8.10.4.3 Tritium Permeation and Recovery for the Flibe/He Blanket Design

A study of tritium permeation and recovery for molten salt for the fusion breeder is reported in Ref. 8.10-14. The results are directly relevant to the fusion electric case. This study assumes tritium to be a gas dissolved in molten salt, with TF formation suppressed. Tritium permeates readily through the hot steel tubes of the reactor and steam generator and will leak into the steam system at the rate of about one gram per day in the absence of special permeation barriers, assuming that 1% of the helium coolant flow rate is processed for tritium recovery at 90 % efficiency per pass. Tritiated water in the steam system is a personnel hazard at concentration levels well below one part per million and this level would soon be reached without costly isotopic processing. Alternatively, including a combination of permeation barriers on reactor and steam generator tubes and molten salt processing is estimated to reduce the leak rate into the steam system by over two orders of magnitude. For the option with the lowest estimated leak rate, 55 Ci/d, it may be possible to purge the steam system continously to prevent tritiated water buildup. At best, isotopic separation of dilute tritiated water may not be necessary and for higher leak-rate options the isotopic processing rate can be reduced.

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The proposed permeation barrier for the reactor tubes is a 10 μm layer of tungsten which, in principle, will reduce tritium blanket permeation by a factor of about 300 below the bare-steel rate. A research and development effort is needed to prove feasibility or to develop alternative barriers. The partial pressure of tritium gas dissolved in molten salt is high, easing the recovery process for which a flash-separator has been chosen. A 1 mm aluminum sleeve is proposed to suppress permeation through the steam generator tubes. This gives a calculated reduction factor of more than 500 relative to bare steel, including a factor of 30 due to an assumed oxide layer.

To gain a better understanding of permeation effects, equations describing steady-state tritium permeation without axial flow have been derived for a multi-layer tube wall within the blanket region. A layer of frozen salt is included, along with fluid boundary-layer resistances. Calculations of the partial-pressure distribution show significant differences for tubes irradiated at different power densities. Molten salt boundary-layer resistance can be important in the absence of a good permeation barrier, or for a low-power tube coated with a nominal 1 μm tungsten barrier. Permeabilities of various metals are shown in Fig. 8.10-18. This nominal permeation barrier will dominate the flow resistance, however, for medium or high power-density tubes closer to the first wall. Examination of the radial flux equation shows a complicated dependence on upstream partial pressure, which reduces to a linear dependence at low pressures where Henry's Law materials become flux limiters and a square-root dependence at high tritium partial pressures where Sievert's Law materials are flux limiting.

An analytical model has been developed to establish the tritium split between wall permeation and reactor-tube flow. Permeation barriers are shown in Fig. 8.10-19. The barriers are shown on the outside of the tubes but could equally well be on the inside. For the molten salt tubes the inside barrier would greatly reduce the tritium inventory in the tube walls and further reduce the already very low corrosion rate. The tritium fraction escaping through the tube walls has been quantified for limiting cases of Henry's Law and Sievert's Law barriers as flux limiters. All parameters of design interest are explicitly included: tritium generation rates and solubility in salt, tube geometry, barrier permeation parameters, and molten salt processing rate and recovery efficiency.

The intermediate helium heat transfer loop has been treated as a well-mixed tank for analytical purposes, with input from the reactor, partial tritium recovery in a slipstream process loop, and Sievert's Law permeation loss to the steam system.

A combination of effective tritium permeation barriers are required on both blanket and steam generator tubes, together with substantial process rates for molten salt and helium systems, in order to hold tritium permeation into the steam system to 55 Ci/d. If this can be done, it may be feasible to simply purge the steam system of incoming tritium with only minor environmental impact and personnel hazard from steam leaks, and without the necessity of costly and hazardous isotopic processing to separate tritiated and ordinary water.

A surprisingly thin (10 μm) tungsten coating will, in principle, provide a good permeation barrier on the blanket tubes. The feasibility of, in fact, reducing tritium blanket permeation by a factor of 300 or so below the bare steel tube rate for some 10^4 m^2 of tube area will require a research and development effort. Other materials or alloys may prove to be superior, probably at the price of greater thickness of coating.

A relatively thick 1 mm aluminum sleeve was selected to suppress permeation through the steam generator tubes. This gave a calculated reduction factor of more than 500 relative to bare steel, including a factor of 30 due to an assumed oxide layer. This is essentially a brute force approach that may well be improved upon by the development of more sophisticated permeation barriers.

Although we have focused attention on a tungsten barrier due to a remarkably low tritium permeability, beryllium and other low-permeability materials such as ceramics and cermets should be considered in a barrier development problem.

The tritium recovery system flow sheet is shown in Fig. 8.10-20. Due to the low solubility of tritium in the reducing salt, a simple flash separator will allow removal of the tritium and other noncondensible gases, mainly helium. Tritium removal from helium is virtually a standard system. The bulk of the tritium is recovered as a hybride on a getter bed, with final cleanup accomplished by catalyzed oxidation and adsorption.

The diffusivity of tritium gas dissolved in molten salt will need to be measured, especially to verify whether or not the fluid boundary-layer barrier is realistic.

Finally, some definitive experimental work on the kinetics of tritium gas conversion to tritiated water at low concentrations in helium is called for. Popular opinion has oscillated over the last decade from an initial optimism that thermodynamics would reduce the gas concentration to nil, to a current pessimism that predicts no gas conversion at all in the main helium loop. The critical experiments remain to be done, both with "clean" walls and particulate-free helium, and in the presence of catalytic surfaces or other reaction promoters. The challenge is to demonstrate a method of drastically reducing tritium gas partial pressure in the intermediate helium loop, and thus suppress permeation into the steam system.

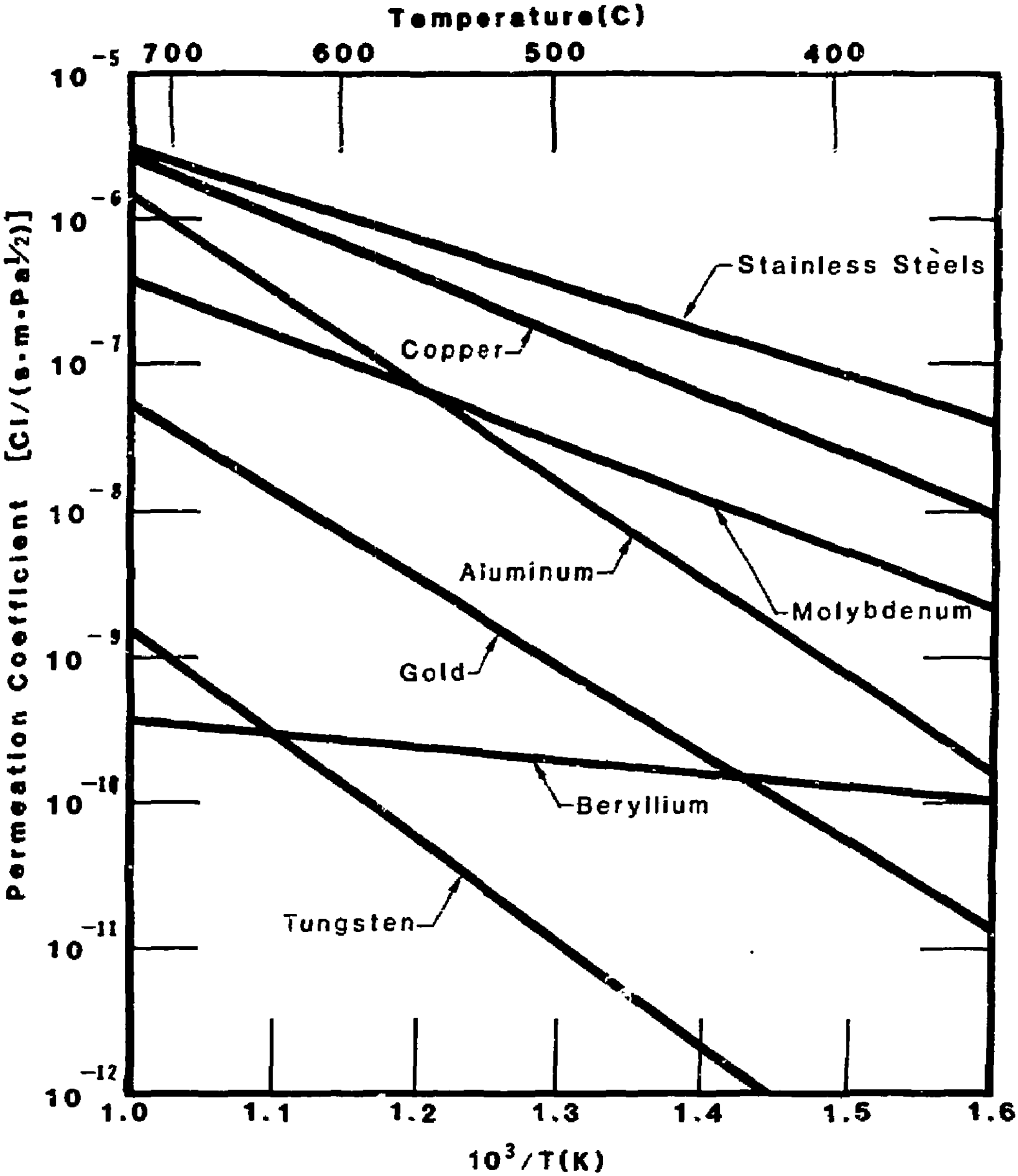

Figure 8.10-18

Permeation coefficient of tritium through metals.

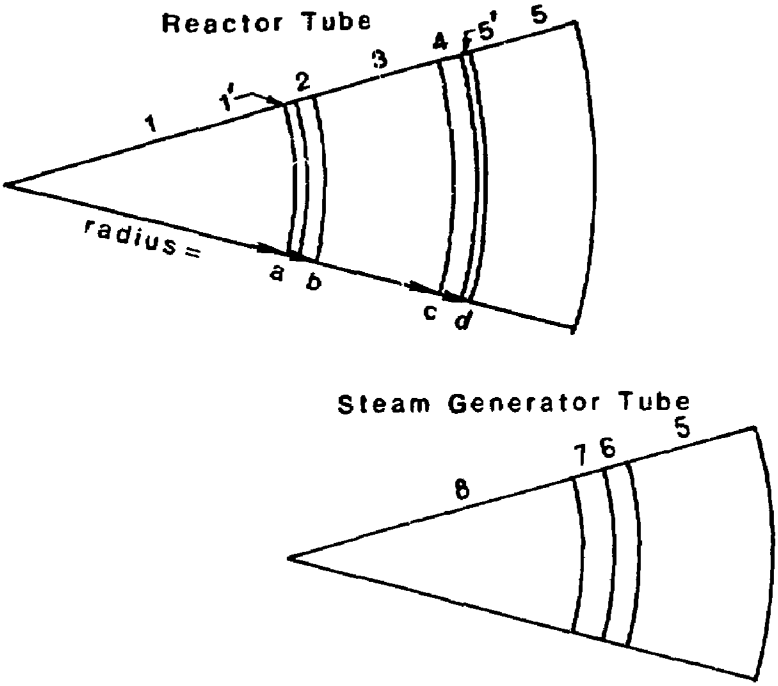

Figure 8.10-19

Permeation Geometry and Materials.

Reactor Tube:

1	molten salt
1'	molten salt boundary layer
2	frozen salt
3	stainless steel tube
4	permeation barrier (tungsten)
5'	helium gas boundary layer
5	helium gas

Steam Generator Tube:

5	helium gas
6	stainless steel tube
7	permeation barrier (aluminum)
8	water/steam

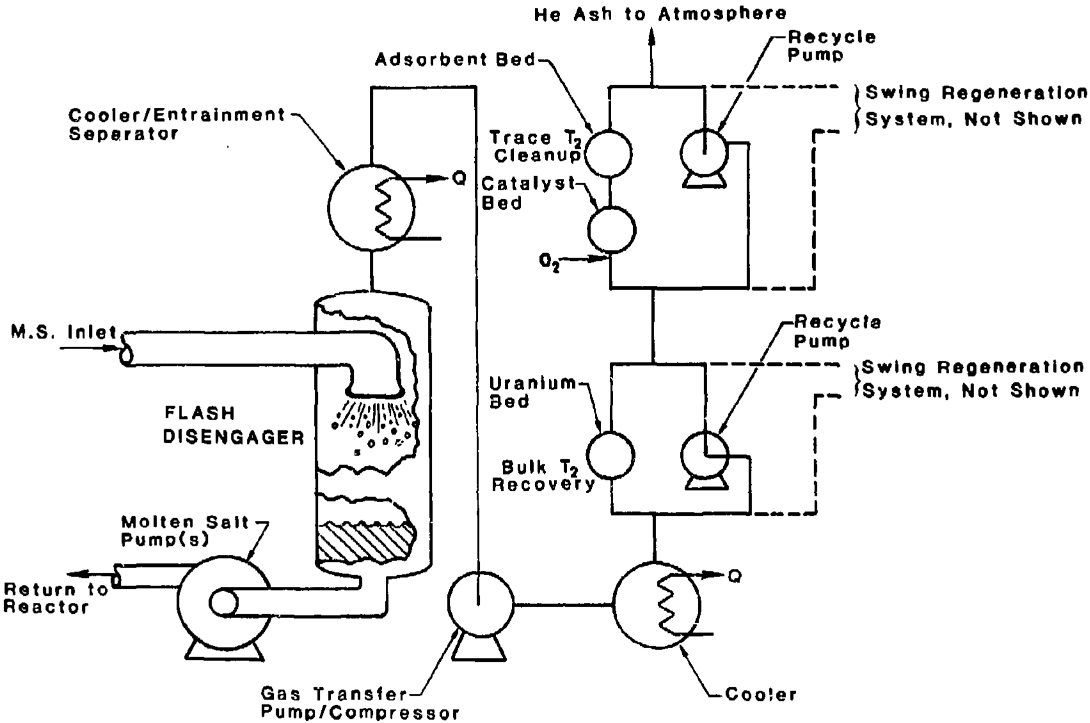

Figure 8.10-20. Molten salt tritium processing