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THE BREEDING BLANKET INTERFACE (BBI)
RECENT RESULTS FOR THE SOLID BREEDER AND THE AQUEOUS SALT
SOLUTION BLANKET CONCEPTS*

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Abstract

The Tritium Systems Test Assembly (TSTA) at Los Alamos is a full-scale facility dedicated to testing tritium processing for fusion reactors. We are involved in a study of adding a Breeder Blanket Interface (BBI) to the TSTA. The BBI is to test the processing required for the tritium output streams for the various fusion reactor breeder blankets. In the current phase of the study, we are evaluating the characteristics of the output from the various blanket types. Emphasis is placed on defining the output stream with respect to H/T ratio, impurity content, and radionuclide content. Reported herein is an assessment for two blanket concepts: solid breeder blanket (ceramic, Li_2O), and aqueous salt solution.

Introduction

The TSTA at Los Alamos National Laboratory (LANL) is a tritium facility dedicated to testing tritium processing for fusion reactors. We are involved in a study [1,2] of adding a Breeder Blanket Interface (BBI) to the TSTA. The BBI, an essential part of the tritium fuel cycle for fusion reactors, must be developed, ready for use, and reliable for the IAEA-sponsored International Thermonuclear Experimental Reactor (ITER). Questions which must be addressed include not only the recovery of bred tritium from the blanket but also how the bred tritium product is to be processed and integrated with the rest of the tritium fuel cycle. The TSTA is fully integrated and it has a tritium throughput of one Kg per day, the same order of magnitude as ITER, depending upon the plasma burn fraction of ITER. The TSTA is the only facility of such a scale capable of performing both steady-state and transient tests on an integrated system. At present the TSTA includes the major fuel cycle components except for the BBI. Addition of the BBI is a logical upgrade to the TSTA. This possible upgrade is the subject of an ongoing study, begun in July 1987, LANL, the Japan Atomic Energy Research Institute (JAERI), and Argonne National Laboratory (ANL). The intent of the program is to install a BBI as an upgrade to TSTA in the 1992-1993 time frame.

The program, begun in July 1987, includes five phases which are:

- Phase 1 The Concept Phase
- Phase 2 Pre-Conceptual Design Phase
- Phase 3 Engineering Design
- Phase 4 Hardware and Construction
- Phase 5 Operation of the BBI at TSTA

The purpose of Phase 1 is to define the tritium product streams for various blankets, so that design of the BBI itself in subsequent phases can proceed. Phase 2 involves pre-conceptual design of the BBI, including definition of components, cost estimates, and a schedule. Currently, the BBI program is in the pre-

conceptual design phase, Phase 2. Status and an overview of the BBI program is presented in a companion paper [1]. Presented herein are results for our analysis of BBI systems for two blankets: aqueous lithium salt solution blanket and solid breeder blanket.

Approach

Phase 1, the concept phase, involved determining the conditions of the product tritium output streams for various blankets. Blankets investigated included most of the major blanket types (liquid metal, solid breeder, aqueous salt solution). The conditions determined included: temperature, flow rate, chemical composition, and concentrations of impurities and radionuclides. As a part of Phase 1, a methodology was developed to systematically evaluate impurity source terms and to follow the transport of impurities and radionuclides through the paths of the system to the blanket output stream. This methodology entailed the following steps:

1. Define the key elements of the blanket system, including the breeder, coolant, structure, method of tritium recovery, and any other parameters that affect the composition of the tritium product stream from the blanket.
2. Determine the source terms for impurities.
3. Calculate the activation rates for the blanket.
4. Determine the transport rates of tritium, the tritium carrying medium, hydrogen, impurities, and radionuclides throughout the blanket system.
5. Determine the conditions of the blanket product stream with respect to composition, temperature, impurity levels, activity levels, etc.

We performed such Phase 1 analysis for three blankets: liquid lithium [3,4] aqueous salt solution [5] and solid breeder [6]. In addition to our Phase 1 studies, a study of the BBI for a liquid Li-Pb blanket was performed [7].

Phase 1 Studies

The concept phase for the aqueous lithium salt solution blanket has been completed and reported [5]. Phase 1 was also completed for the solid breeder blanket [6] and a few key highlights will be presented herein. The basic parameters used in the study for the two blankets are given in Table 1.

Analysis of Source Terms and Transport of Chemical Impurities and Radionuclides in the Product Streams for the Aqueous Salt Solution Blanket

Primary sources of impurities for this system arise from corrosion of the structural material (stainless steel) by the salt solution. These metal components are also the chief sources of radionuclides for the system. Details of levels can be found in Reference 5.

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Table 1
Reference Parameters for the Two Blanket Systems

	Aqueous Lithium Salt Solution Blanket	Solid Breeder Blanket
Breeder material	LiOH (aqueous)	Li ₂ O
Neutron multiplier	Be	Be
Structure	Stainless Steel (SS)	SS
Coolant	Aqueous salt solution	H ₂ O
Tritium concentration method	Water distillation	none
Tritium concentration ratio	100.	--
Tritium recovery method	VPCE ^a	He purge
Tritium carrier	Aqueous salt solution	He + H ₂
Tritium concentration in carrier	20 Ci/L (average)	0.1%
H/T ratio in blanket	2.0 E5 (average)	100.
H/T ratio in BBI inlet	2000.	100.
Tritium capacity - reference, full scale	40. g/day ^b	150. g/day
Scale factor for TSTA/BBI	0.010	1.0
Tritium flow rate - TSTA/BBI	0.40 g/day	150. g/day
Protium flow rate - TSTA/BBI	300. g/day	5000. g/day

^a Vapor Phase Catalytic Exchange

^b Salt solution can be used as the tritium storage.

Analysis of Source Terms and Transport of Chemical Impurities and Radionuclides in the Product Streams for the Solid Breeder Blanket

Levels of trace impurities in the Li₂O and the Be were studied extensively [6]. The existing data on reported impurities in Li₂O [8-15] and Be [16-19] was reviewed in some detail. Recommended impurity levels for Li₂O (Table 2) are summarized. These data were used for the US-ITER design [20].

The impurity levels in the Li₂O and in the Be were used to calculate activation rates and to determine levels of volatile species in the sweep gas. At 600°C the estimated maximum outlet temperature of the blanket, the major impurities from the Li₂O are C (as CO₂) - 4.7 g/day and Na -- 2.7 g/day. The major volatile radionuclide is ³⁵S, with 0.8 Li/day evolved to the sweep gas to recover tritium from Be [20]. Owing to the much larger amount of Be in the blanket and the higher impurity levels, potential contaminant levels are much higher in the Be sweep gas. At 600°C, calculated transport rates (in g/day) are Na-2760., Cl (as BeCl₂)-2300., Ms-1060., Zn-184., Li-40., F (as BeF₂)-16., and many others, <5. The dominant volatile radionuclide from Be is ³⁵S, at 32 Ci/day.

Table 2
Summary: Impurities in Li₂O (wppm)

Element	Recommended Reference Values	Notes, Accuracy
Li		Constituent element
Be	1.	Presence uncertain
B	1.	Presence uncertain degassed to < 8 wppm [24]
N	2.	Presence uncertain
O		Constituent element
F	0.1	Presence uncertain
Na	60.	Typically 30-100 wppm.
Mg	10.	
Al	50.	
Si	50.	
P	1.	Presence uncertain
S	0.1	Presence uncertain
Cl	10.	Heat treatment to ~ 10 wppm.
K	20.	Conc. highly uncertain
Ca	100.	
Sc	0.1	Presence uncertain
Ti	10.	
V	1.	Presence uncertain
Cr	1.	Typ. ~ 1 wppm range
Mn	1.	Typ. ~ 1 wppm range
Fe	50.	
Co	0.2	0.2 - n. activation LiAlO ₂
Ni	10.	Typ. 10-20, sometimes ~ 1.
Cu	10.	Typ. ~ 10.
Zn	10.	Presence uncertain
Ga	1.	Presence in Li ₂ O uncertain, TRIO LiAlO ₂ : 16. by neutron activation and e. spec.
Ge	0.1	Presence uncertain
As	0.1	Presence uncertain
Se		
Br	0.1	Neutron activation, TRIO
Rb	0.1	Presence uncertain
Sr	1.	Neutron activation, TRIO
Zr	1.	Presence uncertain
Nb		
Mo	0.1	Presence uncertain
Ag		
Cd	0.1	Presence uncertain
In		
Sn	1.	Presence uncertain
Sb	1.	Neutron activation, TRIO
I		
Ba	5.	Presence uncertain
La		
Au	0.0005	Neutron activation, TRIO
Pb	0.1	Presence uncertain
Bi		
U	0.1	Presence uncertain, has been observed in Li ₂ O (~ 1 wppm [9]) and in LiAlO ₂ (0.19 wppm [8])

Recent Studies of the Aqueous Lithium Salt Solution

Since our earlier Phase 1 study was completed for LiNO₃ [5], a number of design changes for the aqueous salt concept have occurred which required additional analysis of the salt concept [21]. In the current design [22], the salt is LiOH, the Be is clad, the geometry and the coolant flow are different. The major conclusions of the earlier study are still valid, i.e., that a number of potentially severe problems may impact the design and operation of the blanket. These potential problems include water radiolysis, corrosion of the structure, and hydrogen safety.

Further, we have uncovered another potentially severe problem, electrolytic effects [23]. When a conducting fluid like aqueous LiOH is circulated in the presence of magnetic field voltage is induced. The estimated magnitude of this induced voltage for the current ITER design is 0.1-0.2 V. This 0.1 V induced voltage, when combined with information on a reported polarization curve was used to calculate [24] a uniform steel dissolution rate for ITER, 7.0×10^{-5} cm per day. This corrosion rate is acceptable, however a particular concern is that neither the flow nor the field, are constant within the fusion reactor blanket. Therefore, localized corrosion could be much more severe than the average rate.

Synergistic effects involving combinations of chemical potential, magnetic field, and radiolysis are a concern for the solution chemistry of the aqueous salt design. This chemistry is significantly more complicated than water chemistry. The latter chemistry for fission reactors is still not fully understood after 40 years of intensive study. Thus, we may expect that many surprises will result in the aqueous salt system.

Phase 2 Studies: Pre-Conceptual Design of BBI

Aqueous Lithium Salt Solution Blanket

The flow sheet for the BBI for this blanket concept is illustrated in Fig. 1. The components are:

Figure 1.

BBI systems for the aqueous lithium salt solution blanket.

BBI

The components of the BBI for an aqueous salt solution blanket include a blanket stream mockup (BSM), a blanket fuel cleanup module (BFCU), a cryogenic distillation unit (BISS), and a blanket waste disposal unit (BTWT). The H/T ratio is $10^3:1$, that in ITER, however, the BBI units are sized to a flow which is 0.01 that in ITER to reduce the cryogenic load and size of the BISS unit.

BSM

The blanket stream mockup contains a tritiated water circulation system, a tritiated water preparation unit and a VPCE unit. The 1000 Ci/L tritiated water contains expected impurities.

BFCU

The fuel cleanup unit contains four components, a cooler, 3A molecular sieves at -196°C , 5A molecular sieves at -196°C and a palladium diffuser. Entrained water is removed via the first two components. Other impurities plus a small amount of hydrogen are removed at the 5A sieves. The hydrogen is recovered by cycling it past the diffuser.

BISS

The isotope separation unit recovers the tritium and recycles protium to the VPCE.

BTWT

The tritiated waste unit retains on 5A molecular sieves. An activated carbon bed serves as a final trap prior to exhaust.

Solid Breeder Blanket

The purpose of the Breeder Blanket Interface (BBI) is to perform the necessary processing of the tritium product that is recovered from the blanket. For this study, the reference solid breeder blanket design is US-ITER, normalized to a thermal power of 1000 MW at 20 MeV per fusion. For a solid breeder/ Li_2O blanket, tritium is recovered by sweeping a helium gas stream through channels in the solid breeder. Thus, the form of the tritium that is to be processed is as a dilute gas mixture in helium. Since a small amount of tritium is produced in the Be neutron multiplier in the blanket, a helium purge stream is also used to recover the tritium bred in the Be.

The components of the BBI (see flow sheet, Fig. 2) are:

Figure 2.

BBI systems for the solid breeder blanket.

1. Blanket Stream Mockup

The helium sweep gas mixture (~ 99.8 a% He, 0.2 a% H, 20 appm T, impurities) is blended to simulate the composition of the blanket stream.

2. Molecular Sieve Traps

The tritium product, in the forms HT and HTO is separated from the large volume of He gas by sorption in 5A molecular sieve beds at -196°C . The H_2 , plus impurities are also sorbed and removed from the helium gas stream.

3. Cold Traps

Tritiated water ($\text{HTO} + \text{T}_2\text{O} + \text{H}_2\text{O}$) is separated from the stream by cold traps operating at -100°C . The HT product, plus H_2 and most impurities are not removed from the product stream by the cold traps.

4. Electrolyser

The tritiated water is reduced to the molecular (HT) form and returned to the product stream. Such an electrolyser has been developed by JAERI and tested at the TSTA.

5. Getter Beds

Hydrogen, plus the tritium is absorbed on metal getter beds. At present, the getter under consideration is Zr or a Zr alloy. Sorption would occur at 350° to 450°C and regeneration would occur at 600° to 700°C . Impurities are not absorbed, and the waste stream is processed (Item 7.) Upon regeneration of the getter, the purified hydrogen/tritium stream is sent to the Blanket Isotope Separation System.

6. Blanket Isotope Separation System

The tritium is separated from the hundredfold excess of hydrogen isotope by cryogenic distillation. The tritium product is sent on to the TSTA. The H_2 is recycled to the blanket stream.

7. Blanket Tritium Waste Treatment

The Blanket Tritium Waste Treatment subsystem is designed to process impurities and recover tritium for recycle. The present design involves oxidation and thus the tritium recycle is in the oxide (HTO) form.

Conclusions

Analysis of blanket and BBI systems for the Aqueous Salt Solution Blanket and the Solid Breeder Blanket were presented. For the Aqueous Lithium Salt Solution Blanket, the chemical systems are very complex, involving a number of phenomena, including radiolysis, corrosion, and electrolysis. A system of about 0.01 ITER scale may be added to the TSTA. For the solid breeder blanket, no critical issues were identified. A system of about half-ITER scale, possibly even full scale, may be added to the TSTA.

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