cycle and Water Detritiation System, it must make adjustment to the dose data by taking into account the following:

- ITER S/B and DV Cooling System may have 4 or 12 cooling loops.
- CANDU HT and Moderator System each have only two loops.
- ITER S/B and DV operate at approximate 2.2 MPa and >150 °C.
- CANDU HT and Moderator operate at 10 and 0.7 MPa, respectively.
- CANDU HT and Moderator contain approximately 1 and 25 Ci/kg tritium concentration, respectively.
- ITER S/B and DV contain approximately 1 and 10 Ci/kg tritium concentration, respectively.
- The difference in operating temperatures between CANDU and ITER systems.

6.0 CONCLUSION

From the Occupational Exposure Dose statistics the following observations can be made:

1) The Operators, Control and Mechanical Maintenance groups are exposed to the majority of the Tritium Dose at the plant, while the remaining groups are subject to very little exposure.

2) The yearly Tritium Exposure Dosage for all personnel, working in the plant is far below the Regulatory Limits and works out to <u>approximately</u> as follows:

Operators:	< 0.6 mSv
Maintenance: Control	< 0.5 mSv
Maintenance: Mechanical (TRF) (Station)	< 2.25mSv < 0.5 mSv
Others:	< 0.02 mSv

3) An overall Tritium Safe Design, Operation and Handling shall be planned during the design stage and incorporated during the construction stage, as well as followed up by operational procedures. This will reduce and minimize the risk of Tritium Exposure to all personnel working in the plant.

4) It is expected that ITER could have overall Tritium Airborne Levels and exposure dose less than CANDU's, if ITER could make use of CANDU safety design knowledge, in addition to implementing ITER safety design requirements.

5) ITER should factor its design target below the exposure dose data present in this report, in its preliminary design concept, so that all necessary auxiliary systems, which are needed to achieve the design target, can be identified and included in the design.

7.0 REFERENCES

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TABLE 1

Maximum Permissible Doses[a]

Organ or Tissue	Atomic Radiation Workers				Any Other Person	
	Per Quarter Year		Per Year		Per Year	
	(Rem)	(mSv)	(Rem)	(mSv)	(Rem)	(mSv)
Whole body, gonads, bone marrow	3(b)	30	5(b)	50	0.5	5
Bone, skin, thyroid	15	150	30	300	3(c)	30
Any tissue of hands, forearms, feet and ankles	38	380	75	750	7.5	75
Lungs[d] and other single organs or tissues	8	80	15	150	1.5	15

(a) In determining the dose, the contribution from sources of ionizing radiation both inside and outside the body shall be included.

(b) The dose to the abdomen of a pregnant atomic radiation worker after the licensee is informed of the pregnancy of that worker shall not exceed a total of 1 rem, accumulated at a rate of not more than 0.06 rem per two weeks.

(c) The dose to the thyroid of a person under the age of 16 years shall not exceed 1.5 rems per year.

(d) For exposures to radon daughters, the maximum permissible doses (in working level months) apply instead of the maximum permissible doses for the lungs (in rems).

TABLE 2
AIRBORNE TRITIUM CONCENTRATION IN TYPICAL CANDU STATION

LOCATION	AVERAGE CONCENTRATION (MPCA)	MAXIMUM CONCENTRATION (MPCA)
Moderator Vault	<10	<2000
Reactor Vault	<10	<500
Cooling System Room	<10	<50
Heavy Water Management Area	<0.5	<10

TABLE 3
TRITIUM OCCUPATIONAL EXPOSURE IN TYPICAL CANDU STATION

PERSONNEL	AVERAGE INTERNAL DOSE (mSv/person /annum)	MAXIMUM INTERNAL DOSE (mSv/person/ annum)
Operators	0.05	0.6
Control Maintainers	0.04	0.5
Mechanical Maintainers	0.04	0.5
Others	0.02	0.02

TABLE 4
TRITIUM OCCUPATIONAL EXPOSURE IN TRF/HWMB[1]

PERSONNEL	AVERAGE INTERNAL DOSE (mSv/person/annum)	MAXIMUM INTERNAL DOSE (mSv/person/annum)
Operators	0.004	0.149
Control Maintainers	0.02	0.08
Mechanical Maintainers	0.56	2.25
Service Maintainers	0.057	0.23
Others	0.006	0.07

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[1] TRF/D2O: This is the total INTERNAL DOSE received by the staff working in the Tritium Removal and the Heavy Water Detritiation Facility in 1994.

TABLE 5
TRITIUM EXPOSURE ATTRIBUTED BY SYSTEMS[2]

SYSTEM	CONTRIBUTION
Heat Transport System	10 - 20%
Moderator System	5 - 10%
Heavy Water Upgrader	5 - 10%
Tritium Removal Facility	40 - 60%
ALL	100%

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[2] This is the estimated tritium exposure attributed by the major CANDU Reactors Systems. These estimates provide only relative comparison, as there are not common data based on service and maintenance of all these systems.

TABLE 6
TRITIUM HAZARD LEVEL

AREAS	TRITIUM (MPCA)	
	General	**Maximum**
Reactor Containment:	10	50
Confinement:	100	1000
Enclosed Zone 3 Rooms:	0.1	1
Accessible Zone Areas	0.1	1
Fuelling Machine Containment:	10	50
[3]TRF/HWMM:	0.5	50

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[3] Tritium Removal Facility and Heavy Water Management Building.

TABLE 7

Tritium Surface Contamination Level in HWMB

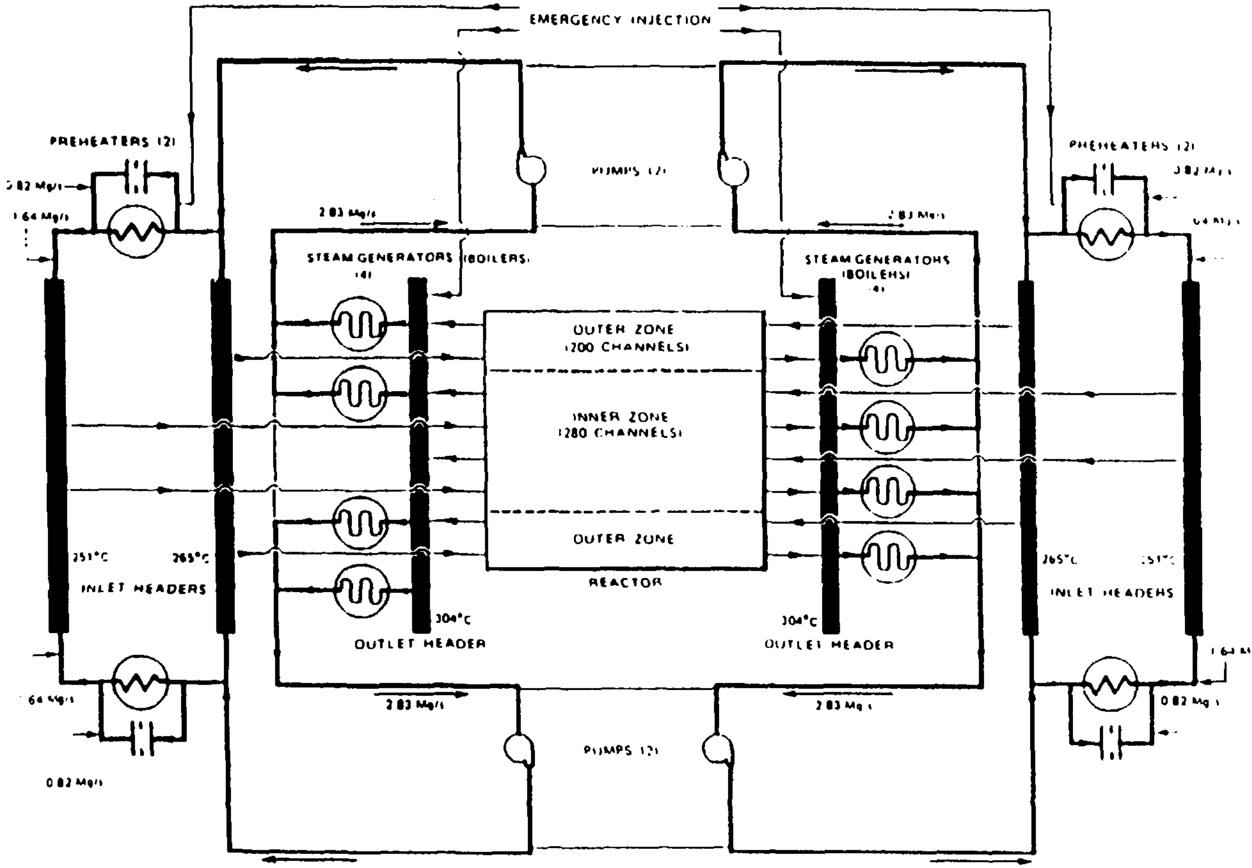
Room Location	1989 - 1993			
	Tritium Surface Contamination[a]		Tritium Surface Contamination[a]	
	Average ($\mu Ci/m^2$)	Maximum ($\mu Ci/m^2$)	Average ($\mu Ci/m^2$)	Maximum ($\mu Ci/m^2$)
TR-004 TRF Chem Lab	<1	<1	<1	<1
D2O Collection Tank Room	<1	<1	<1	<1
TR-102 Vapour Phase Catalytic Exchange Room$^{(\text{Ele. } 100)}$	<1	<1	<1	<1
TR-204 Vapour Phase Catalytic Exchange Room$^{(\text{Ele. } 104)}$	<1	<1	<1	<1
D-003 D2O Upgrader Tower Room	<1	<1	<1	<1
D-100 D2O Control Room	<1	<1	<1	<1
D-107 D2O Drum Storage Room	<1	<1	<1	<1
D-110 TDO Package Unloading Area	<1	<1	<1	<1
D-112 TDO Accessway	<1	<1	<1	<1

[a] 1 MPL Tritium Surface Contamination = 500 $\mu Ci/m^2$

TABLE 8
TRITIUM OPERATIONAL EXPOSURE DOSE DATA

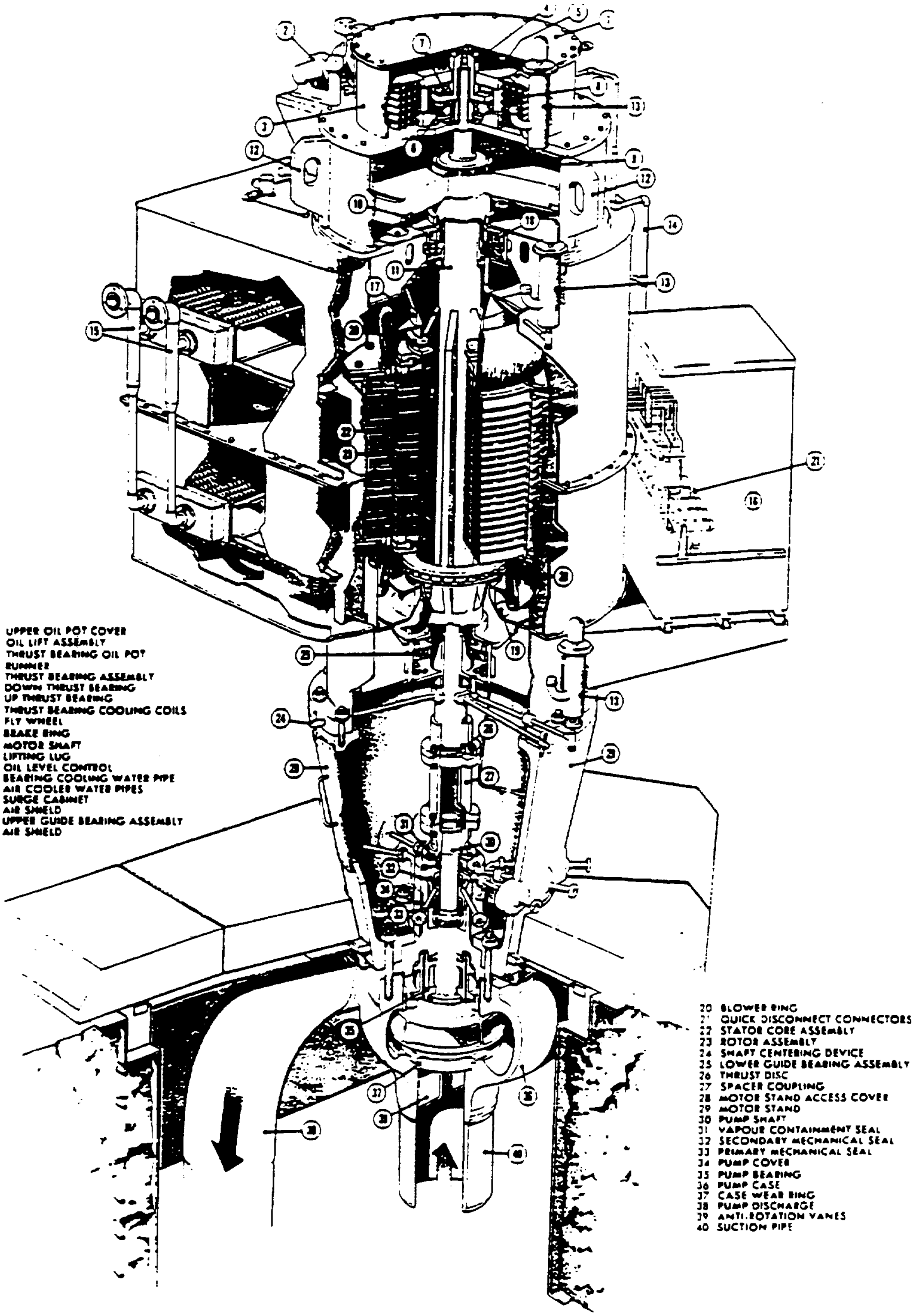
	Persons (Number)	Assigned (Dose)	Month (rem)	Average Dose (rem)
Operators:	283	60	0.213 **January**	0.00355(0.213/60)
	285	75	0.384 **February**	0.00512(0.384/75)
	288	97	0.519 **March**	0.005(0.519/97)
Maintenance: (Control)	148	15	0.063 **January**	0.004(0.063/15)
	148	28	0.089 **February**	0.003(0.089/28)
	157	34	0.113 **March**	0.003(0.113/34)
Maintenance: (Mechanical)	205	84	0.359 **January**	0.004(0.359/84)
	211	88	0.324 **February**	0.003(0.324/88)
	213	107	0.414 **March**	0.003(0.414/107)
Civil Maintenance:	109	15	0.041 **January**	0.0002(0.041/15)
	124	22	0.006 **February**	0.0002(0.006/22)
	134	31	0.054 **March**	0.0017(0.054/31)

In a typical station, out of 2,800 operating personnel, about 1,000 were assigned dose with a total of 20.0 rem (0.2 person-Sievert) due tritium exposure. This works out to be 0.2 mSv/person. CANDU experience has consistently shown that tritium exposure is a small fraction of the total station dose. While there are variations from year to year, tritium dose usually accounts for between 10 - 30% of the total dose.



*The flows indicated are based on the reference design conditions

FIGURE 1-1
Heat Transport System*



1	UPPER OIL POT COVER
2	OIL LIFT ASSEMBLY
3	THRUST BEARING OIL POT
4	RUNNER
5	THRUST BEARING ASSEMBLY
6	DOWN THRUST BEARING
7	UP THRUST BEARING
8	THRUST BEARING COOLING COILS
9	FLY WHEEL
10	BRAKE RING
11	MOTOR SHAFT
12	LIFTING LUG
13	OIL LEVEL CONTROL
14	BEARING COOLING WATER PIPE
15	AIR COOLER WATER PIPES
16	SURGE CABINET
17	AIR SHIELD
18	UPPER GUIDE BEARING ASSEMBLY
19	AIR SHIELD

20	BLOWER RING
21	QUICK DISCONNECT CONNECTORS
22	STATOR CORE ASSEMBLY
23	ROTOR ASSEMBLY
24	SHAFT CENTERING DEVICE
25	LOWER GUIDE BEARING ASSEMBLY
26	THRUST DISC
27	SPACER COUPLING
28	MOTOR STAND ACCESS COVER
29	MOTOR STAND
30	PUMP SHAFT
31	VAPOUR CONTAINMENT SEAL
32	SECONDARY MECHANICAL SEAL
33	PRIMARY MECHANICAL SEAL
34	PUMP COVER
35	PUMP BEARING
36	PUMP CASE
37	CASE WEAR RING
38	PUMP DISCHARGE
39	ANTI-ROTATION VANES
40	SUCTION PIPE

FIGURE 1-2
Heat Transport Pump

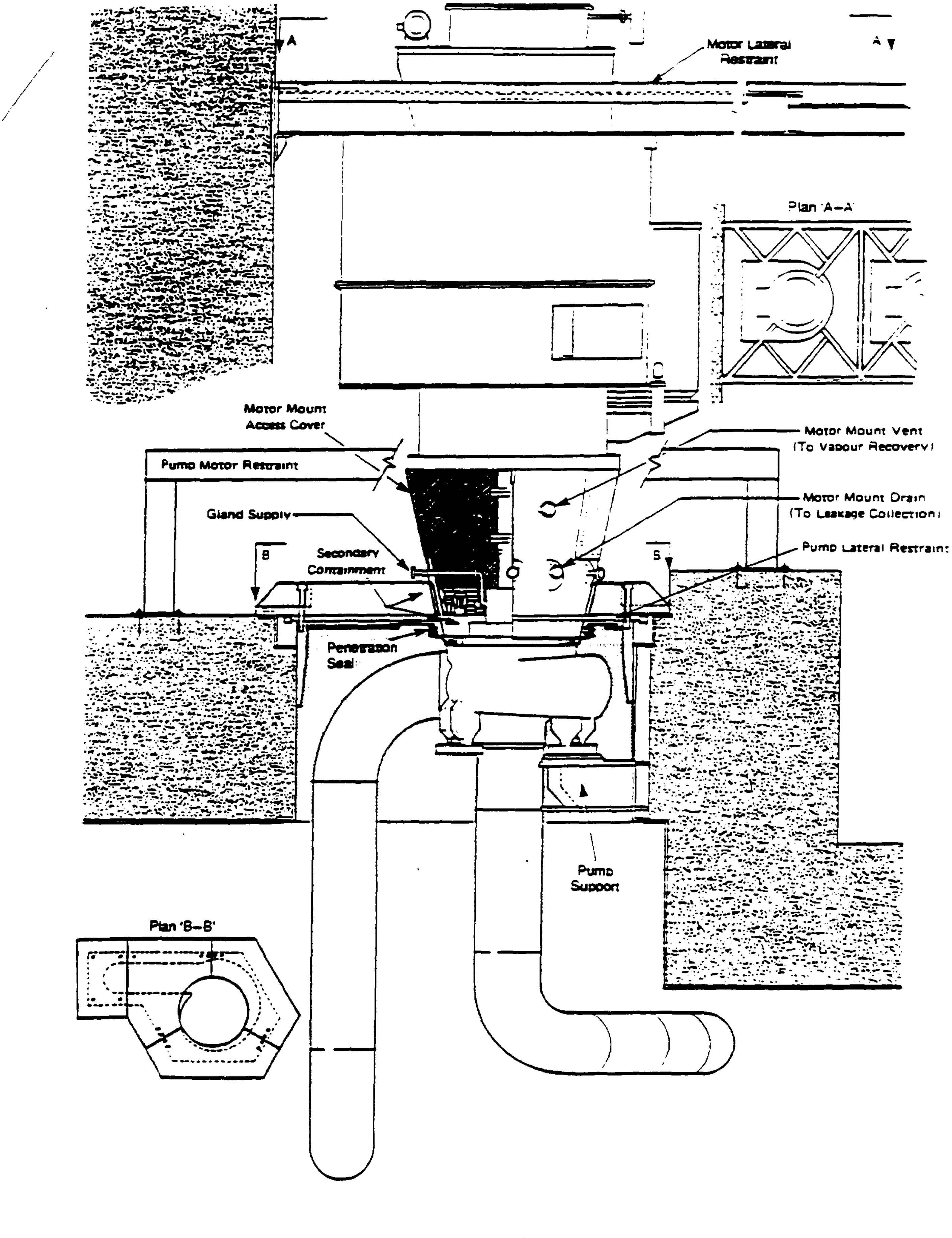


FIGURE 1-3
Heat Transport Pump Seal and Supports

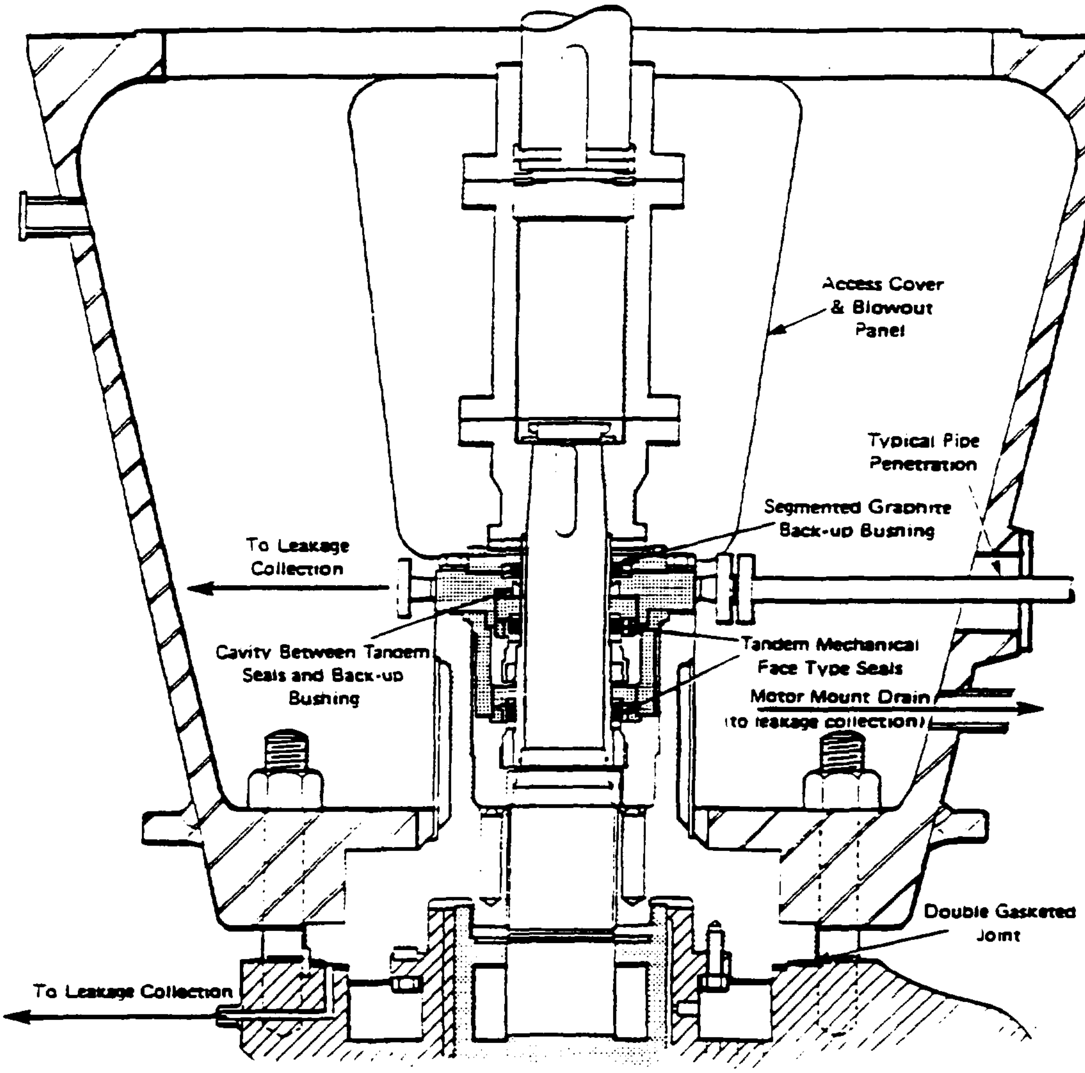
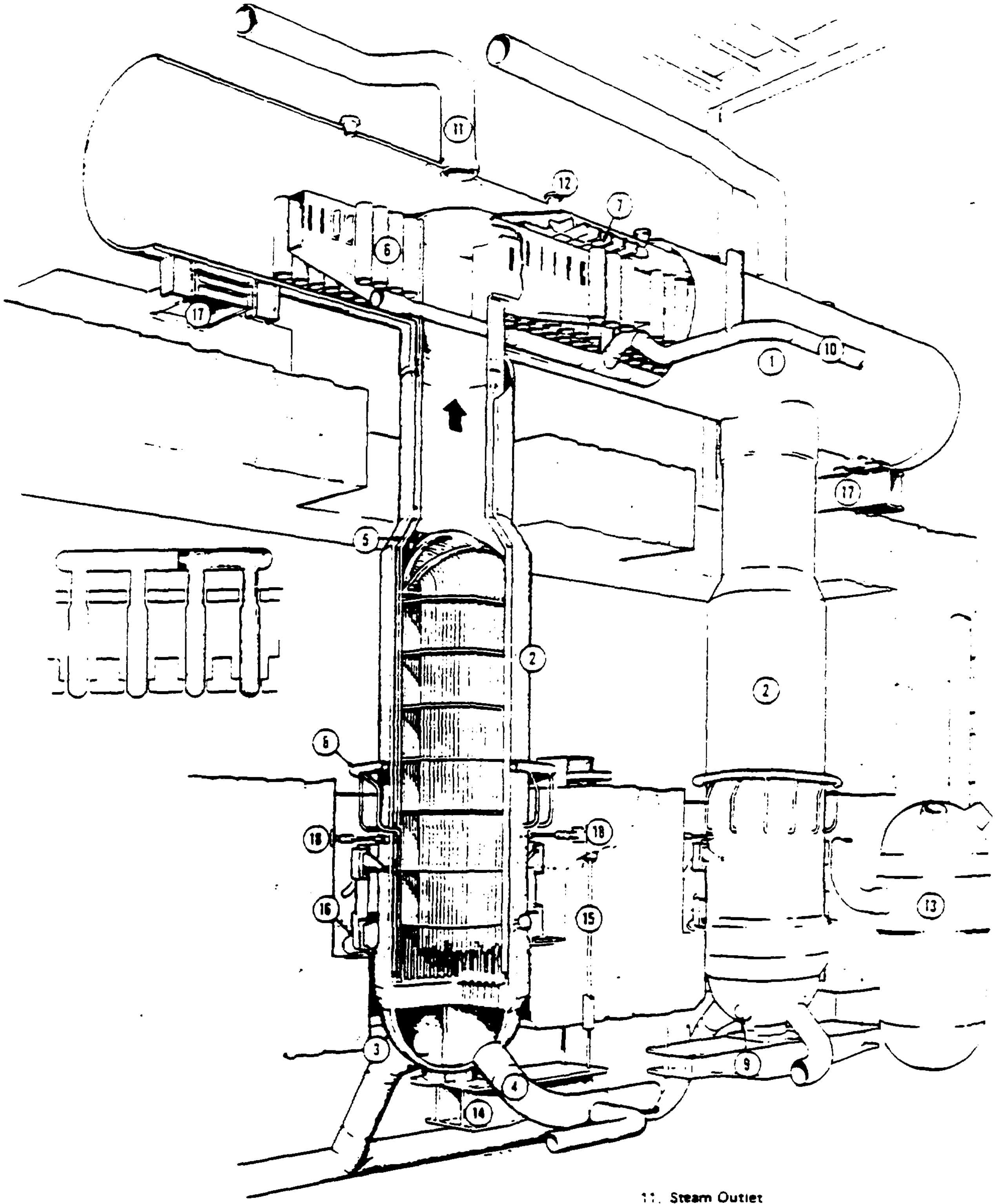
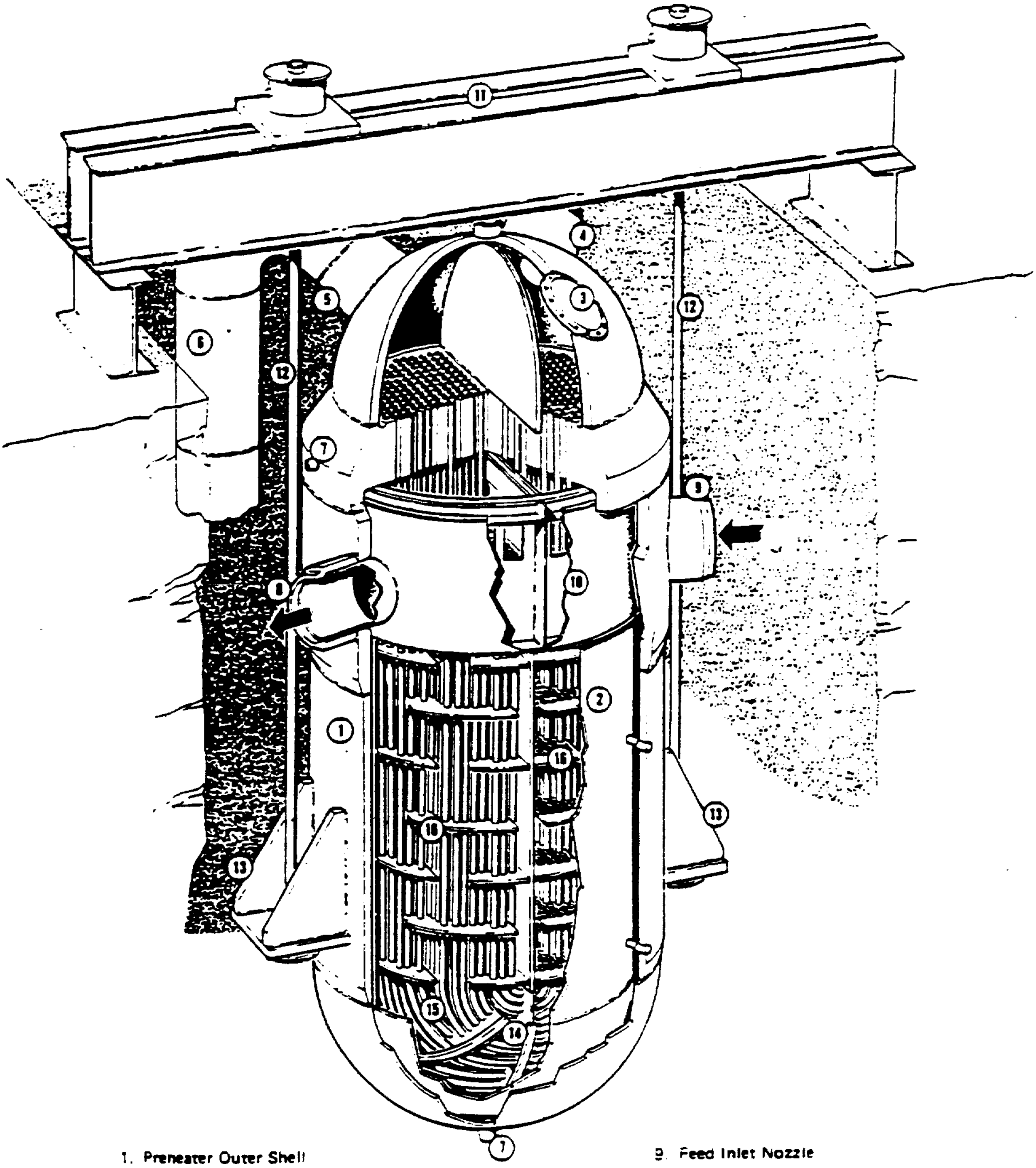


FIGURE I -4
Primary Pump Mount Seals and Bushings



1. Steam Drum
2. Steam Generator (Boiler)
3. Heavy Water Inlet
4. Heavy Water Outlet
5. Downcomer Annulus
6. Cyclone Separators
7. Steam Scrubber
8. Blow-down Piping
9. 16" Manway
10. Feedwater Inlet
11. Steam Outlet
12. Safety Valve Nozzles
13. Preheater
14. Steam Generator (Boiler) Support
15. Support Hangers
16. Steam Generator (Boiler) Vault Seal
17. Drum Seismic Restraints
18. Steam Generator (Boiler) Seismic Restraints

FIGURE 1-5
Cutaway View of Steam Generator (Boiler) and Steam Drum



1. Preheater Outer Shell
2. Shroud
3. Manway
4. Heavy Water Outlet Nozzle
5. Heavy Water Inlet Nozzle
6. Heavy Water Inlet Pipe
7. Drain Nozzle
8. Feed Outlet Nozzle
9. Feed Inlet Nozzle
10. Inlet Flow Distributor
11. Support Beams
12. Support Rod
13. Support Bracket
14. Tube Bend Supports
15. "U" Tubes
16. Baffle

FIGURE 1-6
Preheater

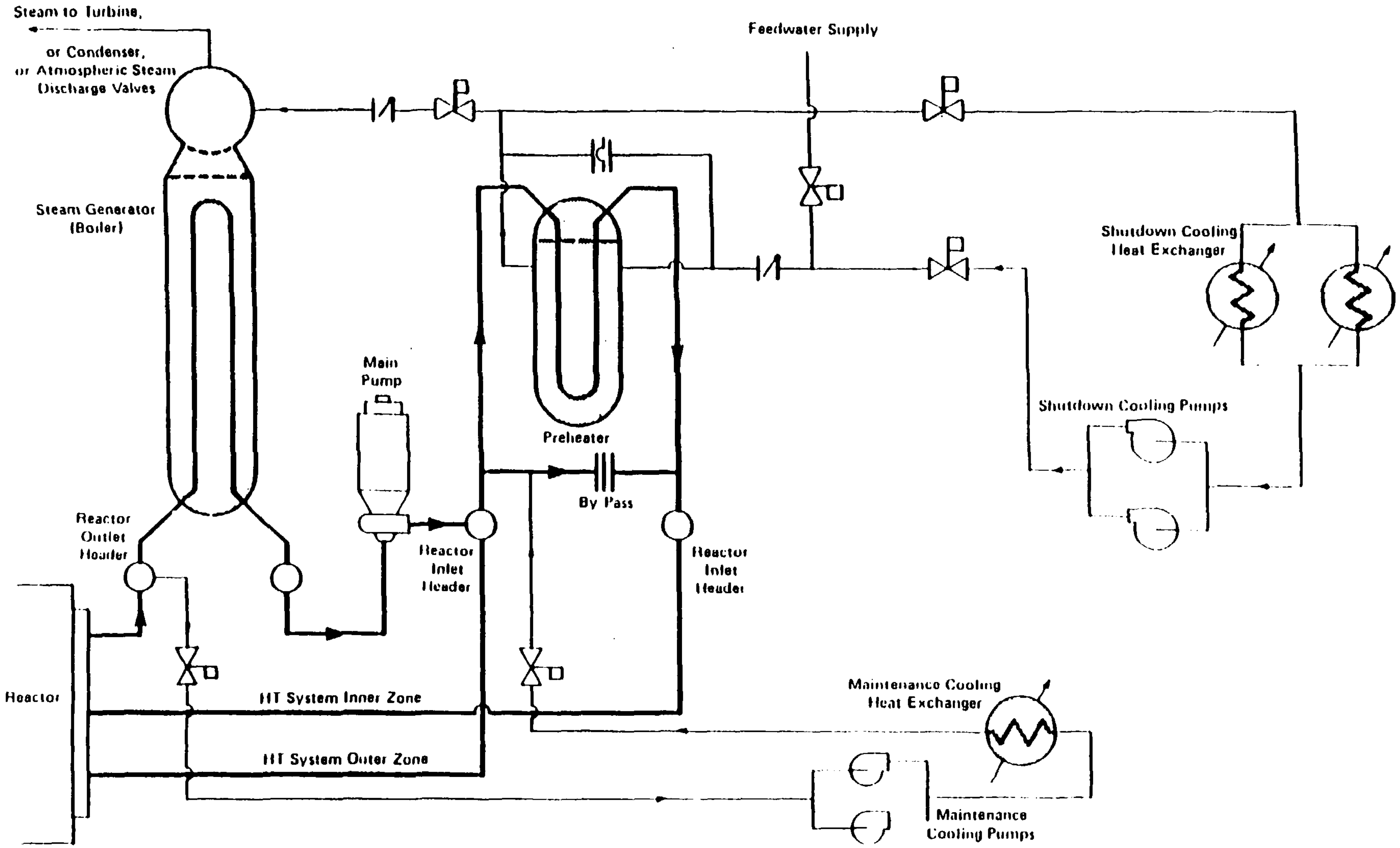


FIGURE 1-7
Heat Transport System Shutdown Cooling and Maintenance Cooling Arrangement

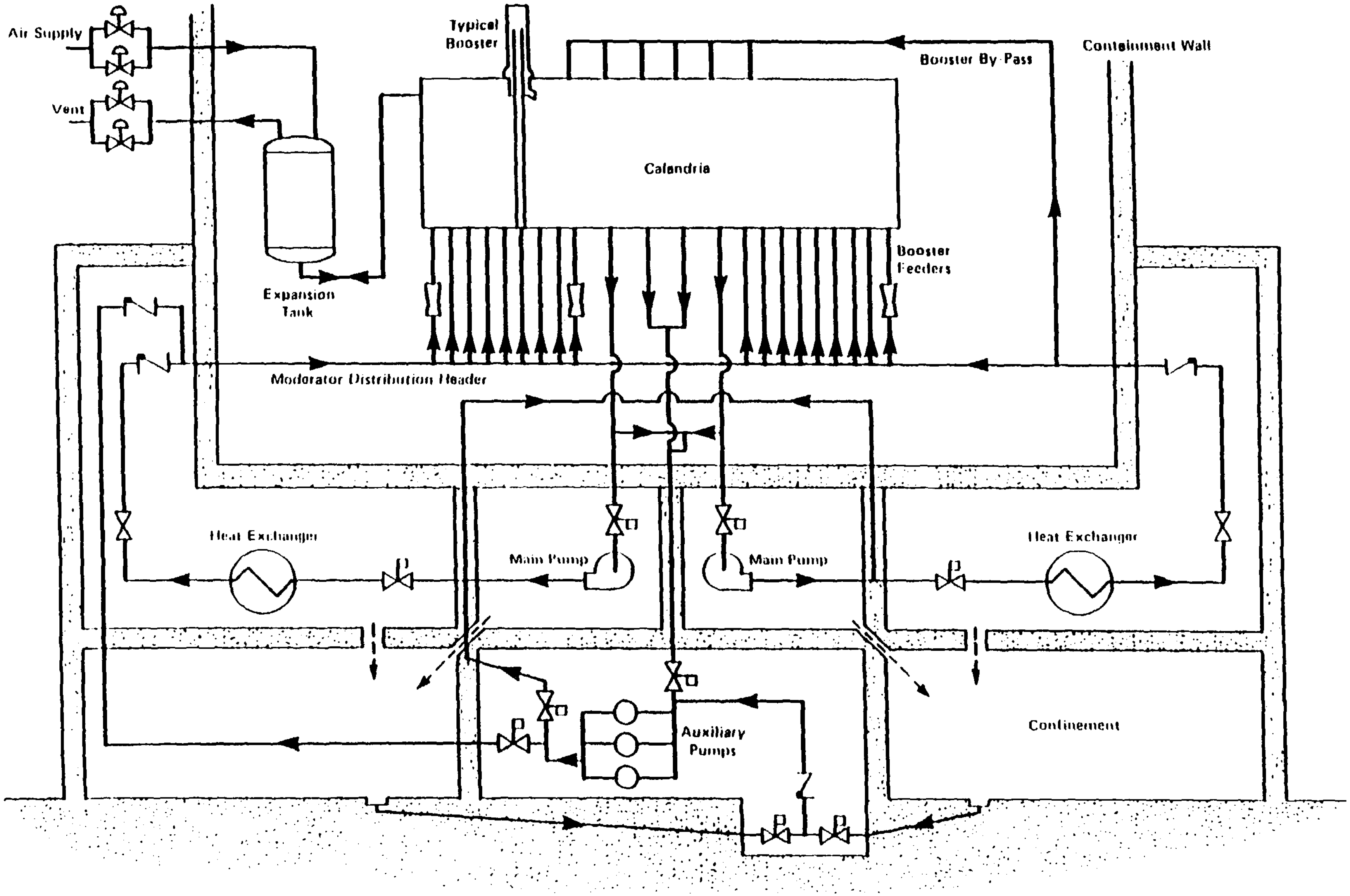
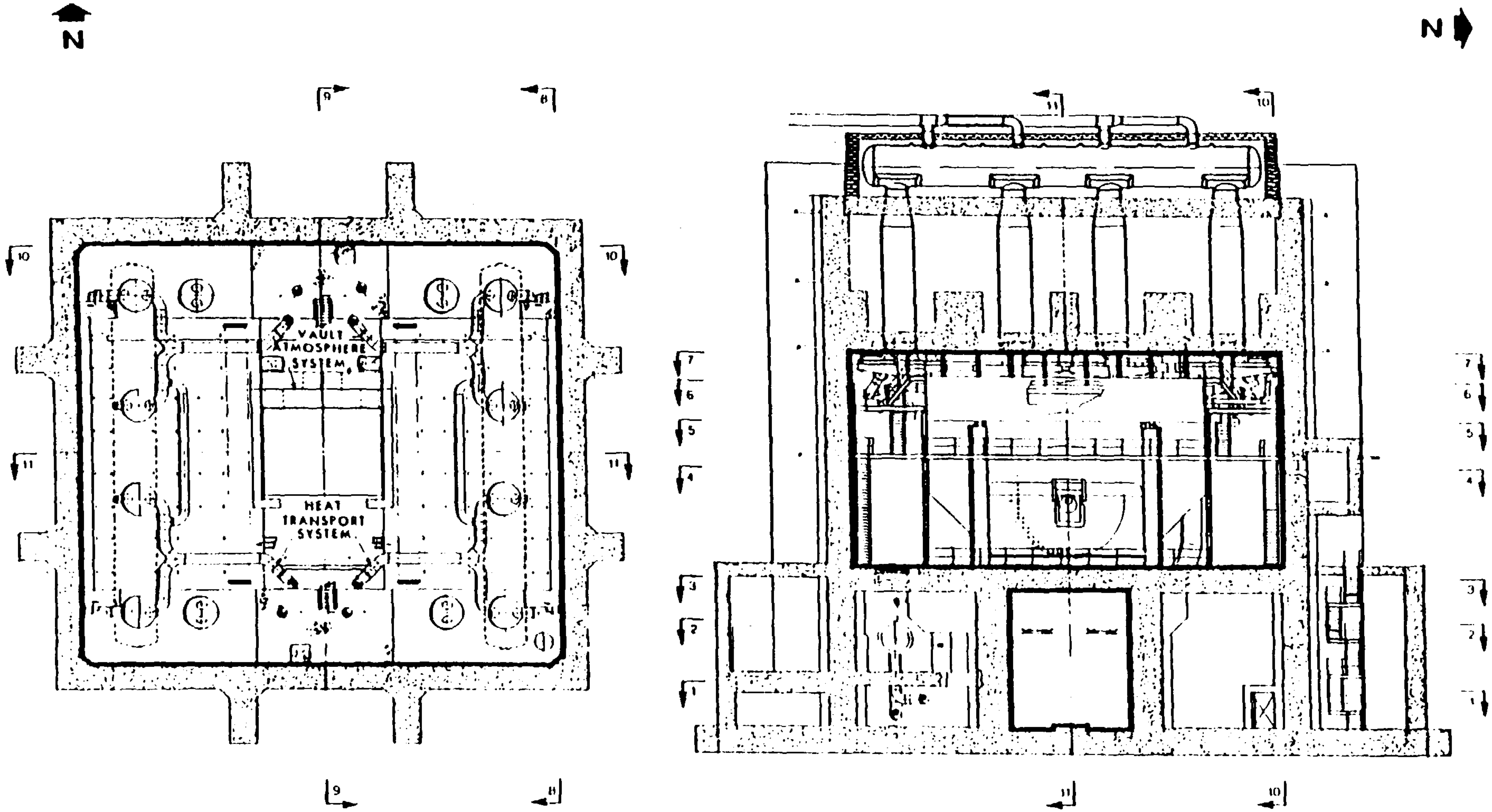


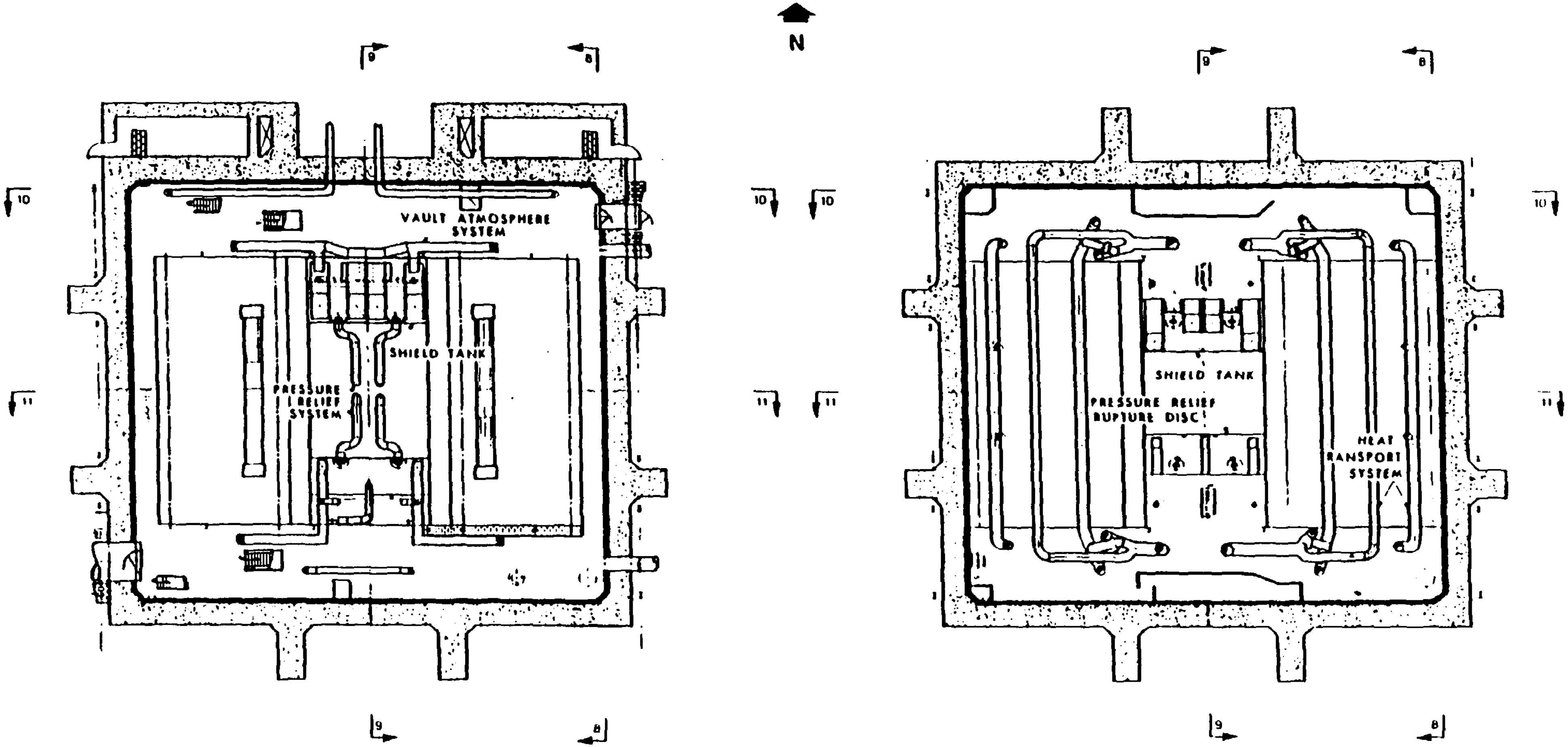
FIGURE 1-8
Main Moderator System



PLAN 7—7

ELEVATION 8—8

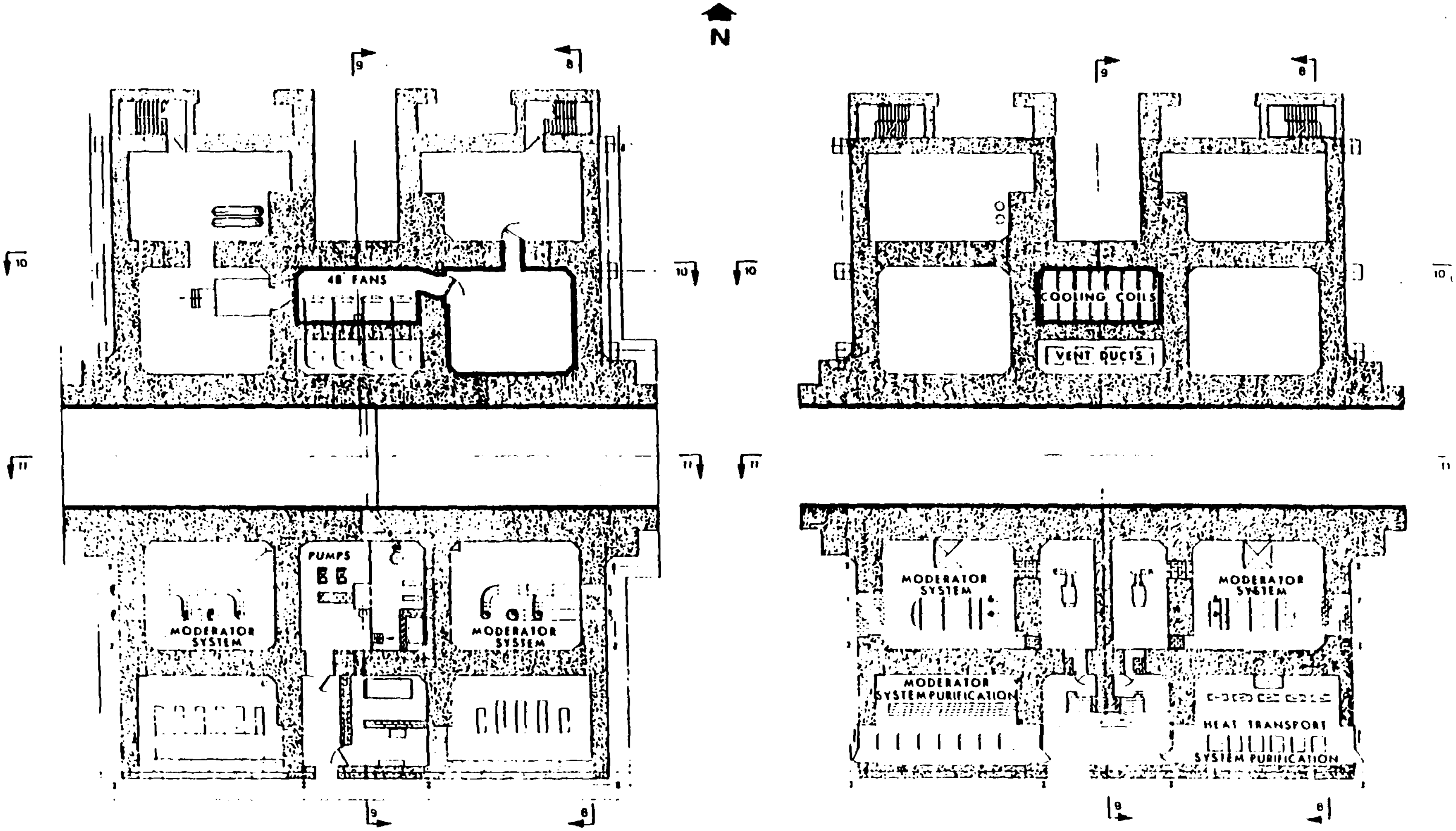
FIGURE 2·1
Heat Transport System Layout



PLAN 5—5

PLAN 6—6

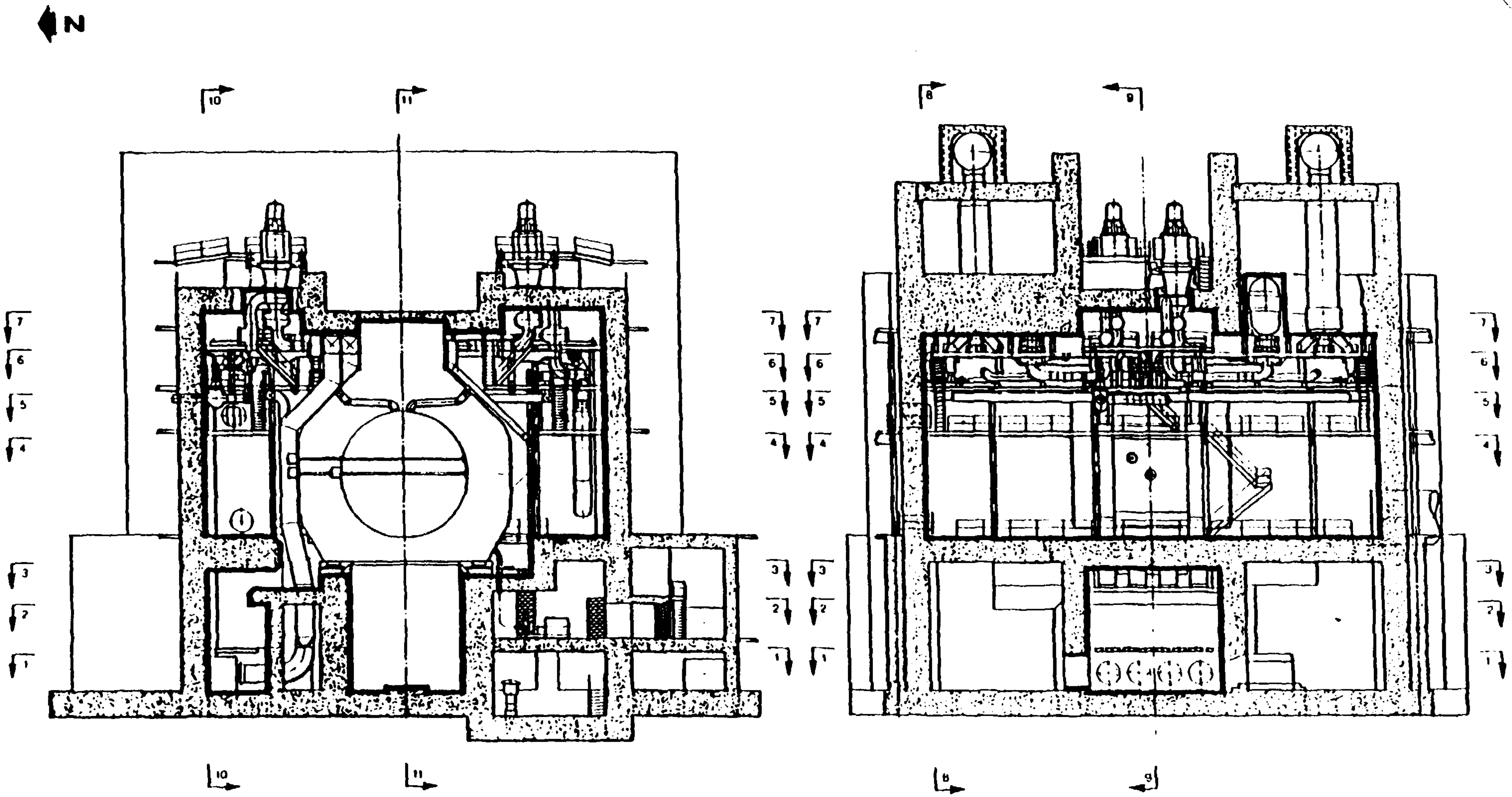
FIGURE 2-2
Heat Transport System Layout



PLAN 1—1

PLAN 2—2

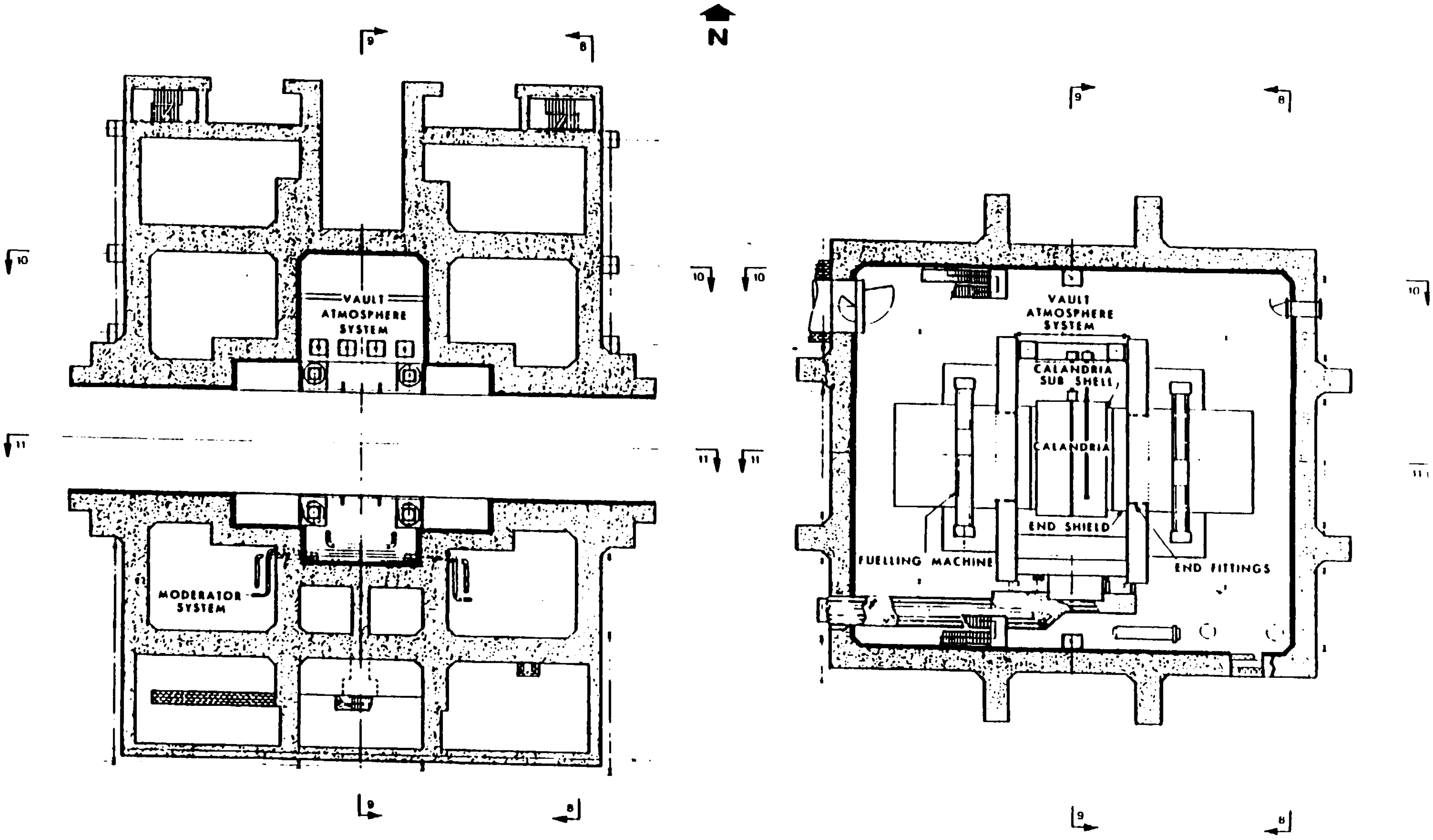
FIGURE 2-3
Moderator System Layout



ELEVATION 9—9

ELEVATION 10—10
LOOKING SOUTH

FIGURE 2-4
Moderator System Layout



PLAN 3—3

PLAN 4—4

FIGURE 2-5
Reactor Vault Layout

Tritium Removal Facility

by Catalytic Exchange and Distillation for Darlington GS

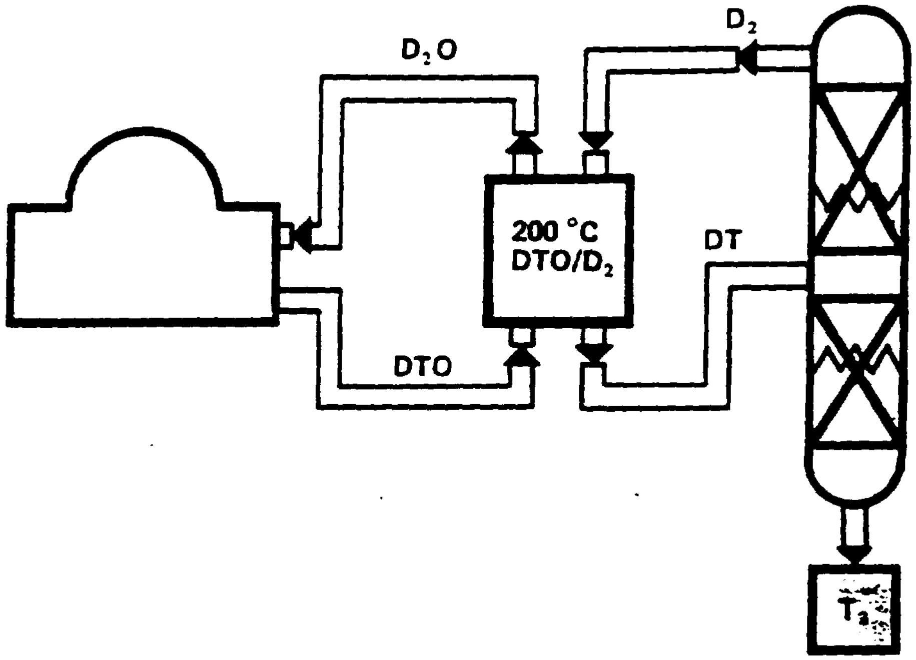


FIGURE 2-.6
TRF- Simplified Flow Diagram

candu.D16