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EFFECT OF THE SELF-PUMPED LIMITER CONCEPT ON THE TRITIUM FUEL CYCLE

P. A. Finn, D. K. Sze and A. Hassanein
 Argonne National Laboratory Argonne, Il 60439

ABSTRACT

The self-pumped limiter concept for impurity control of the plasma of a fusion reactor has a major impact on the design of the tritium systems. To achieve a sustained burn, conventional limiters and divertors remove large quantities of unburnt tritium and deuterium from the plasma which must be then recycled using a plasma processing system. The self-pumped limiter which does not remove the hydrogen species, does not require any plasma processing equipment. The blanket system and the coolant processing systems acquire greater importance with the use of this unconventional impurity control system.

INTRODUCTION

The self-pumped limiter concept (1) removes helium, the major impurity in a deuterium-tritium fusion reactor by trapping the helium in-situ in freshly deposited metal surface layers. The design of the self-pumped limiter must satisfy three requirements. It must trap helium, recycle the tritium and deuterium to the plasma, and permeate protium to the coolant. The self-pumped limiter may be the first wall of the fusion reactor or a slot limiter.

For a fusion reactor, the use of a self-pumped limiter as the impurity control system results in a major reduction in the number of vacuum pumps and vacuum ducts needed. Fewer pumps and ducts means a major reduction in the mass of reactor components, improved shield effectiveness, reduced cryogenic requirements, and most important for the tritium fuel cycle - reduced plasma

processing requirements. The first reactor to be designed with a self-pumped

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limiter was the Tokamak Power Systems Reactor (TPSS). (2) See Fig. 1 for a side view of the simplified reactor.

The use of a self-pumped limiter system in TPSS gave us the opportunity to review the major tritium units in a fusion reactor: 1) the plasma processing system; 2) the blanket tritium recovery system; 3) the atmospheric tritium recovery system; and 4) the tritium support systems. These systems are each treated below.

Tritium Transport and the Self-Pumped Limiter

Two key issues for the self-pumping concept are the tritium inventory in the trapped material and the permeation of tritium and protium to the coolant. The permeation rate must be low enough for acceptable tritium throughput and high enough to remove protium, a poison for the plasma. At a wall loading of 2.5 MW/m^2 , 0.1 g of protium is produced each day. The protium concentration in the plasma (N_p/N_{DT}) is related to the permeation rate at steady state as

$$\epsilon = (N_p/N_{DT}) I_{DT}/M_p$$

where I_{DT} is the current of DT ions to the boundary, M_p is the protium production rate, and ϵ is the permeation removal rate divided by particle impingement rate. An acceptable protium concentration is $<1\%$. Since at 2.5 MW/m^2 , $I_{DT} = 2.5 \times 10^{24}/\text{s}$ and $M_p = 7.9 \times 10^{17}/\text{s}$ and at 5 MW/m^2 , $I_{DT} = 4 \times 10^{24}/\text{s}$ and $M_p = 1.6 \times 10^{18}/\text{s}$, an acceptable ϵ is $>4 \times 10^{-5}$. However, we also desire the total permeation to be less than the tritium breeding rate, $6 \times 10^{20}\text{T/s}$, so the upper limit on permeation should be $\epsilon < 3 \times 10^{-4}$.

A steady state computer code was used to calculate the permeation and inventory of hydrogen isotopes in candidate self-pumped limiter materials. The code assumes an atom implantation flux J_1 at a depth δ where $\delta < d$, $< d$, the

wall thickness. The implantation depth depends on the energy of the DT particles which we have assumed to be in the 100's of eV. Gas molecules are assumed to leave either wall surface (front or back) by recombination limited desorption.

$$J = 2 K_r C^2$$

where C is the dissolved hydrogen concentration near the surface and K_r is the recombination coefficient given by Baskes.(3) The protium concentration in the material is much less than the tritium or deuterium concentration. This effect is taken into account by assuming

$$J = K_r C_H C_{DT}$$

Two cases were considered. In the first, the limiter was the entire first wall, the material used was vanadium and the wall-loading was 2.5 MW/m². The code was run for all cases during the 10 years the first wall limiter is assumed to last. Initially, the wall thickness is 2 mm with a front surface temperature of 967 K and a back surface temperature of 913 K. Each year fresh vanadium is deposited on the wall at a rate of 1.5 mm/y. The thermal conductivity of the vanadium was assumed to be 70% of fully-dense vanadium. Table 1 summarizes the tritium permeation and inventory and the protium concentration in the plasma. As the wall thickness increases, the front wall temperature increases which has the effect of increasing the hydrogen flux reentering the plasma from the front wall surface. Thus, the maximum tritium permeation is at year 0 and the maximum protium in the plasma is at year 10. Both values meet our requirements. The tritium inventory is also acceptable.

Table 1. Self-Pumped Limiter - Tritium Permeation and Inventory^a

Time y	Thick mm	Temp. K	Permeation g/d	Inventory g	Protium in Plasma %
0	2	967	697	1.6	.025
1	3.5	1034	324	2.1	.053
2	5.	1085	197	2.6	.088
4	8.	1189	96.6	3.1	.18
6	11.	1293	57.3	3.3	.30
8	14.	1397	38.1	3.4	.45
10	17.	1500	27.2	3.5	.63

^aTotal wall area is 300 m², material is vanadium, back wall is 640°C,
and D-T particle flux is 2.5 x 10²⁴/s.

In the second case, a slot limiter, the reference case for the TPSS reactor, was examined. The limiter consists of a tungsten coated vanadium front surface and a vanadium slot region where the helium is trapped. One must consider both the front surface and the back slot surface in determining the tritium inventory and the hydrogen permeation. The tritium permeation for the tungsten coated vanadium front surface is 1.2 g/d and its tritium inventory is 0.02 g; however, protium permeation is not adequate with just the front surface. One must also consider the behavior in the slot region at the back surface of the slot limiter. Here, about 15% of the tritium and the protium impinge. For the worst case, at end-of-life when the back side is at its maximum thickness and temperature, the protium concentration in the plasma is 3.5% if one assumes that the recombination coefficient at this back surface is high, i.e., the sticking coefficient is 1, which is probably not representative. If one assumes instead a sticking coefficient of 0.1, the protium concentration in the plasma is 1% which is acceptable and the tritium permeation to the coolant is 23 g/d.

Plasma Processing System

The self-pumped limiter is capable of maintaining needed plasma purity without the use of vacuum pumps, i.e., the fuel is not circulated out of the plasma to a plasma processing system. Rather, the tritium is recycled from the plasma edge while the helium is buried under a deposited layer of vanadium. At reactor startup, the plasma chamber of the reactor is pumped down to less than a torr by a single vacuum pump. The exhaust from this pump would not be recycled. It would be handled by a gaseous waste unit to ensure that tritium was not released to the environment.

Because a fuel cleanup-unit and an isotope separation unit are no longer required for plasma processing, we estimated the cost advantage of eliminating these units. The cost of these units for a conventional system was calculated by assuming the plasma processing rates needed in a reactor with a conventional limiter. In a 2500 MW reactor with a fractional burn of 10%, >2 kg/d tritium and >1.4 kg/d deuterium would be handled throughout a reactor's life. Besides the two cited units, the plasma processing system would require a small solid waste unit, a gas waste unit, a tritiated water unit for breakdown of waste water, secondary support equipment, plus monitors, controls and some analytical equipment. We estimated the total capital cost saved by eliminating the plasma processing system at \sim \$25 M.

Function of the Self-Cooled Blanket

In a self-pumped limiter, the tritium not burnt in the plasma enters the vanadium walls through implantation and diffuses to the self-cooled lithium blanket. The lithium, therefore, serves three functions, breeder, coolant, and tritium processing system. The reactor is no longer dependent on vacuum pumps and a plasma processing system but rather on the blanket processing system which must therefore, be highly reliable.

The reference blanket tritium recovery systems for TPSS is the molten salt extraction system. The component units are centrifugal contactors, electrolysis units, an impurity removal unit, and perhaps a small isotope separation unit. Since in the electrolysis unit a carrier gas is needed to sparge the hydrogen species from the molten salt, the main function of the impurity removal unit is to separate the hydrogen species from the helium sparge gas. The isotope separation unit removes protium from the hydrogen stream. A schematic of this processing system is shown in Fig. 2.

The maximum amount of tritium which diffuses into the lithium from the vanadium is <0.1 kg tritium and <0.07 kg of deuterium per day. This compares with ~ 0.3 kg of tritium being bred each day in a 2500 MW fusion plant at a breeding ratio of 1.5. Thus, the size of the lithium processing system does not have to be increased if a self-pumped limiter is used for impurity control. The system needed to achieve 1 wppm, at a distribution coefficient of 1, consists of sixteen contactor units processing 5×10^4 kg/h of lithium. We estimate its cost to be \$80 M.

At a tritium concentration of 1 wppm in the lithium, the inventory in the blanket is 35 g. The total inventory in the processing system is <5 g in the impurity removal unit, <50 g in the isotope separation unit and <10 g in the molten salt and <20 g in the vanadium alloy structure of the blanket. The total tritium inventory is 120 g.

Atmospheric Processing System

The reference TPSS reactor building is significantly smaller than that of previous fusion power reactors. Therefore, the processing capacity of the atmospheric tritium recovery can be significantly reduced. Four units each delivering $142 \text{ m}^3/\text{min}$ were assigned to the four tritium containing areas, the reactor cavity, the upper level of the reactor building, the hot cell and the steam generator and breeder tritium recovery area. These atmospheric tritium recovery units provided a cleanup rate of 0.2 vol%/min for each area; this corresponded to cleanup in 5-10 d. We did not expect that all four of the areas would require cleanup simultaneously; therefore, one unit was a backup. Several of the units could be dedicated to one area if rapid cleanup was required. Because only four units were needed, they occupied a minimal volume; this further reduced the building volume.

Tritium Support Systems

The components which are included under tritium support systems are: the tritium storage beds, the tritium monitors, the secondary containment units, and waste treatment units. We have assumed that controls for each tritium subsystem are incorporated in the individual subsystems. The tritium storage beds contain nearly all the tritium on-site. For a reserve of three days of burn, 1000 g are in reserve storage beds. This reserve storage is comparable to that in a reactor with a conventional limiter.

CONCLUSIONS

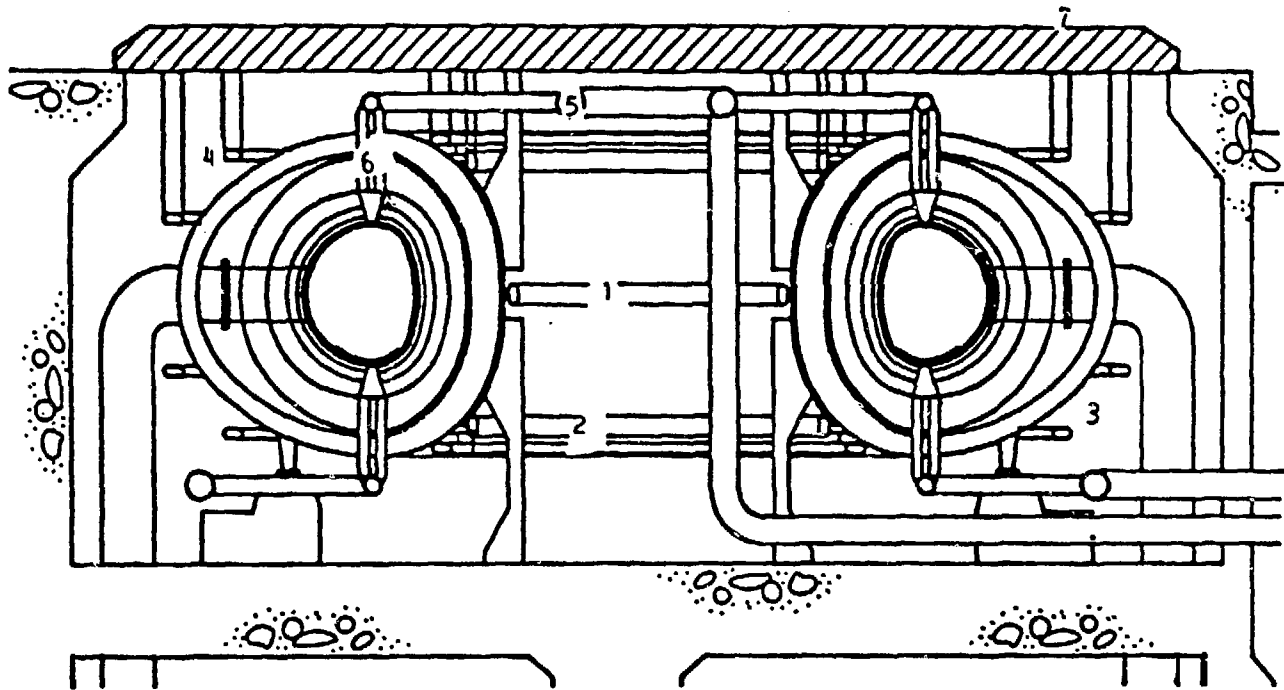
In the TPSS reactor, the use of a self-pumped limiter has three major effects on the design of the reactor tritium systems. First, because there is no plasma exhaust, the plasma processing system is eliminated and its functions are handled by the blanket processing system. Thus, for TPSS, the primary tritium recovery system is the blanket recovery system. Second, the lithium breeder/coolant tritium recovery system, sized to handle the tritium bred, can also easily handle the tritium or deuterium which diffuses from the first wall and/or limiter. With a self-pumped slot limiter, the reference TPSS design, <0.1 kg of tritium and <0.07 kg of deuterium diffuse each day into the lithium; this compares with ~0.3 kg of tritium bred each day for a 2500 MW fusion reactor. This additional material can easily be processed by the lithium breeder/coolant tritium recovery system. Third, the use of the self-pumped limiter minimizes the tritium at risk in the plant since large amounts of tritium are no longer processed each day. We have introduced a passive safety feature by the use of the self-pumped limiter which eliminates the plasma processing system.

REFERENCES

1. J. N. Brooks and K. F. Mattas, J. Nucl. Mater. 121, 392 (1984).
2. D. Ehst, et al., Tokamak Power Systems Studies - FY 1986: A Second Stability Power Reactor, Argonne National Laboratory Report, ANL/FPP/86-1, (1987).
3. M. I. Baskes, et al., "Tritium and Blanket," Chapter VIII, FED INTOR/TRIT/82-5, (1982).

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- 1 EQUILIBRIUM COIL IN CORE CENTER
- 2 EQUILIBRIUM COILS AT CORE BASE
- 3 EQUILIBRIUM COILS AT BASE OF REACTOR
- 4 EQUILIBRIUM COILS AT TOP OF REACTOR
- 5 MAIN OUTLET MANIFOLD
- 6 SECONDARY OUTLET MANIFOLD
- 7 CAVITY COVER



Fig. 1. Side View of Compact TPSS Reactor which has a Self-Pumped Limiter.

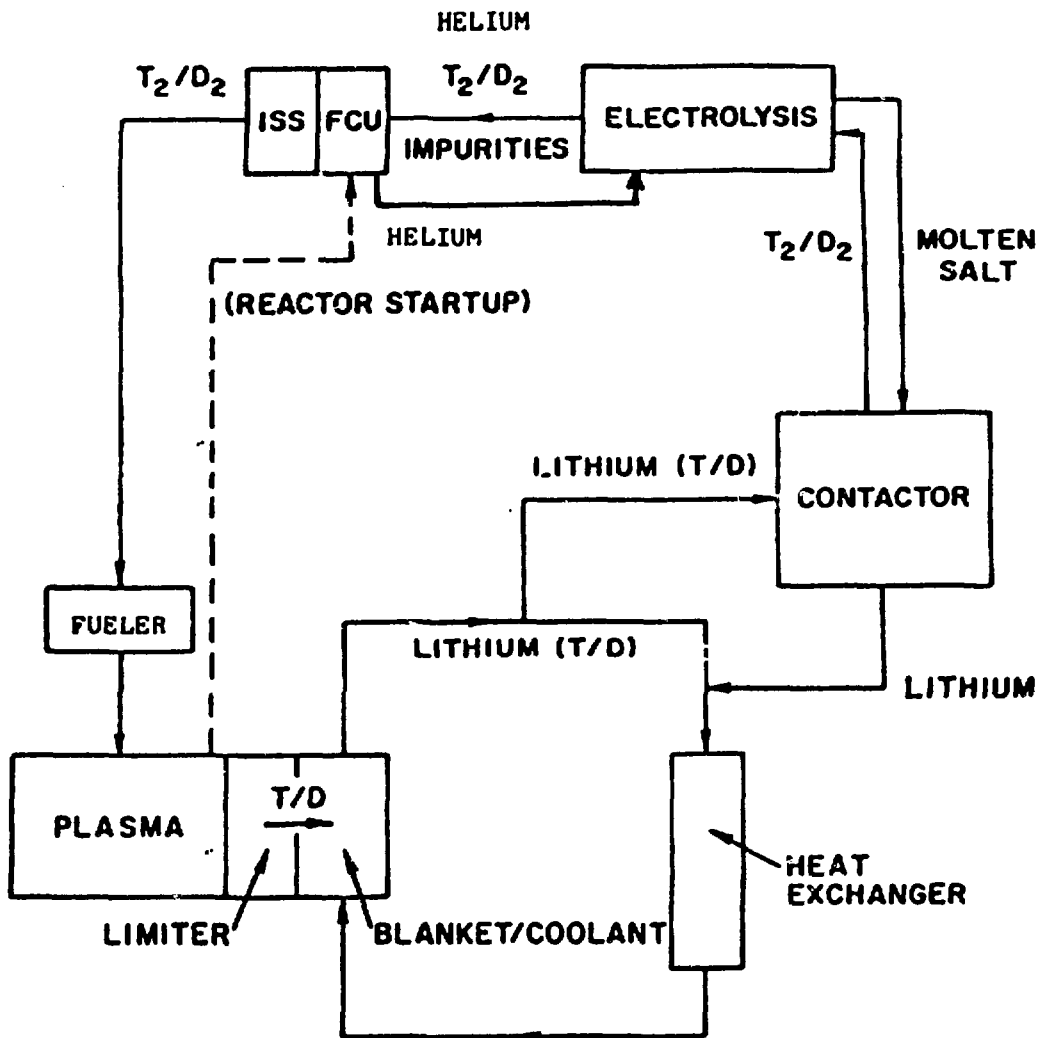


Fig. 2. Schematic of the Tritium Systems Required for the TPSS Reactor.