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THE FUBR-1B EXPERIMENT AND BEATRIX-I

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THE FUBR-1B EXPERIMENT AND BEATRIX-I - G. W. Hollenberg, R. C. Knight, and L. A. Pember (Westinghouse Hanford Company), C. E. Johnson and R. B. Poeppel (Argonne National Laboratory), and L. Yang (GA Technologies)

OBJECTIVE

The objective of this work is to irradiate lithium ceramics in a fast neutron environment to high burnup levels and with large temperature gradients. As a part of the BEATRIX-I, the object of the second part of this experiment is to irradiate materials from IEA participating countries in a similar manner.

SUMMARY

The first insertion of two subassemblies has completed its irradiation in December 1986. This irradiation exposed Li_2O and $LiAlO_2$ to not only high temperatures but also large temperature gradients which are expected in fusion blankets. In addition, it included other materials such as Li_2ZrO_3, Li_8ZrO_6, Li_4SiO_4, and $LiAlO_2$ (spheres and large grain size) some of which will go to high burnups.

The second insertion will contain lithium ceramics from Saclay, France; Casaccia, Italy; Karlsruhe, Federal Republic of Germany; Springfield Laboratories, England; and JAERI, Japan.

PROGRESS AND STATUS

Introduction

A high fluence irradiation experiment on solid breeder materials is being irradiated in the EBR-II reactor. The experiment is evaluating the performance of numerous materials which are presently viewed as candidates for use in a solid breeder blanket for tritium and sensible heat extraction. Accumulation of tritium and helium retention data, along with chemical and physical stability results, will aid not only in direct comparison of the materials themselves but also in the generation of better blanket designs. The experiment features large diameter pellets with large temperature gradients, thus providing a better simulation of actual component operating characteristics.

The objectives of solid breeder irradiation testing are long range in comparison with some other research areas but nevertheless important in the greater context of fusion power's eventual viability. Issues such as tritium self-sufficiency, blanket integrity, and component lifetime will only be further emphasized as an actual D-T fusion power plant nears reality.

At present, an international solid breeder test program has been initiated (BEATRIX) in which the FUBR-1B experiment complements irradiation testing conducted in thermal neutron reactors. In some respects, the FUBR-1B experiment is an extension of a previous experiment which had more limited test objectives (FUBR-1A).

The integrity and lifetime of the solid breeder may seem distant issues, but these issues force compromises of solid breeder design and neighboring structural material design which are basic to the economic credibility of a fusion power plant. Now prime issues related to the swelling (or lack thereof) and breeder integrity are of interest for specific solid breeder materials; but issues such as irradiation effects on tritium recovery and mass transport also require resolution.

Tests such as TRIO,[2] LILA, LISA, EXOTIC, VOM, and CRITIC[3] are devoted to in-situ recovery with the greatest emphasis being placed on temperature transients and purge gas effects in a thermal reactor environment under low exposure, essentially startup conditions. In contrast, the FUBR-1B experiment utilizes closed capsules in a fast neutron environment to achieve moderate burnup levels as shown by comparison to some early FINESSE design goals in Table 1.[5] The FUBR-1B experiment has an additional objective which differentiates it from other solid breeder tests in that temperature gradients have been made purposely large by using some large diameter solid breeder pellets in order to simulate the temperature gradients found in actual blankets. The low cross-section for Li-6 reaction, provided by the fast reactor neutrons, generates almost homogeneous heating throughout the pellets which is necessary for establishing the proper temperature distribution. Thermal stresses and swelling stresses associated with large temperature differences in solid breeder pellets can produce substantial cracking which would otherwise be unobserved. Additionally, temperature gradients and size are expected to influence the spatial dependence of tritium retention. Finally, the upper temperature limit of these solid breeder materials may be best evaluated under conditions of large temperature gradients rather than isothermally. For example, in the case of LiOH vapor transport under isothermal conditions, the high vapor pressure of LiOH at high temperatures leads to Li_2O deposition on the containment walls (metal). But in the case of temperature gradients, such depositions are expected to occur within Li_2O monoliths producing more realistic consequences. Also upper temperature limits for $LiAlO_2$ and the other ternary ceramics have been proposed with only the weakest of technical justification. Hence, irradiation testing under large temperature differences will provide a better definition of these limits.

Table 1. Comparison of design parameters

Test Parameter	FINESSE Blanket	FUBR-1A	FUBR-1B
Material	Li_2O	Li_2O	Li_2O
Peak Tritium Production (10^{20} at/cc)	19	11	33
Solid Breeder	850-510	500*	1000-524
Temperatures (°C)		700*	663-450
		900*	500, 700, 900*
Lithium Cross-Section (barns)	15	1	1
Material	$LiAlO_2$	$LiAlO_2$	$LiAlO_2$
Peak Tritium Production (10^{20} at/cc)	70	11	33
Solid Breeder	1000-350	500*	1127-600
Temperatures (°C)		700*	775-530
		900*	500, 700, 900*
Lithium Cross-Section (barns)	15	1	1

*Almost isothermal, ΔT < 50°C.

Design

In Table 2, the test matrix for the first insertion of the FUBR-1B experiment is provided. Actually, two separate subassemblies are utilized at the same time for this testing. One subassembly contains seven pins for 1 cm diameter pellets that are very similar to those of the FUBR-1A experiment while the other subassembly contains three pins with 1.7 and 2.4 cm diameter pellets. The neutron fluence in Row 7 of the EBR-II reactor is approximately 6.2 x 10^{22} n/cm^2 (E > 0.1 MeV) at 900 FPD with a Li-6 spectrum-averaged cross-section of 0.5 to 2 barns. Because of the low cross-section for the Li-6 reaction, the self-shielding within the pellets is predicted to be less than 5%.

Table 2. FUBR-1B test matrix for first insertion

Material	Diameter (cm)	Density (% TD)	Grain Size (μm)	Temperature (°C)
Reference Materials				
Li_2O	2.4	80	4	1000-524
Li_2O	1.7	80	4	663-450
Li_2O	1.0	80	4	500, 700, 900*
$LiAlO_2$	2.3	80	1	1127-600
$LiAlO_2$	2.3	80	1	775-530
$LiAlO_2$	1.0	80	1	500, 700, 900*
Large Grained and Low Density Materials				
Li_2O	1.0	80	80	700*
$LiAlO_2$	1.0	80	35	500*
Other Materials				
Li_2ZrO_3	1.0	85	2	600*
Li_8ZrO_6	1.0	80	3	600*
Li_4SiO_4	1.0	80	2	500*
$LiAlO_2$ Spheres	1.0	60	30	700*

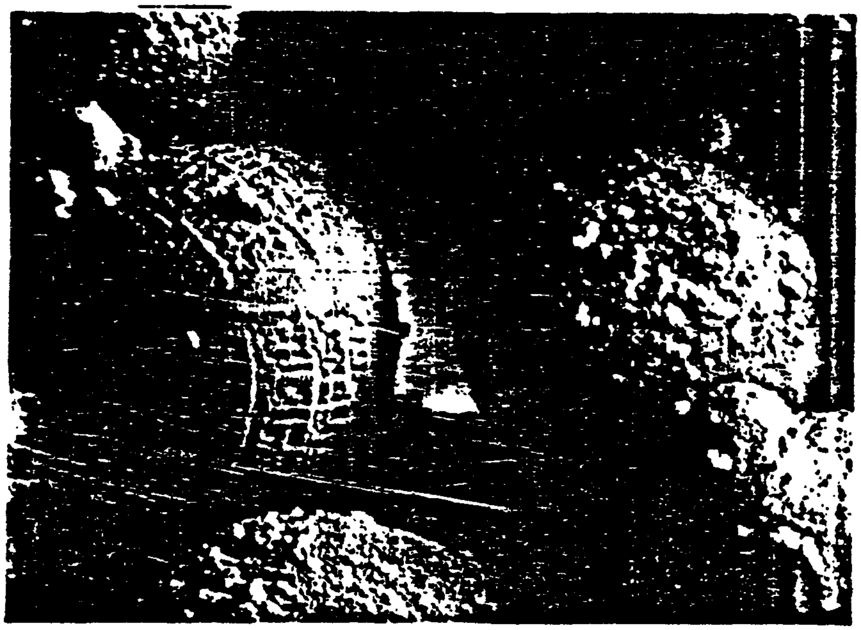
*Almost isothermal, ΔT < 50°C

Materials

In Table 2, the materials contained within the FUBR-1B experiment's first insertion pins are described. The reference Li_2O and $LiAlO_2$ pellets were fabricated with a density of 80% by hot pressing and possessed less than 2000 μg/gm of metallic impurities. Chlorine and fluorine were maintained below 150 μg/gm. The moisture level was measured to be below 0.005 mol% with the carbonate as high as 0.34 mol% in the Li_2O. The grain size of the reference Li_2O was 4 μm; grain size of the reference $LiAlO_2$ was less than 1 μm. In order to evaluate the effect of grain size on the tritium and helium release and other performance parameters, large grained samples of Li_2O (80 μm) and $LiAlO_2$ (35 μm) were included. Early in the development of solid breeder materials, it was thought that large grains would be detrimental to the release of tritium from the blanket; but more recently this has been reconsidered.

Since Li_2ZrO_3 was found to be a stable material which readily released tritium during the FUBR-1A experiment, continued evaluation in FUBR-1B was of interest. A new zirconium compound, Li_8ZrO_6, was initially enthusiastically included in the test matrix because of its potential neutronic advantages. However, Li_8ZrO_6 was found to be unstable during conventional vacuum outgassing, as it disassociated into Li_2O and Li_4ZrO_4. Thus, its role in the experiment diminished to only one capsule. Ultimately, it was determined that by very slow vacuum outgassing, Li_8ZrO_6 could be annealed successfully.

The use of sphere-packed $LiAlO_2$ has been proposed as a method for constructing the complex solid breeder blanket configuration. In an attempt to explore the feasibility of such a concept, stoichiometric $LiAlO_2$ spheres were fabricated by plasma spraying. In Figure 1, a SEM photograph of some of these spheres demonstrates their surface morphology as produced by quenching of the liquified $LiAlO_2$. The diameter of these spheres was approximately 35 μm.



10 μm

Fig. 1. $LiAlO_2$ spheres prepared by plasma spraying granulated $LiAlO_2$ that was hot pressed. Notice the dendritic surface texture.

FUTURE WORK

The schedule for FUBR-1B provides for a 900 FPD irradiation of three pins which will likely end in 1989. At the beginning of 1987 after 300 FPD of irradiation, selected pins will be removed and replaced by pins specifically dedicated to the BEATRIX exchange program of IEA. The designed materials and their source are shown in Table 3. Spheres or pellets of $LiAlO_2$, Li_2O, Li_2SiO_3, Li_4SiO_3, and Li_2ZrO_3 will be provided from Japanese and European sources which will yield a direct comparison between a variety of fabrication techniques.

CONCLUSIONS

The FUBR-1B experiment will significantly enlarge our understanding of the effects of temperature gradients and high fluence irradiation on the performance of solid breeder materials. This experiment provides a closer simulation of operating conditions in an actual fusion power plant's blanket with its higher burnup and larger dimensions. The spectrum of materials now being irradiated and those provided by the BEATRIX exchange program allows a direct comparison of the solid breeder materials that can be fabricated in the world today.

Table 3. BEATRIX/FUBR-1B test matrix second insertion

Capsule	Material	Source	Li-6 Enr. (%)	Diameter (cm)	Density (% TD)	Goal Temp. (C)
S4T	$LiAlO_2$	Saclay	95	2.320	73.5	1115
S4B	Li_4SiO_4	Karlsruhe	95	1.643	89.0	975
S5T	Li_2ZrO_3	HEDL	95	2.320	89.0	1150
S5B	Li_2O	JAERI	56	1.661	89.9	930
B8T	Li_2O	JAERI	56	0.952	88.8	700
B8C	Li_2O	JAERI	56	0.952	88.9	900
B8B	Li_2O	JAERI	56	0.952	89.3	500
B9T	Li_2O	Springfield	56	0.941	82.7	700
B9C	Li_2O	JAERI	56		90.0	700
B9B	Li_2O-sc	JAERI	7.5/0.07	0.800	100.0	500
B10T	$LiAlO_2$	Saclay	95	0.952	74.10	700
B10C	$LiAlO_2$	Saclay	95	0.952	73.02	900
B10B	$LiAlO_2$	Saclay	95	0.952	75.48	500
B11T	Li_2SiO_3	Karlsruhe	95	0.952	80.66	700
B11C	$LiAlO_2$	Casaccia	95	0.952	80.63	700
B11B	Li_4SiO_4	Karlsruhe	95	0.952	91.87	500
B12T	Li_2ZrO_3	Springfield	95	0.941	80.83	700
B12C	$LiAlO_2$	Casaccia	95	0.952	80.83	700
B12B	Li_4SiO_4	Karlsruhe	95		81.65	500

REFERENCES

1. G. W. Hollenberg, C. E. Johnson, and M. Abdou, "Tritium Breeding Materials", presented at Materials in Energy Systems Conference (May 1984).

2. R. G. Clemmer et al., "The TRIO Experiment", ANL-84-55, Argonne National Laboratory, Argonne, IL (September 1985).

3. J. M. Dupouy, "Report of Workshop on Solid Breeder Materials, Ispra, Italy, June 11-12, 1985" (July 1985).

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B10B	$LiAlO_2$	Saclay	95	0.952	75.48	500
B11T	Li_2SiO_3	Karlsruhe	95	0.952	80.66	700
B11C	$LiAlO_2$	Casaccia	95	0.952	80.63	700
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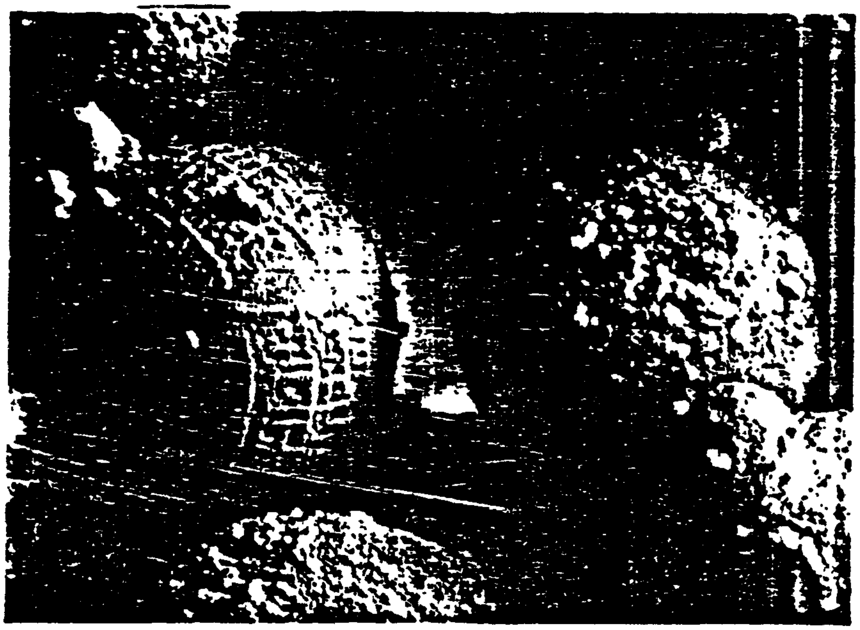

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Solid Breeder Temperatures (°C)	850-510	500* 700* 900*	1000-524 663-450 500, 700, 900*
Lithium Cross-Section (barns)	15	1	1
Material	$LiAlO_2$	$LiAlO_2$	$LiAlO_2$
Peak Tritium Production (10^{20} at/cc)	70	11	33
Solid Breeder Temperatures (°C)	1000-350	500* 700* 900*	1127-600 775-530 500, 700, 900*
Lithium Cross-Section (barns)	15	1	1

*Almost isothermal, $\Delta T < 50$°C.

Design

In Table 2, the test matrix for the first insertion of the FUBR-1B experiment is provided. Actually, two separate subassemblies are utilized at the same time for this testing. One subassembly contains seven pins for 1 cm diameter pellets that are very similar to those of the FUBR-1A experiment while the other subassembly contains three pins with 1.7 and 2.4 cm diameter pellets. The neutron fluence in Row 7 of the EBR-II reactor is approximately 6.2×10^{22} n/cm^2 (E > 0.1 MeV) at 900 FPD with a Li-6 spectrum-averaged cross-section of 0.5 to 2 barns. Because of the low cross-section for the Li-6 reaction, the self-shielding within the pellets is predicted to be less than 5%.

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$LiAlO_2$	1.0	80	1	500, 700, 900*
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Li_2O	1.0	80	80	700*
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Other Materials				
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In Table 2, the materials contained within the FUBR-1B experiment's first insertion pins are described. The reference Li_2O and $LiAlO_2$ pellets were fabricated with a density of 80% by hot pressing and possessed less than 2000 µg/gm of metallic impurities. Chlorine and fluorine were maintained below 150 µg/gm. The moisture level was measured to be below 0.005 mol% with the carbonate as high as 0.34 mol% in the Li_2O. The grain size of the reference Li_2O was 4 µm; grain size of the reference $LiAlO_2$ was less than 1 µm. In order to evaluate the effect of grain size on the tritium and helium release and other