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AUTHOR(S) D. K. Sze and P. A. Finn, Argonne National Laboratory

J. A. Anderson, J. R. Bartlit, and R. H. Sherman
Tritium Science and Technology Group
Materials Science and Technology Division

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Los Alamos Los Alamos National Laboratory
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PAPER

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D.K. Sze and P.A. Finn
Fusion Power Program, Argonne National Laboratory
Argonne, IL USA

and

J. Anderson, J. Bartlit, and R. Sherman
Los Alamos National Laboratory
Los Alamos, NM USA

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D.K. Sze and P.A. Finn
Fusion Power Program
Argonne National Laboratory
9700 S. Cass Ave., Bldg. 205
Argonne, IL 60439 USA
(708) 972-4838

J. Anderson, J. Bartlit, and R. Sherman
Tritium Science and Technology Group
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545 USA
(505) 667-1410

ABSTRACT

During the ITER design phase, the conceptual design of the fuel processing cycle has been established. The fuel processing cycle is designed to be able to handle all the tritium containing streams of the ITER. These streams include plasma exhaust, blanket tritium recovery, pellet propellent, neutron beam exhaust, water coolant detritiation, waste water from the room air detritiation system. The design is very conservative, i.e., the flow rate of each stream is high and the detritiation factor required is very high.

A preliminary optimization study has been carried out to simplify the ITER fuel cycle design. We investigated:

1. The throughput and composition of the input tritium containing streams from various components to the fuel processing cycle.

2. The fraction of those streams needed to be detritiated.

3. The required detritiation factors required for each of the streams.

The results of the investigation determined that the major input tritium containing steams can be reduced by at least a factor of 10. The required detritiation factor can be reduced from a factor of 100 to 10^6. The size of the fuel processing cycle, the tritium inventory and the complexity of this system can, therefore, also be reduced.

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I. INTRODUCTION

The fuel processing system of a fusion reactor processes all the tritium containing streams. It separates tritium from helium and protium. The end product is tritium with a purity suitable for refueling. It will recycle the other products, such as helium, deuterium and protium, for reuse. A small amount of waste will be produced and released to the environment. The tritium contained in the waste has to be acceptable by safety and environmental regulations.

The tritium and hydrogen inventories of the fuel processing system has major impact on the safety characteristics of the fusion reactor. The reference ITER design[1] has a plasma burn fraction of 3%, and a corresponding tritium inventory of 240 g. All of this tritium is in mobile form and is, therefore, highly vulnerable to release. Thus, the tritium inventory in the fuel processing system is a key concern of the safety of ITER.[1] To enhance the safety characteristics of ITER, the tritium inventory in the fuel processing system needs to be minimized.

The plasma exhaust is the tritium containing stream with the largest tritium throughput. For a fixed fusion power, the plasma exhaust throughput is inversely proportional to the plasma burn fraction. The reference ITER design has a plasma burn fraction of 3%. This 3% burn fraction is highly uncertain. Different ideas have been proposed to increase the plasma burn fraction.[2] The real burn fraction will not be known until a fusion device with a long burning plasma is available. The real burn fraction of the ITER can be either larger or smaller than 3%. This burn fraction can also vary as the plasma operating scenario changes. Therefore, the fuel processing system needs to be flexible to be able to handle the variation of tritium containing stream throughput.

II. ITER FUEL PROCESSING SYSTEM SPECIFICATIONS

The ITER fuel cycle investigated the operation of all the reactor components involving tritium.[1] The conditions of the tritium containing streams are thus specified. The throughputs and concentration of tritium containing streams are shown in Table 1. The required separation fractors in the product streams are also shown in Table 1. It can be seen that the required separation factors are very stringent. The reason of the stringent separation factor were not discussed in the ITER report.

Table 1.
Cryodistillation Feed and Product Streams

	Flow Rates (mol/h)	Concentrations (%)
FEED STREAMS		
Plasma Exhaust	71.4	H:1; D:49.5; T:49.5
Solid Breeder Tritium	105	H:99; T:1
Waste Water Detrit. (based on 200 kg/h water feed ~0.1 Ci/kg)	4000	HT:1.2e-4 in H,D
NBI Gas	378	D2:98; T:1.5
V. High Speed PI Gas	40	H:98.8; D:0.15%; T:1%
Low Speed PI Gas	397	H:92; D:4%; T:4%
PRODUCT STREAMS		
T_2 Product		T:80; D:20; $H < 10^{-7}$
H_2/HD Exhaust		$T < 10^{-9}$
NBI D_2		$T < 10^{-9}$ $H < 4\times10^{-3}$

A simple flow diagram of the fuel processing system is shown in Fig. 1. A water distillation column (DW1) is used to enrich tritium concentration in the water. The water is detriated to less than 10^{-5} Ci/kg to be released to the environment. Due to the large water throughput and the required high detriation factor, the water distillation column is large, with 2 m in diameter and 65 m in height. The water with enriched tritium is fed to a vapor phase catalyst exchange (VPCE) unit to transfer the tritium in water to hydrogen stream. The hydrogen stream from the VPCE is fed to an array of cryogenic distillation (CD) unit. The tritium containing stream from the blanket purge gas, the pellet injector propellent gas, the neutral beam gas the plasma exhaust are all fed to the CD's. The tritium product, deuterium product and protein product are the product streams with impurity concentrations specified in Table 1. Due to the different composition of the feed gas and the stringent product streams composition requirement, four different CDs are required.

As shown in Table 1 and Fig. 1, there is a large waste water throughput of 4000 mole/h, with a tritium concentration of 0.1 Ci/kg. The source of this waste water is summarized in Table 2. The unit in the ITER document is kg/d. The column 2 changes the unit to mole/h, to be consistent to the figures in Table 1. It can be seen that there is a factor of 2 difference in the waste water throughput in Table 1 and Table 2. Since the waste water throughput is defined by Table 1, 8000 mole/h will be the figure to use in this paper. The coolant water receives tritium by permeation. The coolant detritiation requirements are not well defined, as can be seen on Table 2. It does not appear to be included in the fuel processing system design, as can be seen on Fig. 1.

With the throughput of the feed steam, the composition of the feed stream, the specification of the products streams all defined, the system size, hydrogen inventory, and the tritium inventory can all be calculated. The cost of the system can be estimated from the size of the required equipments.

III. COMMENTS ON THE ITER FUEL PROCESSING SYSTEM

A careful review of the ITER fuel processing system uncovered the following concerns:

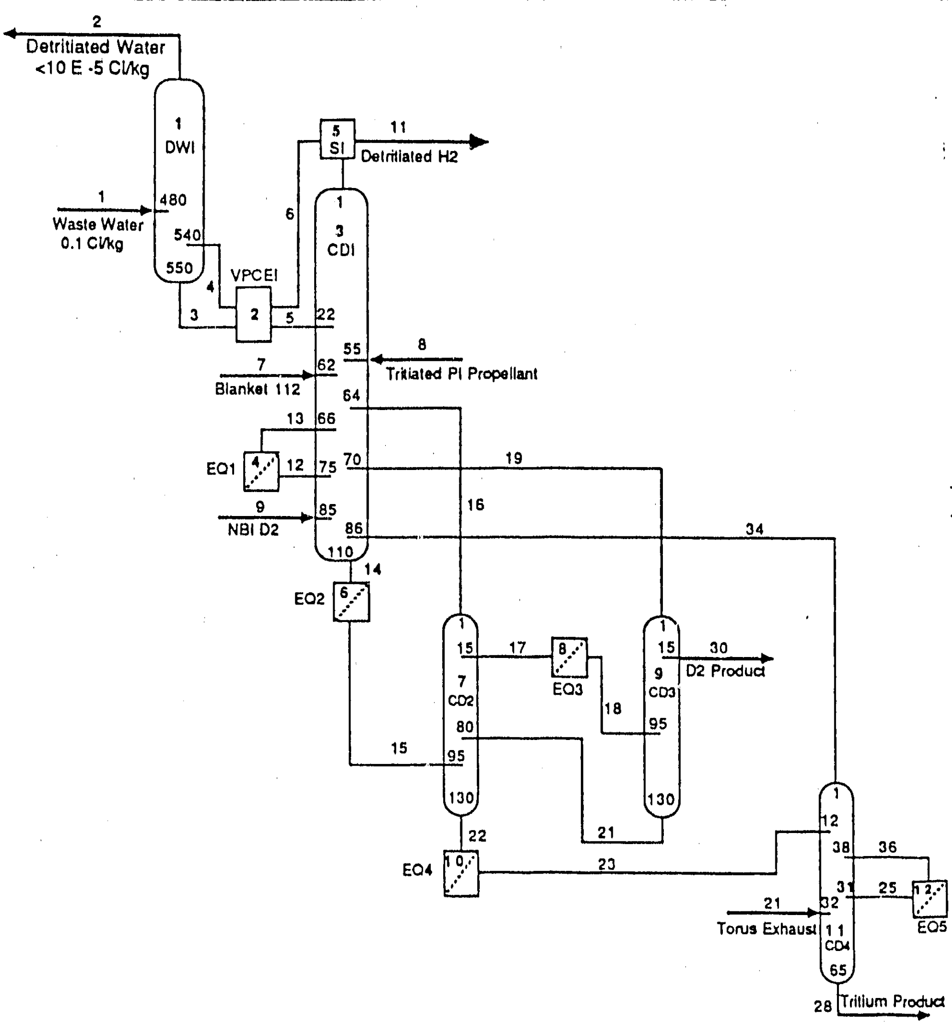

Figure 1. ITER isotope separation system process flow diagram.

1. There is no clear differentiation between the internal recirculation stream (the streams to be reused) and the external recirculation stream (the streams to be released to the environment). The best example of this is the waste water streams as shown in Table 2. The waste water from the post-accident, emergency cleanup are most likely from coolant loop. A cleanup system will be required to remove the impurities picked up during the accident. The water can be returned to the coolant loop without detritiation (so-called internal recirculation). The accident most likely will occur irregularly and infrequently. Therefore, this water stream cannot be used as the coolant stream tritium control.

   On the other hand, the water from the air detritiation, inert gas detritiation and torus cover gas are most likely from inleakage of the air. Since the water is from the atmosphere, and must be returned to the atmosphere (so-called external recirculation). A very high detritiation factor is required to be consistent to the safety and environmental regulations. Since the total allowable tritium release rate for ITER is 20 to 50 Ci/d, we are proposing that the tritium release limit on this external circulating water is conservatively set at .1 Ci/d.

2. Product stream specifications: With the exception of part of the waste water, all the products from the fuel processing system are to be internal recirculated. Therefore, the required detritiation factors are determined by the tritium concentration that components can accept. For instance, the NB propellent can

Table 2. Water Collection from Different ITER Sources

	Flow		Activity (Ci/kg)	
	(kg/d)	(mole/hr)	Tritium	Activation Products
Active Drain System				
- Typical	100	230	10-2-1	0.010-0.070
- Post Accident	1000	2300	<2.5	0.010-0.070
Active HVAC System				
- Air Detritiation	200	460	0.1	0
- Inert Gas Detritiation	40	100	0.001	0
- Emergency Cleanup	100	230	0.01	0
- Torus Maint. Cover Gas	40	100	0.1	0
- Post Accident	2000	4600	<2.5	0
Subtotal	3480	8020		
Coolant Detritiation				
- Divertor	TBD		1	>0.1
- First Wall	TBD		1	0.07
- Diagnostic/Antennae, etc.	TBD		0.01	TBD
- Remote Handling	TBD		0.01	TBD
- Blanket	TBD		0.01	0.01
- Active Storage Pool	TBD		0.1	TBD

accept 1 to 1% of tritium.[4] Thus, it is a wasted effort to reduce T/D ratio in the deuterium stream to much less than 10^{-3}.

Table 3 summarizes different scenarios of the product specifications. The scenario 5 is recommended here. The reasons that the particular product specifications are suggested are:

a. H in D+T. A .1% of protein in DT feed to the plasma will have no impact on plasma performance. The plasma impurity will be dominated by He.

b. T in H. A 1 to .1% impurity in the hydrogen propellent is acceptable.[5] Therefore, a conservative composition of .1% is selected.

c. T in D. A 1 to .1% of tritium impurity in the neutral beam is acceptable.[4] Therefore, a .1% tritium concentration is used.

d. D/T. Since plasma is operated in 50/50 DT mixture, there is no need to separate D and T. The only function of the CD will be to remove protium generated by the D-D reaction.

e. HTO in H_2O. The tritium release rate is set at .1 Ci/d. The 1.2×10^{-10} concentration is consistent to this release rate.

3. Fraction of feed stream operation: The ITER design processes the entire tritium containing streams. However, if the source term of the tritium in the tritium containing stress is small, while the allowable tritium concentration is reasonable, only a fraction of the tritium containing streams have to be fed to the processing system. The rest can by-pass the processing system and return to that component. By simple mass balance, we can reach the following equation

$$m = \frac{T}{\varepsilon C}$$

where m = flow rate of the tritium stream to be processed

Table 3. Product Specifications

	Scenario-1[a]	Scenario-2[b]	Scenario-3[c]	Scenario-4[d]	Scenario-5[e]
H in D+T	1×10^{-5}	1×10^{-6}	1×10^{-11}	1×10^{-13}	1×10^{-3}
T in H	1×10^{-9}	1×10^{-9}	1×10^{-9}	1×10^{-6}	1×10^{-3}
T in D	1×10^{-9}	1×10^{-7}	1×10^{-10}	1×10^{-5}	1×10^{-3}
D/T	0.25	0.25	0.25	0[f]	1
HTO in H_2O	4.6×10^{-12}	6.2×10^{-12}	3.7×10^{-12}	7.6×10^{-11}	1.2×10^{-10}

a- ITER specification as interpreted by Sze.[4]
b- Real ITER specification.[1]
c- Specification achieved by the ITER reference design.[5]
d- Specification investigated by Kveton.[6]
e- Specification proposed here.
f- The D/T = 0. Must be a type from Ref. 6.

T = tritium source term in this stream

ε = cleanup efficiency

c = allowable tritium concentration

and

$$x = \frac{m}{M}$$

M = Flow rates of tritium carrying stream (as shown in Table 1).

x = fraction of those streams needed to be processed.

By carefully documenting the values of the tritium source terms (T) and allowable concentration (c), it can be shown that only a small fraction, about 10%, of all the tritium carrying streams need to be processed.

Another point is that the cleanup efficiency can be relaxed by adjusting the flow rate to the processing system. A 20% increase in this flow rate can relax the cleanup efficiency from .99 to 0.8 for a fixed source term and allowable concentration.

Table 4 summarizes the recommended flow rates from different fusion components to the fuel processing system. It can be seen that the flow rates can all be reduced by approximately a factor of 10.

Table 4.
Flow Rates to the Fuel Processing System

	ITER (mole/h)	This Work (mole/h)
Plasma Exhaust	71.4	7.14
Solid Breeder Tritium	105	105
Waste Water	8000	890
Coolant Water	not specified	900
NBI	378	50
PI Gas	437	100

IV. CONCLUSIONS

A careful review of the ITER fuel processing system identified that the design is far too conservative. A set of product specifications have been set up by ITER to define separation factor required for the T, D, and H streams. This separation factor is too stringent and without documented reasons. Also, the entire tritium containing streams from various components are fed to the fuel processing system. However, by simple mass balance, it can be shown that only a small fraction of that stream, usually around 10%, have to be processed to remove the tritium. The factor of 10 reduction in throughput, and orders of magnitude reduction in required separation factor, will result in a simpler and more reliable fuel processing system with less hydrogen and tritium inventories. The detailed design of the fuel processing system, with the reduced flow rates and separation factors, are in progress.

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