Reactor, Boiler & Auxiliaries - Course 233

MODERATOR PURIFICATION

I. PURPOSES OF SYSTEM

The functions of the moderator purification system are to:

1. Minimize the concentration of soluble (ionic) and insoluble (particulate) impurities. Removing ionic impurities will minimize moderator radiolysis, which is accelerated by increased conductivity from dissolved ions; it will also reduce the amount of activation in the system. Removing particulate impurities will minimize abrasive damage to pump seals and the deposition of crud on valve components and instrumentation. It will also reduce the amount of activated crud in the system.

2. Control boron and/or gadolinium concentrations in response to regulating system reactivity requirements.

3. Remove gadolinium after a poison injection shutdown (Bruce and later stations).

II. CHEMICAL PARAMETERS CONTROLLED BY PURIFICATION

To illustrate typical values of the chemical parameters which are controlled, Table I gives a chemical analysis for the Pickering-A moderator systems.

TABLE I

Chemical Analyses for Pickering NGS-A

(September 26, 1973)

Moderator (IX Inlet)	Unit 1	Unit 2	Unit 3	Unit 4
pH	7.0	7.0	7.0	7.0
Conductivity (mS/m)	0.023	0.034	0.027	0.047
Chlorides (mg/kg)	<0.1	<0.1	<0.1	<0.1
Boron (mg/kg)	<0.1	<0.1	<0.1	2.7
D_2O (Weight %)	99.74	99.74	99.73	99.50
Tritium (GBq/kg)	340	220	240	190
Tritium (Ci/kg)	9.2	6.0	6.4	5.2

1. pH

The pH is kept between 5 and 7 by maintaining purification flow with no chemical additions other than neutron poisons for reactivity control. This pH minimizes both radiolysis of moderator D_2O and corrosion of the moderator system materials, and minimizes the possibility of gadolinium precipitation (likely for pH>7). Conditions which tend to produce an acidic solution (pH<7) rather than a purely neutral (pH=7) solution are:

(a) Cover gas air inleakage resulting in the formation of nitric acid.

(b) Presence of a neutron poison - boric acid or gadolinium nitrate.

2. Conductivity

This is kept <0.1 mS/m typically by continuous purification, and prompt removal of spent resin. Increase in the conductivity will occur when boron and/or gadolinium is being used for reactivity control.

For boron this increase is only ∿0.01 mS/m per mg B/kg D_2O but for gadolinium it is ∿0.2 mS/m per mg Gd/kg D_2O. This means radiolysis products in the cover gas should be monitored carefully when gadolinium is in use (usually on a start up) because radiolysis is generally increased by higher conductivities.

3. Chlorides

Chlorides in the system can cause stress corrosion cracking, particularly in stainless steel. Chlorides may be leached from IX resins which are spent or have exceeded normal operating temperature for a few hours. Control is achieved by removing the resin and cleaning up the chloride using fresh IX resin, (fluorides are also undesirable, attacking Zircaloy in particular, and so the use of teflon tape/gaskets is avoided in the system).

III. SYSTEM DESCRIPTION

All our stations use a bypass flow purification system (Figure 1, inset) around the main pumps, and heat exchangers. A purification system in series with the main moderator pumps (a full flow system) would provide too high a flow for the purification equipment to handle.

(a) Temperature

To take advantage of the cooling provided by the moderator heat exchangers, the inlet to the purification system is taken from the HX outlets, (Figure 1, inset). This is done as the IX resins are temperature sensitive, and should be kept below about 60°C to prevent them from degrading (reducing their useful lifetime) and to prevent them releasing contaminants, such as chlorides.

(b) Pressure

Taking off purification flow from the heat exchangers outlet and returning purification flow to the moderator pump suction header (Figure 1, inset) enables the pump discharge pressure (∿1-2 MPa) to be conveniently used as a pressure source. A typical purification system pressure drop ΔP would be ∿400 kPa.

This method of supplying pressure is also very useful in the case where the reactor is being guaranteed shut down with the moderator in the calandria in an overpoisoned state. As part of the guarantee that poison will not be inadvertantly removed (in addition to the obvious guarantee of valving out the IX columns) most of the main moderator pumps would be shut down and electrically isolated. This should eliminate any purification flow even if the IX columns were accidently valved in during the guaranteed shut down. Adequate moderator flow should still be provided for bulk moderator cooling however.

(c) Flow

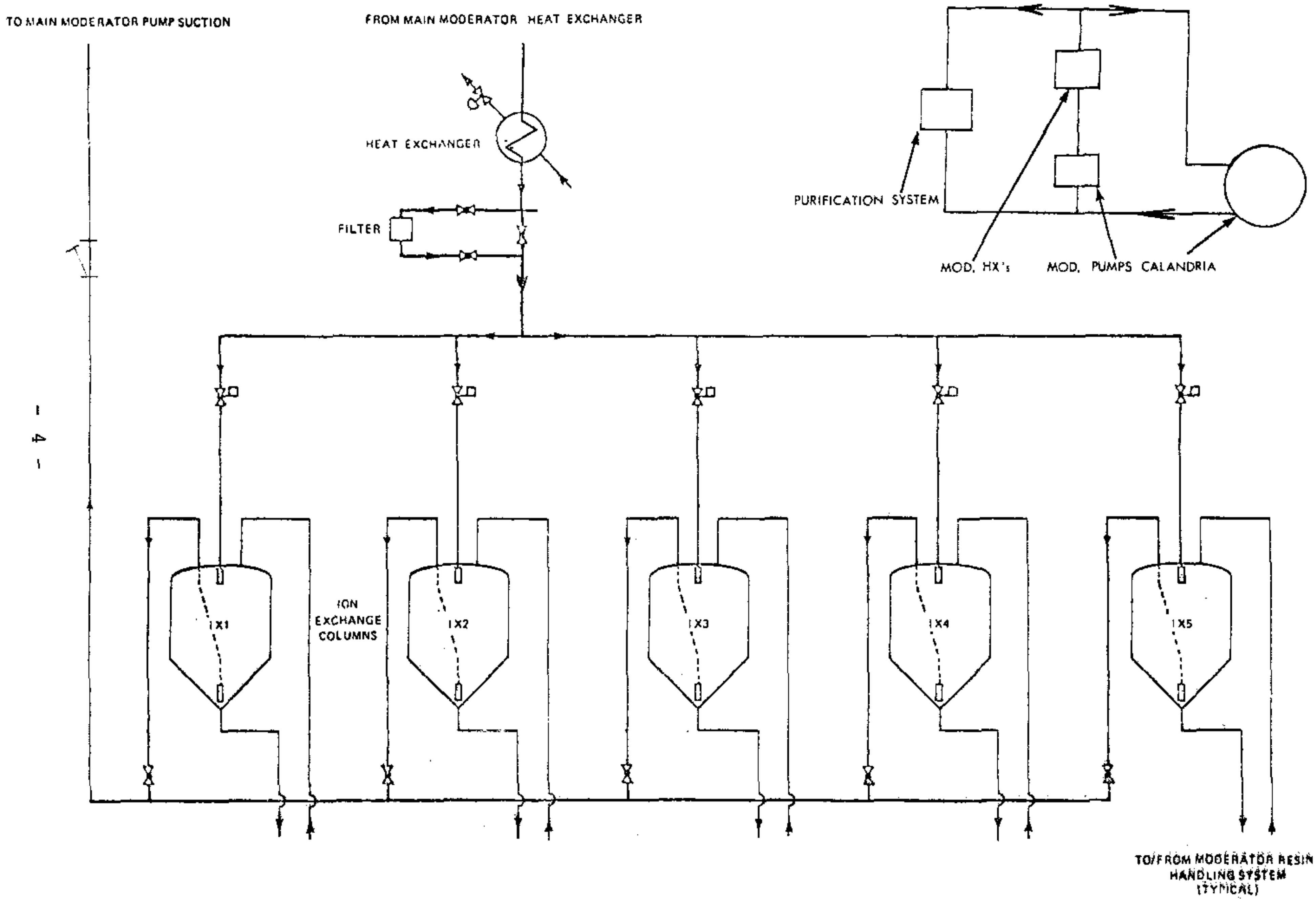
Typical purification system flows are ∿10-40 kg/sec. Depending upon the number of IX in service - the higher the flow, the more rapid the cleanup.

IV. EQUIPMENT DESCRIPTION

The equipment used will be:

1. IX columns
2. Filter
3. Strainer
4. Cooler
5. Piping/Valves

FIGURE 1. TYPICAL MODERATOR PURIFICATION SYSTEM



1. IX Columns

Typically 4-6 columns will be used in parallel, (Figure 1, to allow for removal of resin while still purifying). The number of columns depends on the poison removal requirements. In stations having a gadolinium poison injection system for shutdown, and using gadolinium for Xe simulation, 6 columns would be used typically, the split being:

- one for normal clean up
- two for boron removal
- three for gadolinium removal.

The resins used in these columns may, in some stations, be the same however. For example at PNGS-A (with no Gd removal) a mixed anion/cation resin performs normal cleanup and boron removal. At Bruce the normal cleanup and gadolinium resins are the same.

The columns (see Figure 2) are situated in a concrete shielded vault or pit, as activated corrosion products accumulate on the resins and N-16 and O-19 circulate through them during operation. Conical bottoms are used on the columns to ease resin removal by slurry operation. Resin addition is via a penetration at the top of the column.

An important design feature, shown in Figure 2 is the screens used to keep the resin inside the column. These should be small enough to prevent resin breakthrough. This would increase radiolysis if the resin fines (the very small size resin beads) got into the calandria. The screens should not be so small as to cause screen plugging, however, and hence low purification flow.

2. Filter

A filter (or filters) may be present on the purification inlet line to the IX columns to prevent insolubles from entering and clogging the IX resin, before it is spent. The resin itself will, to a certain extent, perform filtering. Filters will be declared spent on a high ΔP, indicating they are plugged with insolubles.

Sometimes moderator filters are used only during commissioning. However, normal operation without filters will usually result in higher activation product fields in the system.

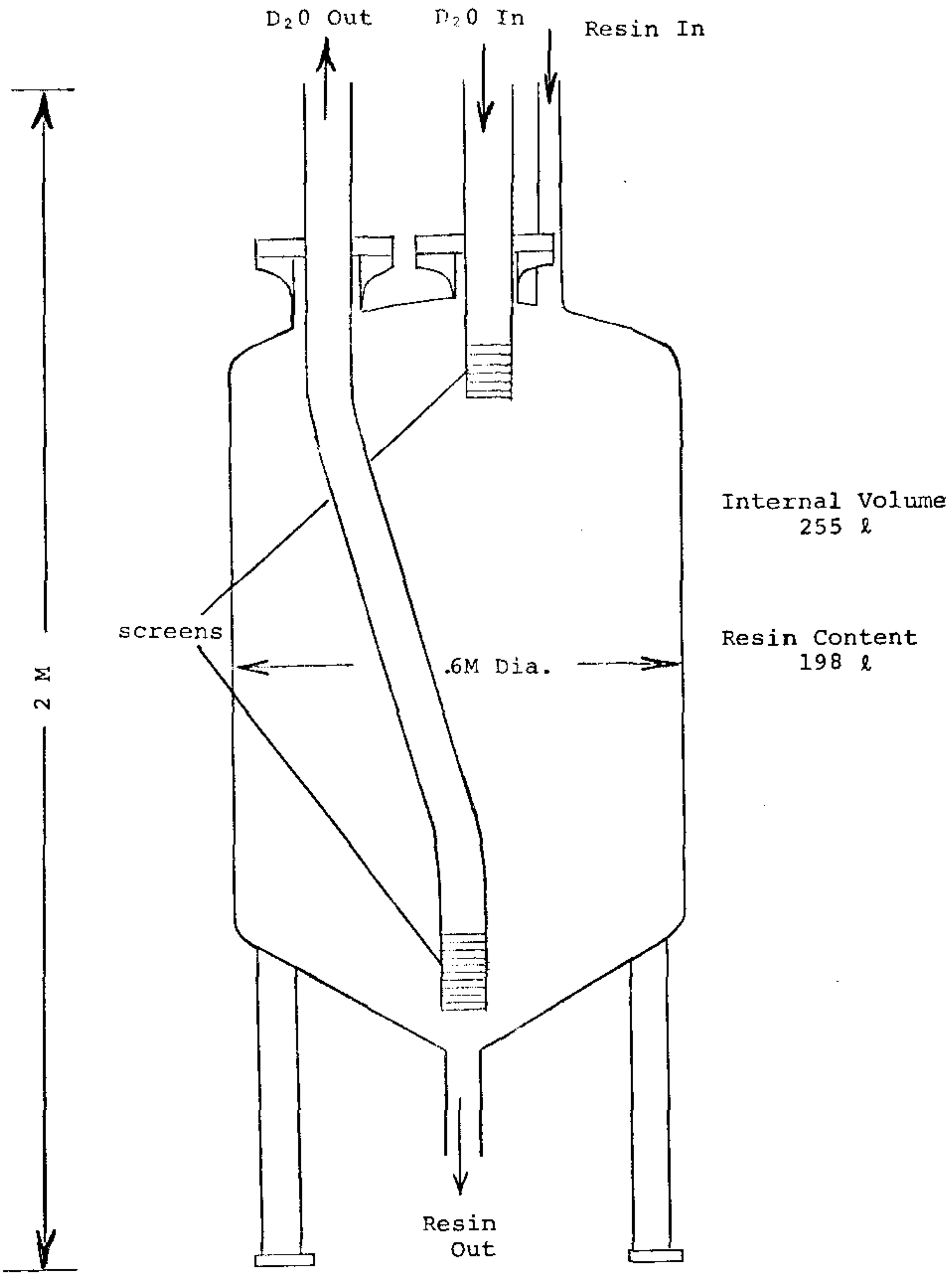


FIGURE 2 BRUCE MODERATOR AND HEAT TRANSPORT
ION EXCHANGE COLUMNS

3. Strainer

A strainer will be installed at the outlet of the IX columns to prevent the escape of resin into the main system, should the resin screens pass any resin. Resin fines in the moderator would accelerate the rate of radiolysis and result in higher cover gas D_2 concentrations.

4. Purification Cooler

Some stations have a small heat exchanger installed on the IX column inlet, as shown in Figure 1, to prevent resin overheating, if the purification temperature is likely to exceed $\sim$60°C during operation - for example, during the use of boosters which put additional heat into the moderator.

5. Piping and Valves

Piping is stainless steel to minimize corrosion. Typical locations of isolating valves are shown in Figure 1. Motorized valves located on the IX column inlets are operated conveniently via control room handswitches. This enables selection of individual columns to be made easily without field operations, and is convenient for reactivity control when boron or gadolinium is in use. (i)

V. OPERATING FEATURES OF THE SYSTEM

Important differences in the operating characteristics of the various moderator IX resins are discussed below:

(a). Normal Cleanup

For normal cleanup, one IX column (flow $\sim$10 kg/s) is adequate. A typical cleanup half life, defined to be the time taken for the conductivity (ionic impurity concentration) to be halved, would be $\sim$6 hours at 10 kg/s. This is shown in Figure 3, which illustrates moderator cleanup half life versus purification flow. A column used for normal cleanup would last a few months, typically.

(i) Pickering NGS-A cannot however automatically select individual columns.

Spent resin is determined by high conductivity and/or high chloride readings in the column outlet, or a high ΔP across the column. The valving into service of spent moderator IX resin after it has previously been valved out of service is likely to result in a cover gas D_2 excursion from the increased radiolysis resulting from increased moderator conductivity.

Note that normal purification cannot be used if gadolinium is in the moderator for a Xe simulation during a start up. The reason for this is that the normal cleanup IX resin will remove the gadolinium.

(b) Boron Removal

Boron cleanup rates cannot be determined using Figure 3 because the rate of removal depends on the boron concentration in the water due to the resin used being different to that in the normal clean up columns.

When a column has a high boron concentration and the water is low in boron, the column will re-equilibriate or elute more boron back into the water. Because of this, boron is removed (or pulled) in a 2 or 3 stage process with 2 or 3 columns operating on different moderator boron concentrations.

For cleanup of normal impurities and Gd, the cleanup half life does not depend on the concentration of the impurities, but on only the purification flow rate and the total mass of moderator D_2O. (Boron differs from gadolinium here as boron is only weakly ionized in solution unlike gadolinium).

A two-stage removal would take boron concentration from, say 3 mg B/kg D_2O (28 mk worth) down to 0.5 mg B/kg D_2O in the first stage, using one column. This column, which becomes saturated, is then isolated ready for resin removal. Second-stage boron removal from 0.5 mg B/kg D_2O to lower concentrations is then done by a second column. This column is then used for the next first stage removal, when required, to fully utilize its resin.

If boron is being used for a Xe simulation (only at PNGS-A) 28 mk worth (assuming no Xe is in core on start-up) has to be cleaned up within about 48 hours.

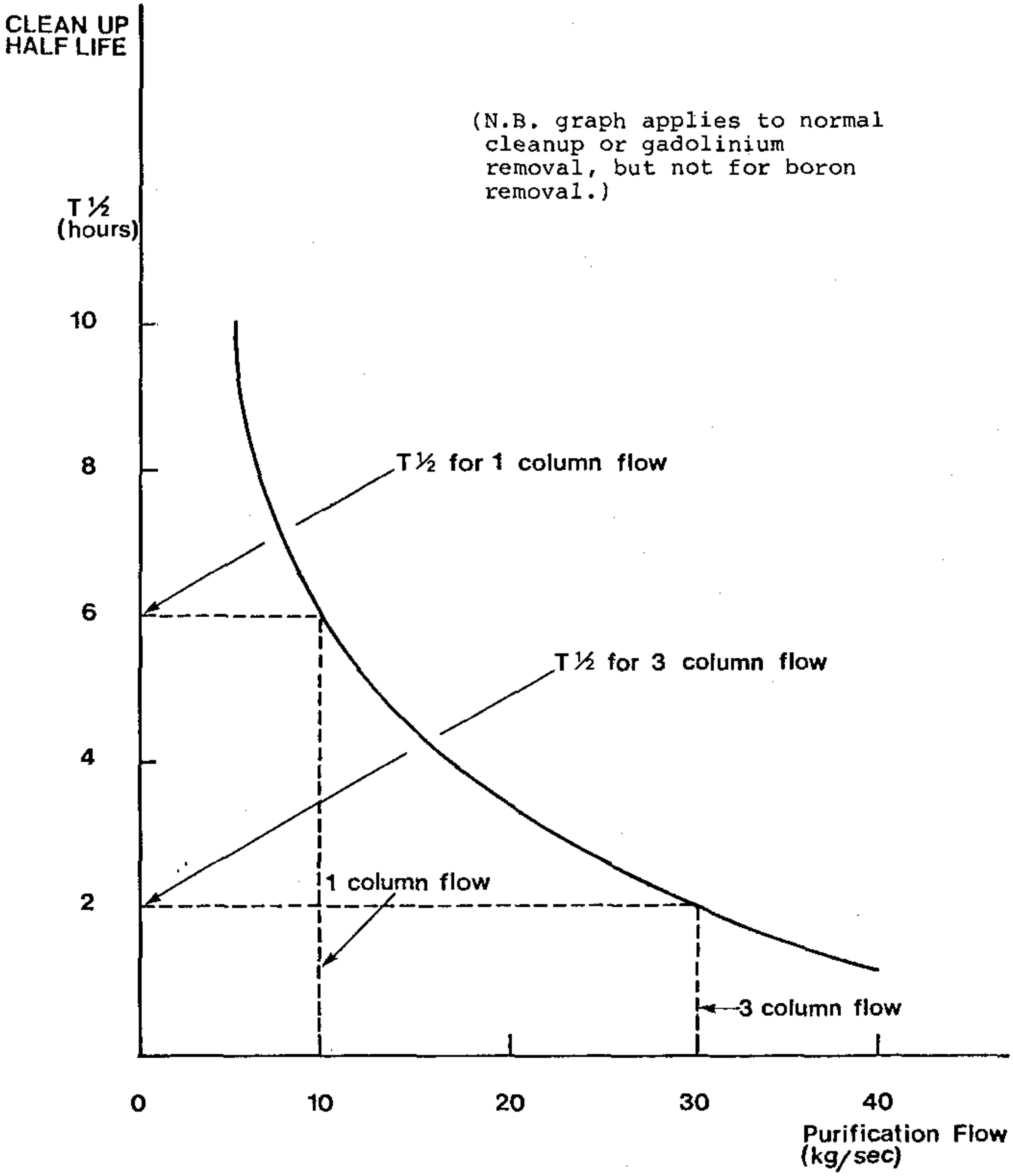


Figure 3. TYPICAL MODERATOR PURIFICATION HALF LIFE FOR DIFFERENT PURIFICATION FLOWS. (MOD.=336 Mg D_2O)

Boron may also be added to the system directly from the resin. If a low boron content feed solution is fed to a column saturated at a higher feed concentration, boron will be eluted slowly until, if left long enough, the boron content of the column reaches equilibrium with the new feed. The elution of boron is sometimes useful to provide small amounts of negative Δk, but can also lead to unwanted boron additions unless the conditions of IX resins is continuously monitored.

(c) Gadolinium Removal

Gadolinium, unlike boron, is easily removed, or "pulled", by IX resin with clean up half lives determined by Figure 3. The same type of resin is used as in the normal cleanup column.

(i) When Gd is used for Xe simulation, little IX removal is required, because the mk rate at which Gd is burned out in the neutron flux closely matches the rate at which negative Xe reactivity builds up. Any imbalance between these two rates, as detected by rise or fall of average zone level, can be corrected either by temporarily valving in a Gd IX column (too much Gd) or by adding Gd (too little Gd).

(ii) When the poison injection system operates to shut down the reactor, it puts a concentration of ∿880 mk into the moderator. This concentration would be reduced by a factor of 32 to ∿0.8 mg Gd/kg D_2O within ∿40 hours when the Xe concentration has decreased sufficiently (to 28 mk) to enable startup to proceed without delay. This removal takes a minimum of five cleanup half lifes ($32 = 2^5$).

Figure 3 shows that the cleanup half life with three Gd IX columns in use is about 2 hours. Thus the minimum time to remove poison following a poison injection shutdown is about 10 hours. This is well within 40 hours for the Xe to decay to 28 mk worth but too long to prevent a Xe poison shutdown.

ASSIGNMENT

1. State 3 purposes of the moderator purification system.

2. Explain the difference between boron and gadolinium removal by IX resin.

3. If it takes one IX column to drop a boron concentration from 10 mg/kg to 5 mg/kg, will it take one or more columns to drop an initial concentration of 5 mg/kg to 0 mg/kg? Explain.

4. Can you think of any (nuclear) reason why IX column motorized inlet valves should fail (on loss of power to valve) in the closed rather than open position?

5. Explain why the moderator conductivity of unit 4 in Table I is higher than the other units.

6. State a possible cause and a likely consequence and possible action to be taken, of the following:

   (a) Moderator purification return high conductivity.
   (b) Moderator purification low flow.
   (c) Moderator purification high temperature.
   (d) Purification strainer high ΔP.

7. State the possible consequences of not having any boron removal IX resins available ready for service in the moderator purification system.

   (a) While operating at full power with no boron in the moderator.
   (b) Prior to start up 30 hours after a shutdown.

   Assume Gd is not used in this example for reactivity control because no Gd facilities are used in the station.

8. Explain generally how IX resin in a column can be changed while still maintaining some purification flow.

9. In your own station check and comment on the current values of moderator

   (a) pH
   (b) conductivity
   (c) boron
   (d) gadolinium
   (e) chlorides

   List the limits for (a) to (e) above in your station.

10. Check how often the various IX columns are refilled with resin and the resin types used in your station.

11. Check how often the filters are replaced in your station.

12. In your own station state how long, typically it would be acceptable to have moderator purification flow unavailable in the following uses:

    (a) normal full power operation
    (b) overpoisoned guaranteed shutdown.

D.J. Winfield