CONF-860917--14

FEB 0 2 1987

BEATRIX - THE INTERNATIONAL BREEDER MATERIALS EXCHANGE

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CONF-860917--14

DE87 004668

ABSTRACT

The BEATRIX experiment is an IEA-sponsored effort that involves the exchange of solid breeder materials and shared irradiation testing among research groups in several countries. The materials will be tested in both closed capsules (to evaluate material lifetime) and opened capsules (to evaluate purge-flow tritium recovery). Pre- and post-irradiation measurement of thermophysical and mechanical properties will also be carried out.

1. INTRODUCTION

A critical element in development of fusion energy is the blanket for breeding tritium fuel. A program[1] is in progress to develop a data base for materials properties and irradiation behavior that can be used in evaluation and selection of a prime candidate breeder material. Lithium-containing ceramic materials (e.g., Li_2O, $LiAlO_2$, Li_4SiO_4, Li_2ZrO_3) are being given strong consideration because they offer the potential for tritium breeding, high-temperature stability, and ease of tritium recovery. Laboratory studies to measure the thermochemical, thermophysical, and mechanical properties of each material are underway. Irradiation experiments to test the response of each material to a neutron environment are being undertaken through a coordinated exchange of candidate breeder materials to ensure correlation among test environments and materials. The in-reactor experiments will give information on the response of the breeder material to a neutron environment and on the ease of tritium recovery.

Year-long capsule irradiation experiments (FUBR-1A)[2] have affirmed the attractiveness of ceramic breeder materials because of their chemical stability, resistance to radiation damage, and low tritium retention. These experiments also showed that swelling of Li_2O may be its least desirable property in comparison to the other ceramics. Since swelling is thought to be caused by defect and helium production, it is likely that swelling will be proportional to burnup and will increase at higher burnup levels. In situ tritium recovery experiments with $LiAlO_2$ (TRIO)[3] revealed low tritium solubility with this material, indicating that blanket tritium inventory is likely to be well below design guidelines. Complementary laboratory experiments on both irradiated and unirradiated materials are being undertaken to more rigorously define the tritium transport and release mechanisms. Such data are needed as input to models for analysis of breeder blanket designs.

2. DISCUSSION

Because of the detailed technical knowledge required to understand the performance of a ceramic breeder blanket, an international collaborative effort has been established to conduct cooperative research on tritium breeding solids including Li_2O, $LiAlO_2$, Li_4SiO_4, Li_2SiO_3, and Li_2ZrO_3. This effort, which is under the auspices of Annex II to the International Energy Agency Implementing Agreement for a Program of Research and Development on Radiation Damage in Fusion Materials, involves the exchange of materials and shared irradiation testing. Participants in this program include Canada, European Communities, Japan, and the United States. Contributing laboratories include CEA/Saclay, KfK/Karlsruhe, JAERI/Tokai, AERE/Springfield, CRE/Casaccia, and Argonne and Westinghouse-Hanford. This exchange program, named BEATRIX (Breeder Materials Experimental Matrix), will allow comparison of materials preparation and fabrication methods, irradiation techniques, and tritium extraction methods. Materials prepared by one partner will be irradiated in another partner's reactor. The irradiation experiments are of two types: closed-capsule tests to evaluate material lifetime, and open-capsule tests to evaluate _in situ_ tritium recovery.

The in-reactor experiments are likely to impose thermal gradients upon the ceramic solid. Such temperature gradients may produce changes in the solid that could influence tritium transport and release. Thus, the in-reactor experiments are designed to more clearly define the relation between the thermal behavior of the solid and the mechanisms of tritium recovery.

Closed-capsule experiments will be done in mixed-spectrum reactors (HFR,[4] OSIRIS,[5a,b] and NRX[6a]) and in a hard-spectrum reactor (EBR-II[2]). These experiments are listed in Table I.

TABLE I. BEATRIX: CLOSED-CAPSULE TESTS

Laboratory	Reactor	Experiment	Materials
Westinghouse/ Hanford	EBR-II	FUBR-1B	(Li_2O, γ-$LiAlO_2$, Li_2SiO_3 (Li_4SiO_4, Li_2ZrO_3)
ECN/Petten	HFR	EXOTIC	(Li_2O, γ-$LiAlO_2$, Li_2SiO_3)
CEA/Saclay	OSIRIS	ALICE	(γ-$LiAlO_2$)
KFK/Karlsruhe	OSIRIS	DELICE	(Li_2SiO_3, Li_4SiO_4)
AECL/Chalk River	NRX	CREATE	(Li_2O, γ-$LiAlO_2$)

Probably the most detailed experiment, in the sense of variety of materials, is FUBR-1B because it involves five different materials, which are supplied by six different partners and are in three different configurations. Table II lists the material fabrication details and experimental temperatures. This test will afford comparison of materials preparation and fabrication techniques for candidate breeder materials that will be irradiated under identical conditions. The experiment is also the only long-term (~2 yrs), high-burnup irradiation experiment in a hard-spectrum reactor. The data will significantly enlarge our understanding on the effects of temperature gradients and high fluence on the performance of solid breeder materials.

In the mixed-spectrum tests, a variety of materials will be tested using different irradiation vehicle designs in different reactors. The design of the EXOTIC[4] capsule allows for both open- and closed-capsule tests to be conducted simultaneously. In situ tritium extraction tests and detailed postirradiation tests (solubility and thermophysical and mechanical

TABLE II. BEATRIX: FUBR-1B TEST MATRIX

Capsule I.D.	Material/Source	Pellet Characteristics: ^{6}Li Enrichment (%) [a]	Diameter (cm) [b]	Column Length (cm) [c]	Density (%)	Predicted Centerline Temperature (°C)
S4T	$LiAlO_2$/Saclay	95	2.320	5.08	80	900
S4B	Li_4SiO_4/Karlsruhe	95	1.646	5.08	95	775
S5T	Li_2ZrO_3/HEDL	95	2.320	5.08	80	1150
S5B	Li_2O/JAERI	56	1.646	5.08	80	900
B8T	Li_2O/JAERI	56	0.952	5.71	86	500
B8B	Li_2O/JAERI	56	0.952	5.71	86	700
B8C	Li_2O/JAERI	56	0.952	5.71	86	900
B9T	Li_2O[d]/JAERI	7.5/.07	0.8	5.71	100	500
B9B	Li_2O/Springfields	56	0.951	5.71	80	700
B9C	Li_2O/JAERI	95	spheres[e]	5.71	80	700
B10T	$LiAlO_2$/Saclay	95	0.952	5.71	80	500
B10B	$LiAlO_2$/Saclay	95	0.952	5.71	80	700
B10C	$LiAlO_2$/Saclay	95	0.952	5.71	80	900
B11T	Li_4SiO_4/Karlsruhe	95	0.952	5.71	80	500
B11B	Li_2SiO_3/Karlsruhe	95	0.952	5.71	80	700
B11C	$LiAlO_2$/Casaccia	95	0.952	5.71	80	700
B12T	Li_4SiO_4/Karlsruhe	95	spheres[e]	5.71	95	500
B12B	Li_2ZrO_3/Springfields	95	0.952	5.71	80	700
B12C	$LiAlO_2$/Casaccia	95	0.952	5.71	80	700

[a]Pellet enrichment to ±2% ^{6}Li - except single-crystal Li_2O
[b]Pellet diameter to ±0.002 cm - except single-crystal Li_2O
[c]Pellet column length to ±0.02 cm
[d]Single crystals; half of the crystals enriched in ^{6}Li to 7.5%; the other half to 0.07%
[e]High-density spheres of 700-μm size

properties) will be carried out. The irradiation period is typically 25 days; temperatures of 400° and 600°C will be used. The materials being irradiated have been prepared by the USA, JAERI/Tokai, SCK/CEN-Mol, and SNL Springfields. The EXOTIC experiment affords a direct comparison of Li_2O prepared by Argonne, Tokai, and Springfields. The ALICE[5a,b] and DELICE experiments are a continuing series of closed-capsule tests focused principally on the lithium aluminates and lithium silicates, which are to be irradiated in the OSIRIS reactor for 26-day cycles also at 400° and 600°C. Materials are supplied by the USA (ALICE) and Germany (DELICE). Post- irradiation tritium release studies will focus on diffusion and desorption phenomenology. Irradiated materials from the ALICE experiments will also be used for measurement of fracture and tensile properties and compared with similar measurements made on unirradiated materials originating from the same lot. In the recently completed CREATE[6a] experiments, γ-$LiAlO_2$ and Li_2O were irradiated in sealed capsules, and the tritium release behavior was examined in postirradiation annealing experiments. Sweep gas composition, structural material, and ceramic characteristics were varied to determine their effect on release rate and the form of the released species.

Recent tritium release studies have shown that sintered materials of Li_2O[7] and Li_4SiO_4[8] exhibit high tritium diffusion even at temperatures as low as 400°C. The inclusion of solid breeder materials in the form of single crystals, high-density spheres, and sintered product (in experiments like ALICE and DELICE) will afford an excellent comparison of tritium diffusion in materials of different configuration. In the scope of this collaborative effort, diffusion coefficients from all tests will be compared to avoid a given experiment biasing the results.

The open-capsule tests (tritium recovery by purge-flow) provide complementary data on tritium release behavior for each solid under irradiation. Such data are extremely valuable in assessing steady-state tritium inventory and the influence of purge gas chemistry on tritium recovery. Several different purge-flow experiments are part of the BEATRIX materials exchange, and these are listed in Table III. These open-capsule tests will be performed in the HFR[6b], SILOE[7,9] and NRU[10] reactors. Each experimental system is equipped with an analytical train (gas station) for analysis of the tritium content of the purge gas and for characterization of the form of the released tritium, i.e., oxidized or reduced. Typically, the purge gas will contain small amounts of hydrogen to improve tritium desorption, through exchange, from the breeder surface.

The EXOTIC and LILA experiments will be the first purge-flow tests on Li_2ZrO_3, a material that exhibited excellent performance in the FUBR-1A irradiation. The CRITIC experiment test vehicle is quite similar to that of TRIO,[3] except for the fact that annular pellets of Li_2O, rather than $LiAlO_2$, are being irradiated. The LISA experiment will give attention to the silicates, with Li_4SiO_4 being present in the form of high-density spheres. The VOM-23H experiment will also contain high density spheres of Li_4SiO_4 (from Karlsruhe) in addition to rods of γ-$LiAlO_2$ (from Saclay).

TABLE III. BEATRIX; PURGE-FLOW TESTS

Laboratory	Reactor	Experiment	Materials
ECN/Petten	HFR	EXOTIC	(Li_2SiO_3, $Li_2Si_2O_5$, Li_2ZrO_3, Li_4SiO_4)
CEA/Saclay	SILOE	LILA	(γ-$LiAlO_2$, Li_2ZrO_3)
KFK/Karlsruhe	SILOE	LISA	(Li_2SiO_3, Li_4SiO_4)
JAERI/Tokai	JRR2	VOM-23H	(Li_4SiO_4, γ-$LiAlO_2$)
AECL/Chalk River	NRU	CRITIC	(Li_2O)

3. CONCLUSION

Complementary irradiation experiments supported by detailed laboratory studies on materials preparation, fabrication, and properties will considerably enlarge the properties data base necessary for evaluation and selection of a prime candidate for the tritium breeder material. Data from several of the above experiments were reported at ICFRM-2, and other data will be forthcoming. Data from FUBR-1B will not be available until early 1989 because of the lengthy irradiation period.

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