Reactor, Boiler & Auxiliaries - Course 233

MODERATOR AND MAIN MODERATOR SYSTEM

I MODERATOR D_2O FEATURES

There are some important operational features of the moderator D_2O that are discussed below:

1. Moderator Isotopic
2. Moderator Activation Products
3. Moderator Pressure, Temperature

(Moderator chemical control is not included here but is dealt with in chemistry courses and in this course in the section on the moderator purification system.)

1. Moderator Isotopic

(i) Acceptable Range

High moderator isotopic is required so that the moderator can fulfil its prime function of slowing down fission (fast) neutrons efficiently with a minimum of absorption, ie, be an effective moderator. The acceptable range of isotopic in our plants is $\sim$ 99.50% to 100% purity. (Remember that the impurity here is H_2O.)

Moderator isotopic within this range will provide sufficient reactivity to achieve criticality and hence ability to operate at high power. The isotopic is directly related to reactivity and hence to fuel costs (see Table 1).

TABLE 1

Moderator System Isotopic Data (Pickering)

Change in D_2O Isotopic	±0.1%
Δk Change	±3.6 mk
Fuel Cost Penalty	±600,000 $/year

* Zero penalty taken for 99.75% D_2O

The relationship in Table 1 is because the higher the isotopic the smaller the number of parasitically absorbed (wasted) neutrons. This means the fuelling rate is lower at the higher isotopic. A lower fuelling rate is also the same thing as saying that the fuel burn up (MW(th) hr produced/kg U) is higher. 99.75% is used as a reference value for zero fuel cost penalty in calculating fuel costs as this % is the reactor grade D_2O produced by BHWP. In practice, the moderator isotopic is maintained, if possible, at or above reactor grade, see Figure 1, illustrating the PNGS-A isotopics since 1973.

(ii) Lower Limit

Moderator isotopic must be kept at or above a lower limit of around 99.50%. (This number may vary according to the fuel burn up in the core and the fuelling rate being maintained). Operating at around the lower limit will produce a lack of reactivity requiring a compensating positive reactivity to maintain criticality.

This could be provided by the withdrawal of adjuster rods (or insertion of boosters, BNGS-A) if the zone control system cannot maintain average zone level above its lowest operating level. If adequate positive reactivity cannot be provided to maintain criticality using adjusters then the reactor will become sub-critical and shut down. This will occur at about the lower isotopic limit.

(iii) Upper Limit

As far as reactor operation is concerned, there is no upper limit on isotopic, which can be increased by make up with higher isotopic D_2O from the moderator upgrader.

In practice, the limit is determined by two economic factors:

(a) the higher cost of moderator D_2O upgrading as the isotopic increases, mainly due to the cost of extra steam requirements.

(b) the lower cost of fuelling due to higher burn up as the isotopic increases.

The highest isotopic used to date is 99.85%, at Pickering. (See Figure 1.)

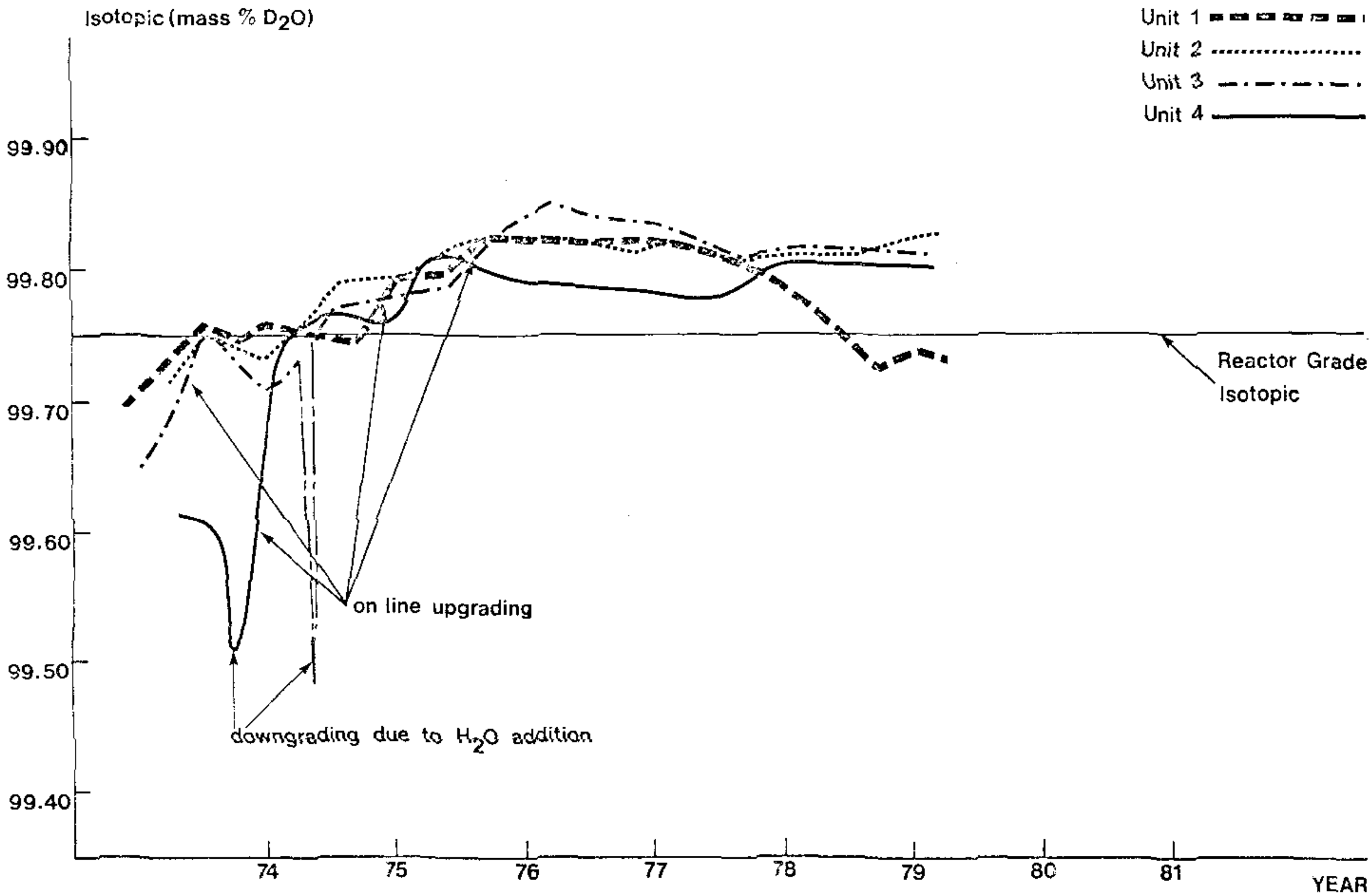


FIGURE 1. - PICKERING MODERATOR ISOTOPICS

Table 2

Change in moderator isotopic from reference operating value 99.75%.	Short term effect on reactor at full power operation.	Long term effect on reactor at full power operation.
I. Isotopic slowly increasing *from upgrader bottom products* being used for moderator make up. (eg, See Figure 1.)	No observable effect, *isotopic change too* small.	Fuelling rate (bundles/ *week) reduced slightly.* Higher average fuel burn up.
II. Downgrading of less than $\sim$0.3%.	Operation continues with a drop in average liquid zone level, (adjuster(s) possibly out).	Increased fuelling rate needed to return (and maintain) zone levels/ adjusters to normal operating positions. Lower average fuel burn up.
III. Downgrading of greater than $\sim$0.3% (this would correspond to $\sim$1 Mg of H_2O added to the moderator typically containing 300 Mg D_2O).	Shutdown, if positive Δk from zones/adjusters is inadequate to maintain criticality.	Lengthy shutdown ($\sim$weeks) until new or upgraded D_2O supplied.

To summarize the above considerations, Table 2 gives the effects on reactor operation (short and long term) as a result of changing the isotopic. This brings out the practical importance of the limits discussed above.

Downgrading During Normal Operation

The isotopic is controlled by periodic make up additions of D_2O at or above the system isotopic. This is necessary as day to day downgrading of moderator D_2O does occur, continually decreasing the isotopic. Sources of this downgrading are:

(a) accidental additions of H_2O or downgraded D_2O by error or by equipment failure.

(b) make up additions of less than system isotopic.

(c) air and H_2O vapour ingress from the moderator D_2O collection system tank returns.

(d) cover gas air and H_2O vapour ingress.

Effect (a) is generally the largest, (b) is controlled by good D_2O management and (c) and (d) are very small.

2. Moderator Activation Products

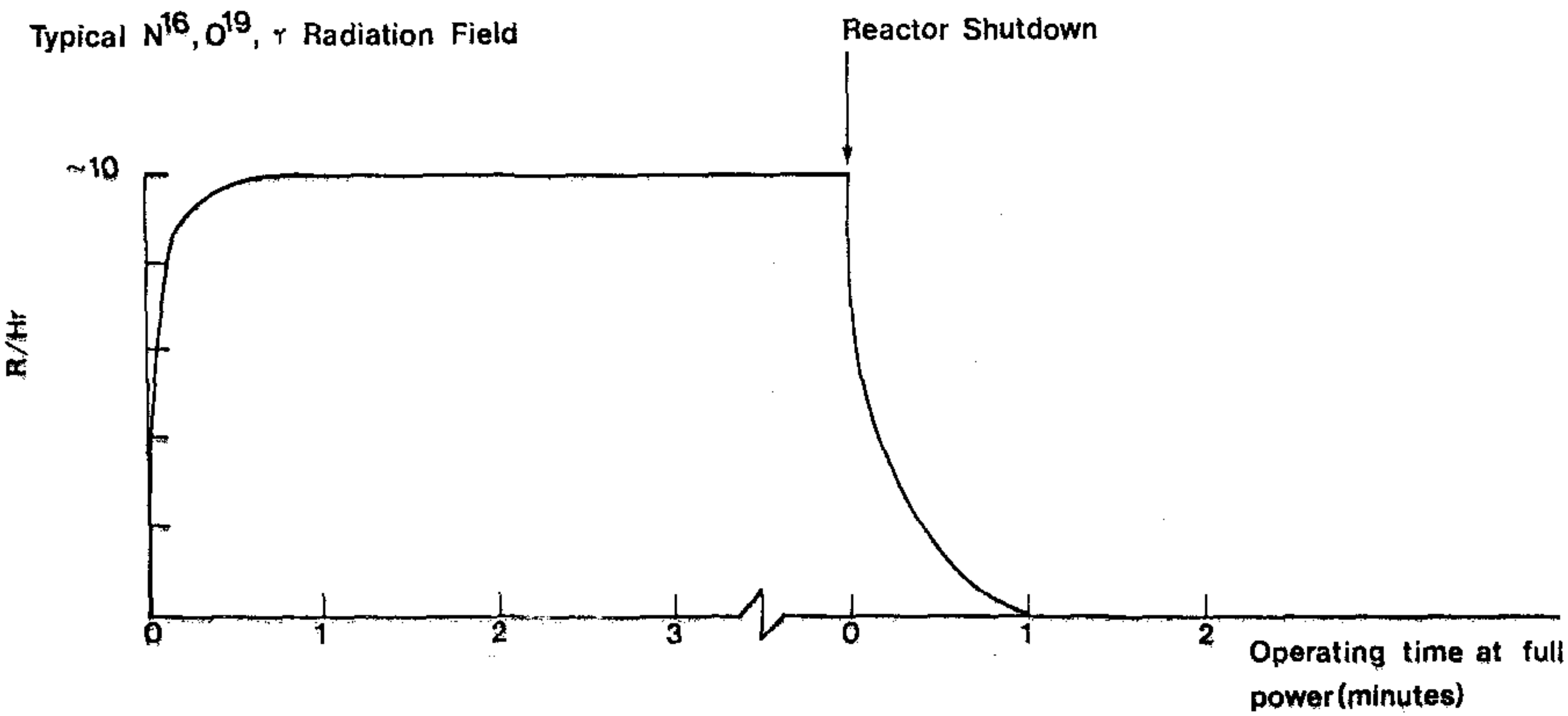
(i) Nitrogen -16, Oxygen -19

These β,γ emitting, short half life (seconds), activation products are produced by neutron absorption reactions (see 433) with the oxygen of the moderator D_2O inside the calandria. They are the main reason for moderator equipment requiring substantial shielding and having limited accessibility on power.

The build up in concentration of these isotopes to an equilibrium level is shown in Figure 2. Note that equilibrium radiation fields are established within minutes of a start up to full power. Units are given in terms of typical moderator equipment radiation fields produced. However the fields will vary considerably according to distance of the equipment from the reactor as the half life is so short.

N.B. Some stations may also have a significant fast neutron field from moderator equipment while at power. The source is from photoneutrons, produced by the reaction: $\gamma + D^2 \longrightarrow p + n$. The γ rays here are mainly from the β,γ decay of N-16.

FIGURE 2. - MODERATOR N-16, 0-19 RADIATION FIELD BUILDUP



Radiation Protection Consequences of N-16, O-19

The intense γ fields from N-16 and O-19 during reactor operation result in moderator equipment being located in access controlled areas. Access for on power maintenance and/or field inspection of equipment is controlled by a door or gate opened by keys obtained from a key accounting alarm system in the control room. Above the 'access power', which is the % of full reactor power at which access hazards are considered to exist in controlled areas, removal of a key provides an alarm for the control room operator to warn him of personnel occupancy of a controlled area.

A further precaution due to these on power access hazards is the requirement for hold-off tags to be placed on reactor power level controls during occupancy so that the reactor neutron flux and resulting N-16/O-19 γ fields are not increased. (In addition, access to controlled areas also requires a Work Authorization and doses received during the access are recorded in the Radiological Log).

Where access is made to access controlled areas when the reactor power is less than the 'access power level' then protection against increases in N-16 fields is provided for field personnel by the unit operator lowering (with production managers approval) the neutronic trip (ie, lin N, rate log N) setpoints to values specified in the operating manual in these circumstances.

(ii) Tritium

This β emitting isotope is produced by thermal neutron absorption in deuterium of the moderator D_2O inside the calandria. Because of tritium's long, 12 year half life the moderator tritium concentration (measured in Ci/kg D_2O) builds up slowly to an equilibrium concentration. Figure 3 shows the build up, assuming continuous full power operation for 50 years with no moderator makeup additions or transfers. Typically the equilibrium concentration will be 50-80 Ci/kg D_2O, which is very high in terms of the radiation protection requirements then necessary.

In practice, the actual build up to equilibrium will be less than that given in Figure 3 due to two operating features:

(a) the reactor capacity factor

(b) the amount of, and tritium concentration in, make-up/replacement additions to the moderator D_2O.

FIGURE 3. - MODERATOR TRITIUM BUILDUP AT FULL POWER (NO MAKEUP).

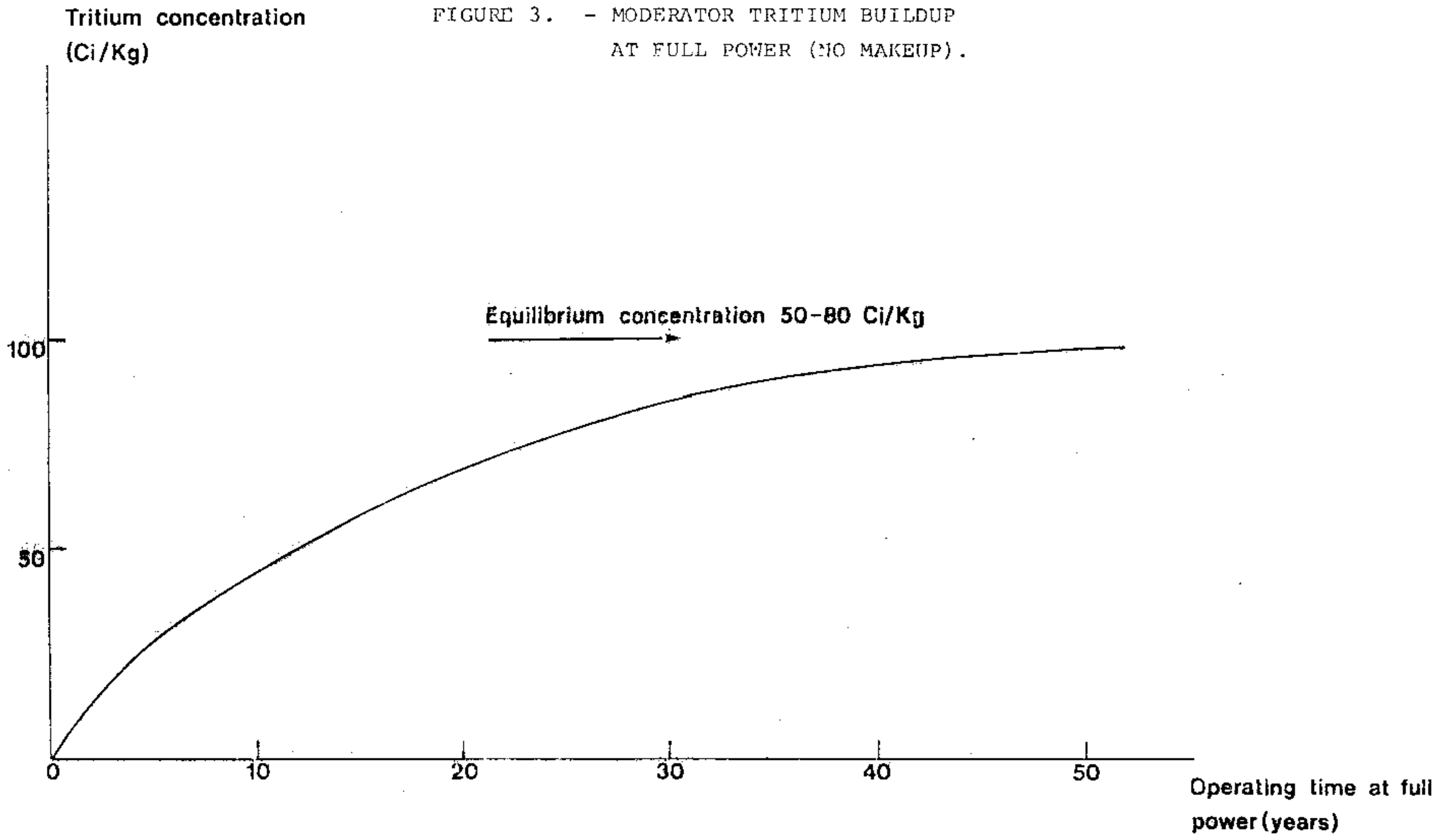
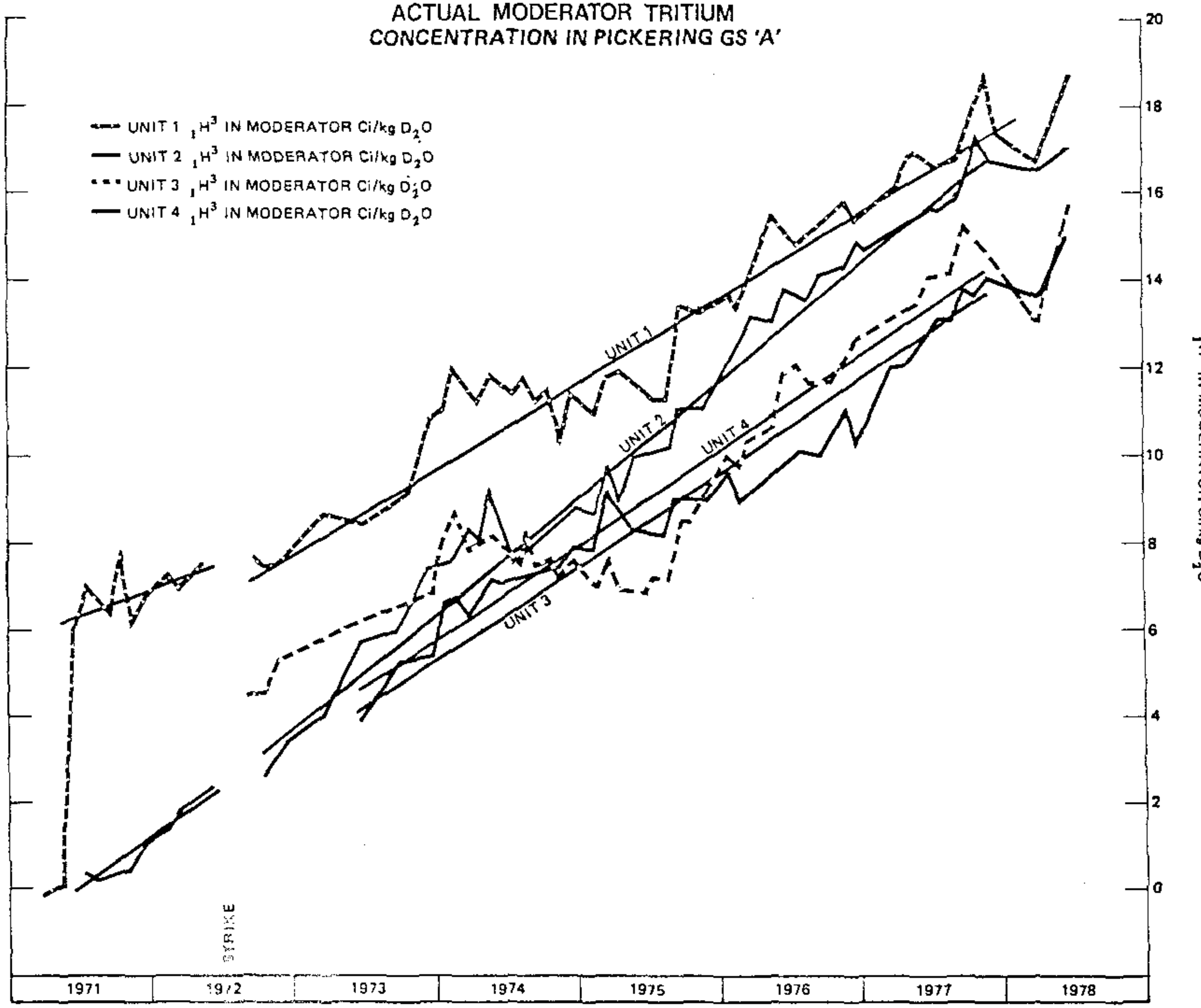


FIGURE 4
ACTUAL MODERATOR TRITIUM
CONCENTRATION IN PICKERING GS 'A'



The actual variation in moderator tritium concentration during 1971 - 1979 is shown for the Pickering A Units in Figure 4.

The straight lines show the average values, variations from these lines are due to (a) and (b) above. No very significant increases or decreases are evident except the initial 'increases' due to the use of tritiated D_2O from other plants/units for the initial moderator charge of units 1, 3 and 4.

Radiation Protection Consequences of Moderator Tritium

Continual build up of tritium concentrations to 50-80 Ci/kg D_2O is very undesirable as field access to moderator system equipment becomes more and more restrictive as the station gets older.

In addition high Curie concentrations in the moderator do become a major source of the tritium airborne emissions to the environment which could become limiting as far as the tritium Derived Emission Limits (DEL) are concerned.

As a result of the long tritium half life there will be no significant reduction in moderator tritium concentrations when the reactor is shut down. This is in contrast to N-16 on shutdown.

Airborne tritium in the moderator equipment rooms can however be reduced on shutdown (compared to full power operation) if equipment is isolated and depressurized. In this case leaks are minimized enabling the vapour recovery system to remove the tritiated D_2O vapour in the atmosphere. After a few years of moderator tritium build up, opening up of moderator system equipment for maintenance will produce concentrations so high as to require the mandatory use of plastic suits and hoods.

Reduction of Moderator Tritium Concentrations

There is only one long term solution to reducing moderator (and also HT) tritium concentrations and that is to extract the tritium in a tritium separation plant. Ontario Hydro is expected to be operating this type of plant by 1988.

The shorter term solution, which is currently being carried out, is to minimize tritium doses by a tritium displacement program. This program involves removing tritiated HT D_2O from operating units and adding it to the moderator systems of new stations. The HT systems are then made up/replenished with non-tritiated, virgin D_2O. The rationale for this program is discussed below.

Comparison of Moderator and HT Tritium Concentrations

A difference with important practical consequences exists between the equilibrium tritium concentrations in HT and moderator systems. Moderator equilibrium concentration will be $\sim$30 - 40 times the HT equilibrium tritium concentration.

Two fundamental reasons for this large difference are:

(1) The thermal neutron flux is higher in the moderator than in the HT D_2O by a factor of about 2. The reason for this is that the moderator is the source of thermal neutrons while the fuel (closer to the HT D_2O) is a thermal neutron sink (absorber).

(2) The fraction of time spent by the HT D_2O actually inside the core (ie, fuel channels) relative to the total circulation time in the main system (ie, feeders, boilers, pumps) is much smaller than the same fraction for moderator D_2O. Therefore moderator D_2O spends longer inside the core than HT D_2O and hence absorbs more thermal neutrons and therefore has a higher tritium concentration.

Another way of saying the same thing is that most of the HT D_2O is outside the core while most of the moderator is in the core (calandria). This effect contributes about a factor 15 to the tritium concentration differences.

It is desirable to keep both moderator and HT tritium concentrations as low as possible, but especially important to keep HT concentrations low because the HT system is a high pressure system and contains hundreds more potential leakage points than the moderator system. HT D_2O is usually kept below 2 Ci/kg by adding either virgin or less active water (see 30-1). HT D_2O containing more than 2 Ci/kg of tritium is used for moderator system make up.

This technique of tritium displacement then tends to decrease the HT tritium at the expense of the moderator tritium and has an important application in D_2O management in the plant in that high Curie moderator water should not be added to low Curie HT water. This would result in increasing unnecessarily the tritium concentration of low Curie water.

3. Moderator Pressure and Temperature

(i) Pressure

Low pressure operation of the moderator is a very desirable feature of the CANDU system. Unlike a US Pressurized Water Reactor (PWR) which requires a large, high strength complex pressure vessel to contain high pressure, high temperature moderator, the CANDU uses a relatively simple and inexpensive low pressure calandria vessel and low pressure equipment for the moderator system.

The maximum pressure in the moderator circulating system is at the moderator pump discharge (typically 1-2 MPa) the specific value depending on the pressure supply requirements of the various systems/equipment supplied with moderator D_2O. Moderator pressure in the calandria itself is fixed by maintaining the He cover gas, above the moderator, at just above 1 atmosphere (see section on cover gas).

It is also important to realize that the D_2O system pressure in the moderator heat exchangers is greater than the pressure of the light water (low pressure service water) providing the heat sink for the heat exchangers. This minimizes the possibility of downgrading the moderator in the event of a moderator heat exchanger tube leak. The disadvantage however is that a tube leak will then lead to a tritiated D_2O leak into service (lake) water which is likely to lead to a forced outage due either to the expense of replacing lost D_2O or to the quantity of tritium being released to the environment.

Maximum overpressure of the moderator in the calandria is determined by the rupture pressure of the calandria rupture discs (typically $\sim$140 kPa(g)) used to protect the calandria and in-core components.

(ii) Temperature

As boiling moderator D_2O would be an undesirable moderator (because of the lack of uniform density which would produce localized in-core reactivity effects), it is kept in the liquid phase.

The minimum pressure in the calandria is fixed by the cover gas at 1 atmosphere so that the maximum (calandria outlet) moderator temperature will have to be controlled at less than 100°C. Our plants maintain an actual maximum between 40°-80°C, depending on the plant. Temperature control is achieved by control valves regulating the flow in the low pressure service water to each moderator heat exchanger. The temperature limits set will be specific to each plant but will be for the same general reasons, ie, to prevent undesirable thermal stresses between the calandria and the end shields which have separate cooling systems.

An advantage of the low temperature of the CANDU moderator (in addition to the advantage of low pressure) for plants without a moderator dump system, is that in a severe accident involving loss of coolant with fuel overheating and ruptured pressure tubes, the moderator can act as a heat sink. This useful heat sink would not be available in a CANDU with a dump tank (nor in a PWR reactor where the moderator is the coolant).

Moderator temperature will also affect the reactivity as mentioned above. A boiling moderator would produce non-uniform reactivity effects which is undesirable from a zone control point of view. In the liquid phase the reactivity effect of temperature is not very large (a few μk/°C) so that a fairly large moderator temperature change ∿20-30°C would be needed to produce any measurable change in reactivity (∿ fraction of a mk) as seen in a change in liquid zone level. The reactivity effect may be positive or negative with temperature depending on the fuel burnup (see 227 notes).

One practical use which could be made of this effect is to provide extra reactivity on a reactor trip to extend the poison override time by changing the moderator temperature setpoint. However, as the reactivity available is small and as any change in temperature may come closer to the limits set for the mechanical reasons mentioned above, little use is made of this feature in our plants.

A further point of importance is that precautions should be taken with moderator equipment supplied with service water cooling or with moderator D_2O equipment in areas of ambient temperature <4°C. These precautions will help to prevent freezing of D_2O and hence possible equipment damage, as D_2O freezes at 3.8°C.

II. MODERATOR MAIN CIRCULATING SYSTEM

1. Functions of the System(i)

The main function of the moderator circulating system is to cool the moderator. The moderator must be cooled regardless of reactor power level.

In addition, this system also provides D_2O tie-in connections for various components and systems, for cooling supply and other functions. The moderator circulating system also maintains a required moderator level in the calandria. (In units with dump tanks this is done in conjunction with the helium cover gas system). The control methods used to perform this function and the reasons for them will not be discussed in these notes. The methods differ between stations; station systems lessons should be referred to for specific details.

Some of the major functions of the main moderator circulating system are discussed below in more detail.

(a) Moderator Cooling

To appreciate the cooling process all the heat sources in the moderator are considered first and discussed below. Table 3 gives a summary of heat sources for different reactor operating states. Typical values in MW(th) are quoted for a 540 MW(e) unit.

Heat source A is the thermalization (slowing down) by moderator D_2O of fast neutrons released by the fission process. The heat source value will be proportional to the neutron power.

B is the absorption in the moderator D_2O of fission γ's (prompt γ's). As with A the reactor has to operate at a significant neutron power level for this to be a heat source.

On shutdown, both A and B heat sources are effectively gone within the 2 to 3 seconds that the reactor takes to shut down.

(i) Do not confuse the system functions with the function of the moderator D_2O itself, ie, slowing down fast neutrons.

C is the absorption of fission product γ radiation which, on shutdown, decays much more slowly than A and B. The decay rate is approximately a factor ten in the first day.

Heat source D is thermal radiation and conduction from hot pressure tubes and end fittings into the moderator, via the annulus gas space, whenever the HT D_2O is hot pressurized (reactor at power <u>or</u> hot shutdown).

Source E is the absorption of β, γ radiation emitted from activated components in contact with, or close to, the moderator. Example of these components are:

- calandria
- calandria tubes
- pressure tubes
- end fittings
- end shields
- reactivity mechanisms and associated guidetubes.

This heat source will be present during operation and shutdown. During shutdown, radioactive decay will decrease this heat source slowly, as with C above.

Moderator pump heat F is always present when the pumps are operating, and is a small contributor to the moderator heat. The only practical use of this pump heat is to help raise moderator temperature to its operating value prior to reactor startup (heat from the hot fuel channels is also useful for this purpose).

The net heat input into the moderator system is then the sum of all the above minus the moderator system heat losses to the ambient (surrounding) atmosphere. These heat losses are very small due to the low temperature operation and are unimportant.

The main moderator system cooling capability then has to be adequate to remove the net heat produced by the above sources and to be able to maintain the moderator temperature at the required setpoint. At full power therefore, all duty pumps and heat exchangers will be required, but during shutdown a reduced cooling capability is adequate, see Table 3.

Table 3: Moderator D_2O Heat Sources

REACTOR STATE	HEAT SOURCE IN MODERATOR	TYPICAL MW(TH) FOR A 540 MW(e) UNIT		MODERATOR SYSTEM DUTY REQUIREMENT
FULL POWER	A. Fast neutron slowing down. B. Absorption of fission γ's.	62	90	100% of system cooling capacity needed (all duty pumps on, all HX's in service).(i)
	C. Fission product γ absorption.	20		
	D. Heat from fuel channels.	2.6		
	E. β,γ absorption from activated components.	5.0		
	F. Pump heat.	0.4		
SHUTDOWN, MODERATOR IN CALANDRIA, HT D_2O HOT	C. D. E. F.	20 (max) 2.6 5.0 (max) 0.4 (max)	28(ii)	One pump, one HX adequate a few hours after shutdown.
SHUTDOWN, MODERATOR IN CALANDRIA, HT D_2O COLD	C. E. F.	20 (max) 5.0 (max) 0.4 (max)	25	One pump, one HX adequate a few hours after shutdown.

(i) If boosters are used (eg, BNGS-A) then their heat contribution could add as much as ∿80 MW(th) at power from fission heat and fission product heat, so extra auxiliary moderator pumps will be installed to provide additional reliability.

(ii) This will decrease by about a factor ten during the first day following a shutdown.

(b) Component Cooling by Moderator System

While providing a heat sink for the heat deposited by the various heat sources discussed above, the moderator heat exchangers also provide an important cooling function for various reactor components. Table 4 summarizes these components and states how cooling is provided under different reactor operating conditions. Of these components, A to C, which are in core, are cooled at full power by natural convection circulation of the moderator and some forced convection flow from the calandria inlet line.

To aid in this type of cooling, the in-core guide tubes for adjusters, control absorbers, SDS2 injection tubes and shut-off rods are perforated. This feature allows the rods and cables inside the tubes to be cooled by direct contact with moderator D_2O.

For out-of-core components D in Table 3, sprays are installed in the inside of the guide tubes at Pickering NGS-A just below the reactivity mechanism deck. These sprays are supplied by a line from the moderator heat exchanger outlet (at the lowest moderator D_2O temperature) to provide moderator D_2O to cool the out-of-core guide tubes and the reactivity mechanism rods and/or cables inside, during operation and shutdown. The main source of heat in these out-of-core components is absorption of neutron, beta and gamma radiation from the reactor core.

Stations after Pickering NGS-A omit this feature, as natural convection via the reactivity mechanism cover gas (He) is adequate for heat transfer. This is acceptable as all stations after Pickering NGS-A have large volumes of shield water (H_2O) around the calandria and the out-of-core guide tubes, and this provides adequate heat conduction.

When the reactor is shutdown and the moderator removed or dumped from the calandria, cooling of the components A, B and C cannot be done by natural convection of the bulk moderator. It is nevertheless important to cool these components even during shutdown when there is no moderator in the calandria. The heat is produced in them on shutdown due to absorption of β,γ radiation from fission product decay and activated core component decay. In particular, the calandria tubes require adequate cooling, as tube temperatures above normal would lead to undesirable stress, as a result of thermal expansion, on the calandria end shields into which the tubes are rolled. Cooling is then achieved by the calandria

Table 4: Cooling Function of Moderator System

COMPONENT	COOLING METHOD		
	FULL POWER	REACTOR SHUTDOWN	
		MODERATOR IN CALANDRIA	MODERATOR OUT OF CALANDRIA
A. CALANDRIA	Circulation of moderator	Circulation of moderator	He or air filling, calandria sprays*
B. CALANDRIA TUBES	Circulation of moderator	Circulation of moderator	He or air filling, calandria sprays*
C. IN CORE REACTIVITY MECHANISM COMPONENTS	Circulation of moderator	Circulation of moderator	He or air filling, calandria sprays*
D. OUT OF CORE REACTIVITY MECHANISM COMPONENTS	(i) Moderator sprays* (ii) Thermal conduction and thermal radiation to shield water	(i) Moderator sprays* (ii) Thermal conduction and thermal radiation to shield water	(i) Moderator sprays* (ii) Thermal conduction and thermal radiation to shield water
E. DUMP TANK	Dump Tank sprays	Dump Tank sprays	Dump Tank sprays
F. DUMP PORTS	Dump Port sprays	Dump Port sprays	Dump Port sprays
G. BOOSTER RODS	Forced circulation by moderator system	Forced circulation by moderator system	Natural convection cooling

*Pickering NGS-A

sprays, which operate continually during operation and shutdown. The calandria sprays are normally submerged in the moderator while the reactor is at power so that their cooling function is actually used only when the moderator level is lowered.

Reactors without dump tanks are not equipped with calandria sprays as it will be only rarely that the moderator is not available in the calandria. Helium (or air) filling of the calandria is adequate for natural convection cooling in this case, providing the moderator is not removed from the calandria during the first few days following a shutdown while the β,γ heat source is rapidly decaying.

In reactors with dump tanks, cooling is also provided for the internals of the dump tank and dump ports by sprays supplied with moderator D_2O for reasons similar to those that required cooling supplied to the calandria tubes in reactors with dump tanks.

An additional cooling function at Bruce NGS-A is booster rod cooling. As noted in Table 3, the heat produced by boosters can be very significant compared to the other heat sources, and so cooling is very important, especially as overheating boosters can give rise to large quantities of fission products in the moderator as a result of a rod defect. Hence additional cooling reliability in the main moderator system is required. At Bruce, three auxiliary pumps, on a more reliable class of power than the main pumps, provide backup cooling in the event of a main pump failure. Lack of cooling water for boosters even for a few minutes, if they are in core or just removed from core, is likely to lead to rod defects so this cooling function is extremely important.

Moderator D_2O Supply Functions of the Moderator Main System

There are a number of auxiliary moderator systems, tied into the main system, which are supplied with moderator D_2O for various purposes. The tie-in locations are illustrated in Figure 5 and discussed below.

(i) Moderator Purification System:

A few percent of main moderator flow is taken from the heat exchanger outlet. At this point, the temperature is the lowest in the moderator system. This take off point is desirable to minimize the possibility of overheating the purification system IX resin. The pressure required to circulate purification flow through the purification system components is also designed to be adequate from this tie-in point. The ΔP required for this purpose is obtained from that between the heat exchanger outlet and the pump suction as shown in Figure 5. This ΔP also provides the driving force for the resin slurry operation during spent resin and fresh resin transfer from and to the moderator IX columns.

(ii) Spray Supplies:

If the reactor has calandria and dump tank sprays they will be supplied from the moderator heat exchanger outlet as in (i) above because of the requirement for low temperature and adequate pressure supply head. The sprays return the D_2O directly back into the calandria or dump tank D_2O.

(iii) Sample Station Supply:

Chemical sample lines for moderator main system (and also auxiliary systems) D_2O leading to a sample station cabinet will be available from locations which vary according to the station.

(iv) Liquid Poison System Tank Supply:

The moderator liquid poison system tank is supplied with D_2O, when filling is required, from the main moderator system. The moderator heat exchanger outlet is the source of pressure for the supply. The D_2O in the liquid poison tank is then returned to the main system D_2O when the tank contents are added to the calandria during poison system addition.

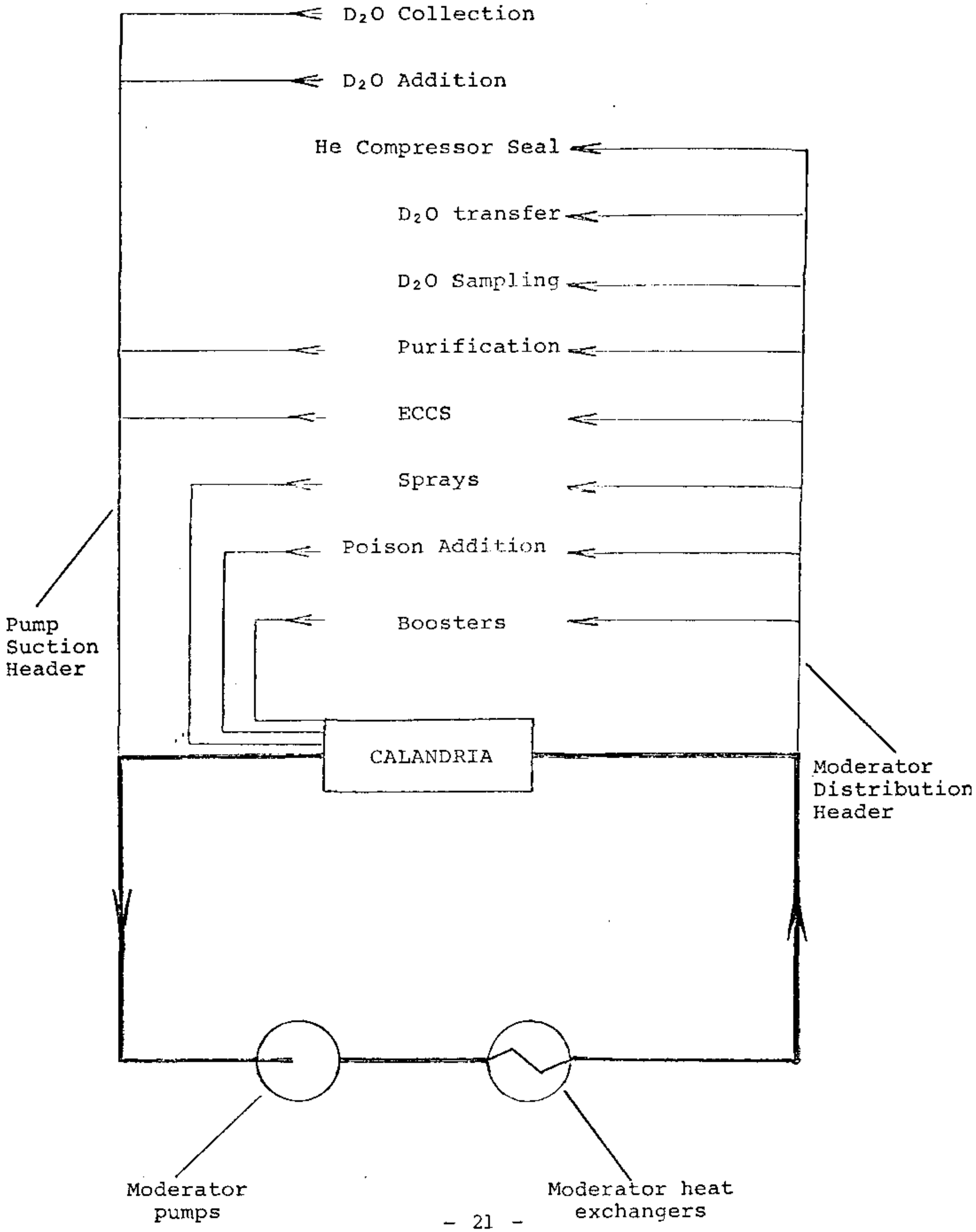
(v) Liquid Ring Cover Gas Compressor D_2O Seal Supply:

If the cover gas system compressors are the liquid ring seal type, then the seal supply will be moderator D_2O from the moderator heat exchanger outlet, utilizing the pressure available from this point to provide adequate flow.

(vi) Emergency Core Cooling (Emergency Injection, Emergency Core Injection) D_2O Supply:

At Pickering NGS-A the ECC initial injection and long term supply, in the event of a large HT loss of coolant, is supplied by the moderator system. Supply is from the moderator heat exchanger outlet, utilizing the supply pressure of the moderator pumps and the relatively cooler temperature available from this tie in point.

Figure 5: Moderator Main System Input/Output Connections



(vii) Other Connections To and From the Main Moderator System:

In addition to D_2O supply functions, the main system will have a number of tie-in connections, for various other purposes mentioned below:

- D_2O leak off connections from moderator equipment (pumps, cover gas ring seal compressors) to the moderator D_2O collection system.
- D_2O transfer lines to transfer D_2O into and out of the main system
- Instrument connection lines for the measurement of parameters used for alarm and/or control purposes such as pressure, flow, moderator level and conductivity.

ASSIGNMENT

1. Explain why reactor power changes are limited during on power access to access control areas containing moderator equipment.

2. Explain why neutronic trip setpoints are lowered during access to access controlled areas even if the reactor is below the access power level.

3. State how and why calandria tubes must be cooled when the reactor is shutdown.

4. For your own station state whether or not there are any specific differences in the cooling methods stated for components A to G in Table 4.

5. Calculate the annual cost in \$ (using Table 1) of adding 1 drum (220 kg) of H_2O to the moderator system (99.750% isotopic, mass = 300 Mg) from a fuel cost penalty point of view. Assume no subsequent upgrading is performed.

6. If on line upgrading is used following an incident such as in question 5, what is the cost to bring the moderator isotopic back to 99.750%? Obtain the on line upgrading cost/kg from your station D_2O engineer.

D.J. Winfield