

ANL/TD/CP--82059
Conf-940664--13

Paper

TRITIUM RECOVERY FROM LITHIUM BASED ON COLD TRAP*

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May 1994

Submitted to the Third International Symposium on Fusion Nuclear Technology, University of California at Los Angeles, June 27 - July 1, 1994.

* Work supported by the United States Department of Energy/Office of Fusion Energy, under Contract No. W-31-109-Eng-38.

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ABSTRACT

A concept to recover tritium from lithium, based on a cold trap, has been developed as a part of the U.S. contribution to ITER. The cold trap process can only reduce tritium concentration to about 400 appm, which is far above the ITER design goal of reducing tritium concentration in lithium to ~1 appm.

To achieve this lower goal, protium is added to the lithium to a concentration higher than the saturation concentration of the hydrogen isotope at the cold trap temperature. Thus, LiH and LiT will precipitate out together at the cold trap. The tritium from the cold trap can be recovered by heating the Li(H+T) to 600°C for decomposition. The H and T then can be separated by cryogenic distillation process.

* Work supported by the U.S. Department of Energy, Office of Fusion Energy, under Contract No. W-31-109-Eng-38.

1. Introduction

Lithium is one of the primary candidates for the tritium breeding material for a D-T fusion reactor. A self-cooled lithium concept is also one of the candidates for the ITER blanket design [1]. However, tritium recovery from lithium to the level intended (~1 appm) remains to be a key technical issue. This is due to the very high tritium solubility in the lithium, and the very low tritium concentration required in the lithium to minimize the tritium inventory in the breeding blanket. Various tritium recovery processes have been proposed, among which are the molten salt recovery process [2], the permeation window [3], the gettering process [4], and the distillation process [5]. All of the processes have its own unique problems, as is described by Moriyama [6].

The molten salt recovery process is the only process which has demonstrated the capability to recover tritium from lithium to the desired concentration (~1 appm). However, the returning lithium will be contaminated by the salt. The effect of the salt impurities in the lithium to the material compatibility inside the blanket has not yet been determined.

A new tritium recovery process from lithium, based on cold trap, has been developed under ITER activities. The cold trap was discussed before as an option to recover tritium from lithium, but was rejected because cold trap can only reduce hydrogen concentration to ~400 appm [7]. It was decided that this hydrogen concentration was far above the required limit and therefore the cold trap was never further considered as an option. The new proposal suggests the addition of protium in the lithium so that, while the tritium concentration is only 1 appm, the total

hydrogen concentration exceeds the saturation concentration at the cold trap temperature. Thus, upon cooling down the lithium stream, the tritium will be precipitated out together with protium. The precipitated out material is Li(H+T), which will be decomposed at 600°C for tritium recovery. The tritium will be separated from the added protium by cryogenic distillation.

2. Principle of Cold Trap

The cold trap process has been developed to remove tritium from sodium in the LMFBR program [8]. Although the tritium partial pressure near the melting temperature of the sodium is $\sim 10^{-4}$ torr, a cold trap can reduce the partial pressure of the tritium to about 10^{-9} torr by isotope swamping effects. Protium was either added, or diffused from the steam side to the sodium such that the total hydrogen partial pressure was reduced to 10^{-4} torr, while the isotope effects kept the tritium partial pressure to 10^{-9} torr. A similar cold trap process is proposed here to reduce tritium concentration, instead of partial pressure.

The lithium-hydrogen phase diagram is shown in Fig. 1. The regime marked by Li+LiH(s) is the regime within which LiH becomes supersaturated and precipitate out. This is also the regime within which cold trap will operate. The solubility of LiH in the lithium, given by the solid curve on the left, was measured and given by the following equations for H [9] and D [10], respectively

$$\log_{10}(X_H) = 1.523 - 2308/T$$

$$\log_{10}(X_D) = 2.321 - 2873/T$$

in which X is the mole fraction and T is in K.

The cold trap temperature is assumed to be 200°C. At this temperature, the solubility of LiH in the lithium is 440 appm, while the solubility of LiD in lithium is only 177 appm. It is not clear if the difference of the solubility is due to the isotopic effects, or due to the experimental uncertainties. For this paper, the solubility of LiH is used as the cold trap concentration.

Thus, if the cold trap temperature is 200°C, the saturation concentration of total hydrogen is 440 appm. If protium is added to the lithium in excess of 440 appm, the total hydrogen concentration will exceed the saturation concentration at 200°C. At this condition, tritium will precipitate out together with protium, although the tritium concentration is well below the saturation limit.

Figure 2 [7] shows the cold trap behavior of different impurities from lithium. The solid curves are the saturation curve of N, O, H, and C in the lithium. The data points are the cold trap results of those four impurities from lithium. It is clear that cold trap will reduce the hydrogen concentration very close to the saturation limit.

3. System Description

Table 1 summarizes the parameters for blanket tritium recovery system for ITER as defined by ITER JCT Naka. As can be seen, the lithium flow rate to the tritium recovery system is very modest. (For

comparison, the lithium flow rate for cooling is 45,000 m³/hr, or 1000 times larger.)

Figure 3 shows the schematic flow diagram of the tritium recovery process based on cold trap. The lithium will exit from the blanket with protium concentration of 440 appm, and tritium concentration of ~1 appm. Protium is added to this lithium stream to increase protium concentration to 1320 appm. This lithium is fed to a cooler to reduce its temperature to ~200°C, after which it is passed to a cold trap. The lithium will exit from the cold trap at the saturation concentration of 440 appm. If we ignore isotope effect at this time, the tritium concentration should be 0.3 appm. After heating to the desired temperature, this lithium is fed back to the reactor.

The cooler and the heater can be combined as a regenerator heat exchanger to save power requirement.

Any inefficiency of the cold trap can be compensated by increasing the lithium flow rate to the tritium recovery process.

4. Regeneration

The tritium deposited in the cold trap is in the form of LiH+LiT. This can be regenerated by heating. At 650°C, the hydrogen partial pressure over LiH is about 10 torr. Assuming the tritium recovery rate is 20 g/fph, the protium recovery rate will be 4.2 kg/hr. At 650°C and 10 torr, the flow rate of the regeneration process can be calculated by the ideal gas law to be 3200 liter/s.

5. Hydrogen Separation

The tritium recovered has to be separated from the protium added to the lithium. This H/T separation system was added to the ITER tritium plant. The flow diagram of the overall tritium plant is shown on Fig. 4. The block represents the additional component for the blanket tritium recovery system. This system increases the overall tritium inventory in the tritium plant by 7 grams, and added additional 500 w refrigeration power requirement.

6. Conclusions

A new tritium recovery process from lithium has been developed as part of ITER activities. The cold trap design and regeneration have been developed in the fast breeder program. The lithium-hydrogen phase diagram appears to be well documented to provide essential information on the cold trap design. The flow rate, both on lithium flow and on the purge gas, appears to be reasonable. The total power requirement is about 500 kW, which is acceptable. A research program is being formulated to verify the feasibility of this process.

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Table 1. Parameters for Tritium Recovery System

Lithium volume	
in-reactor	350 m ³
out-of-reactor	350 m ³
Total	700 m ³
Reactor fusion power	2.5 GW
Maximum ITER duty factor	50%
First wall permeation rate	16 g/fph
Tritium recovery rate	16 to 26 g/fph
Allowable tritium concentration in lithium	
design goal	1 appm
design limit	3 appm
Lithium flow rate	67 m ³ /h

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- Figure 4** ITER EDA - ISS and water detritiation including T recovery from Li breeder.

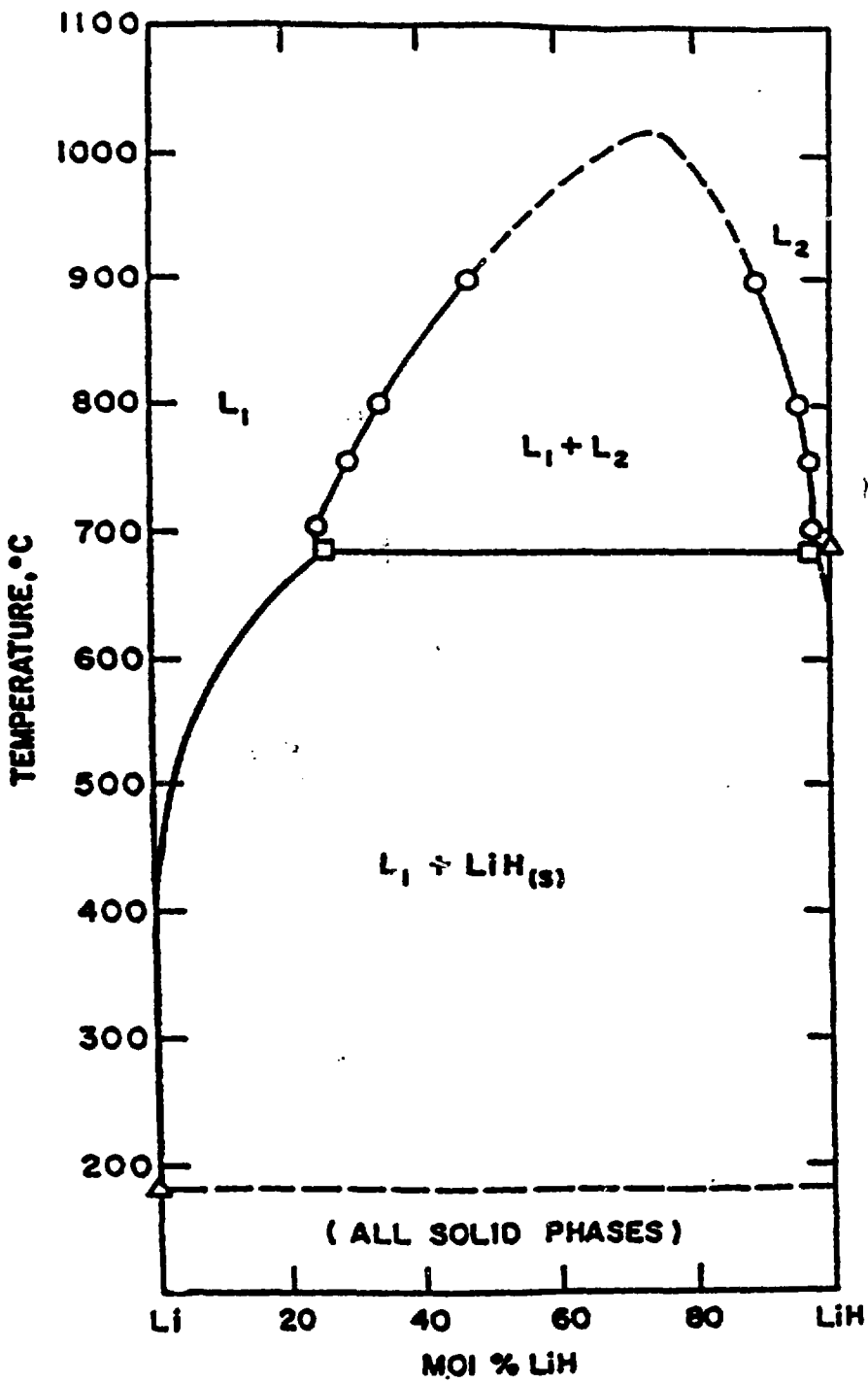


Figure 1
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 Tritium Recovery from Lithium
 Based on Cold Trap

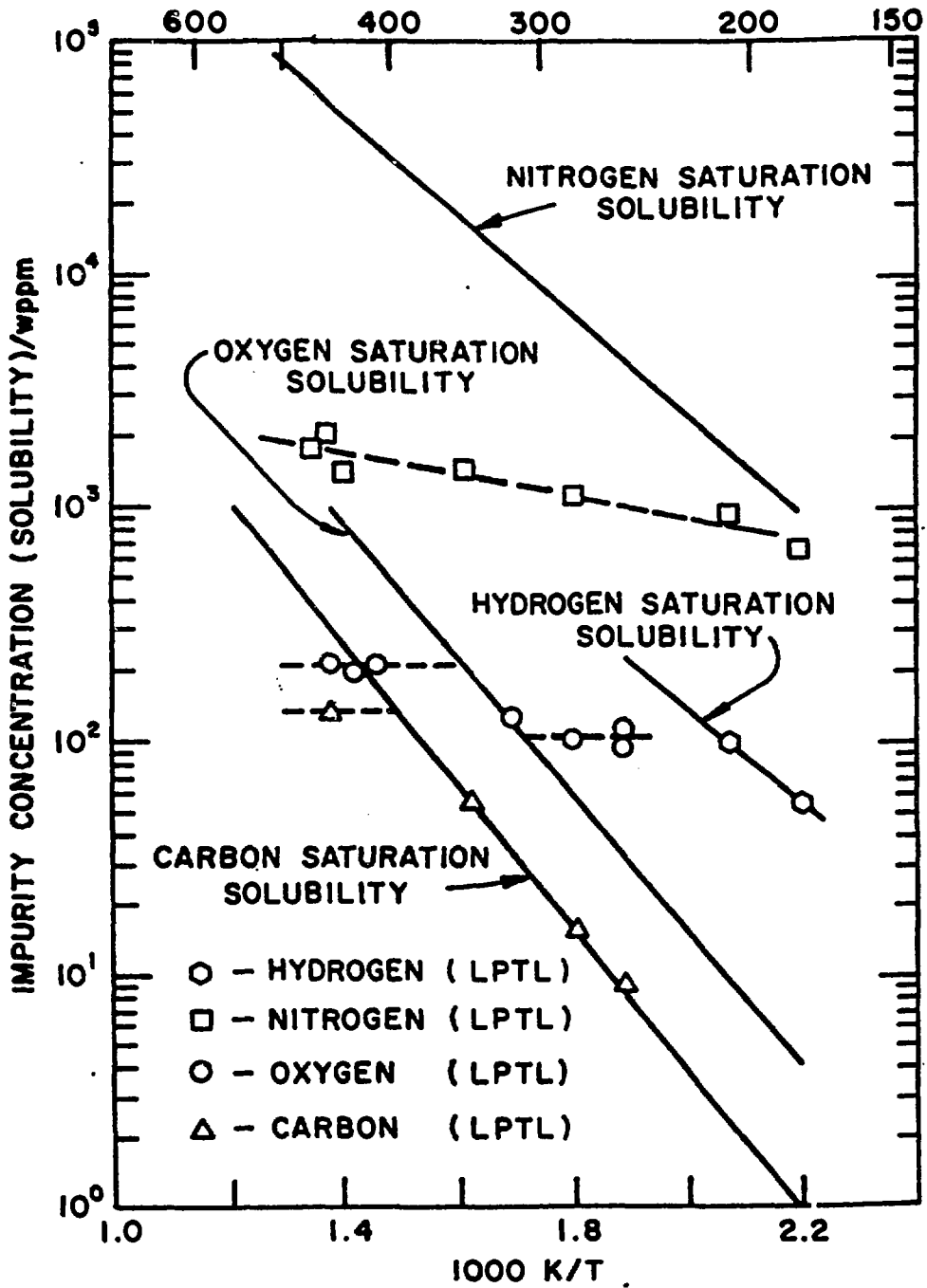


Figure 2
D.K. Sze, R.F. Mattas, et al.
Tritium Recovery from Lithium
Based on Cold Trap

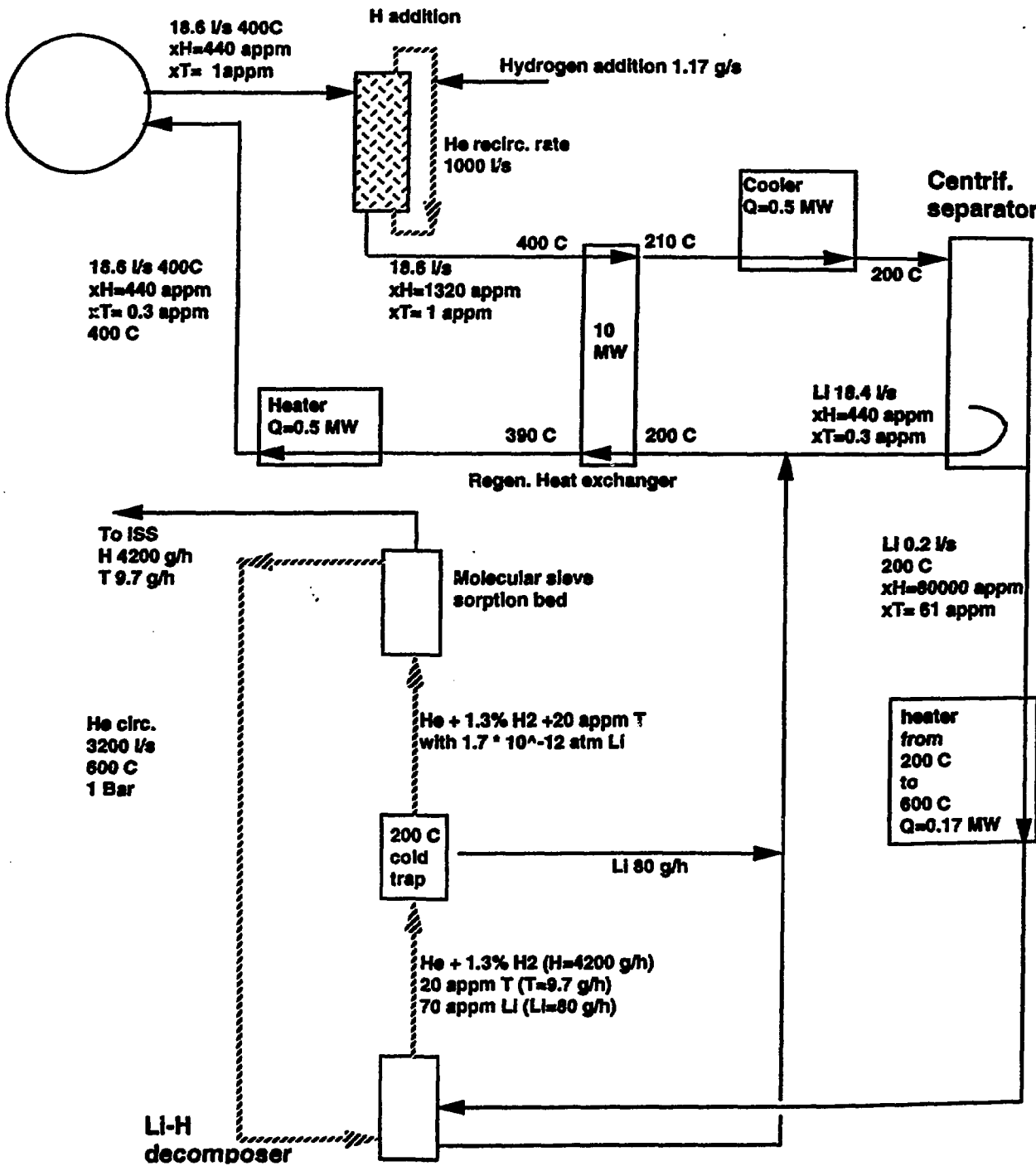


Figure 3
 D.K. Sze, R.F. Mattas, et al.
 Tritium Recovery from Lithium
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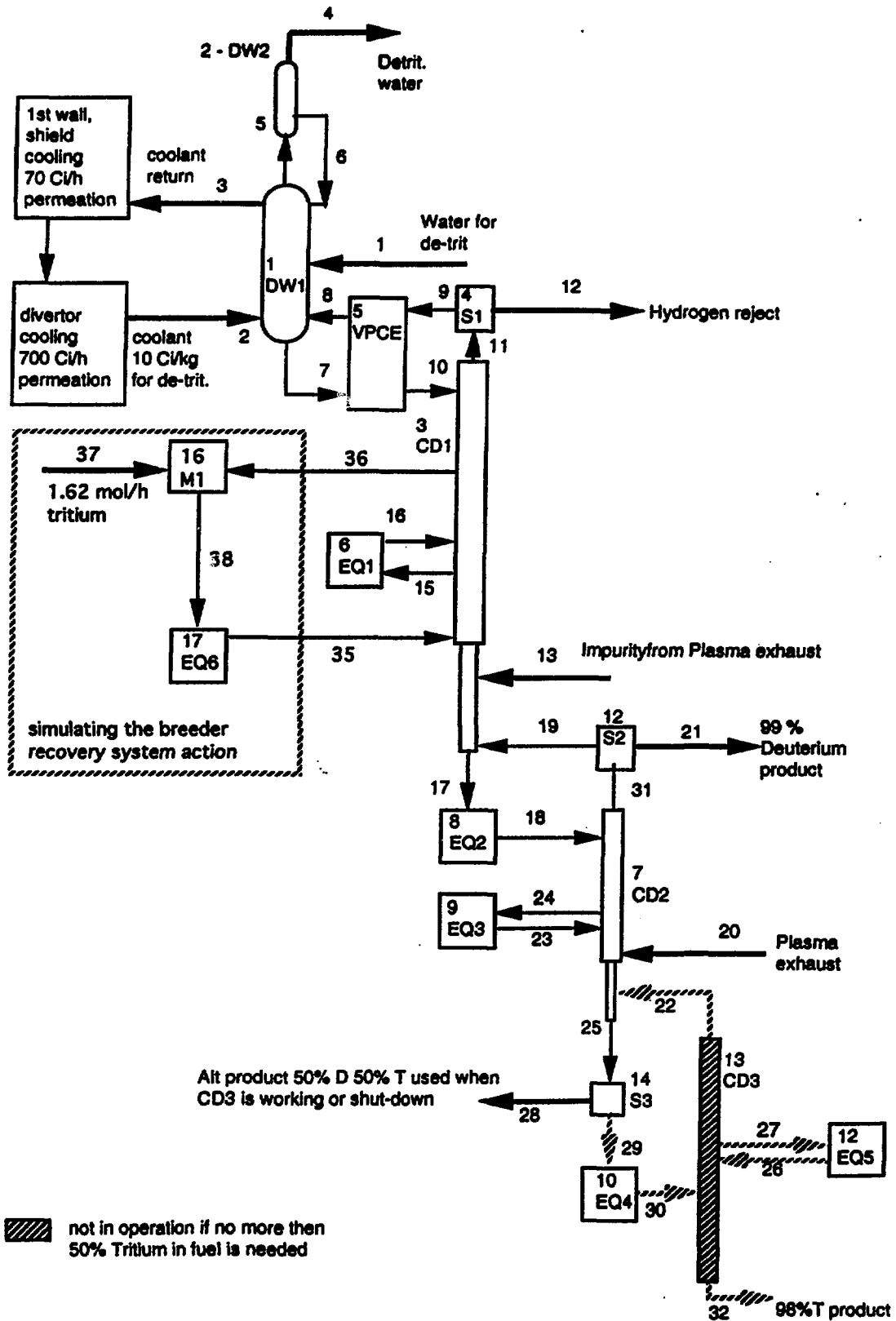


Figure 4
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 Tritium Recovery from Lithium
 Based on Cold Trap