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AN IRRADIATION EXPERIMENT FOR LITHIUM CERAMICS

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Figure 1

Solid breeder materials are required in D-T fusion reactor blankets to convert fusion neutrons to tritium and thermal energy while providing some neutron shielding for the magnets. Lithium compounds such as Li_2O, $LiAlO_2$, Li_4SiO_4 and Li_2ZrO_3 have been proposed as solid breeder materials. Tritium is necessary to maintain the fuel supply for the D-T fusion reaction. No high burnup irradiation performance data is available for these materials in a neutron environment prototypic of the fusion blanket. The FUBR Experiment in EBR-II has been designed and built to evaluate the irradiation performance of these materials.

Figure 2

Tritium release is the most important parameter of interest for both the selection of the best solid breeder material and development of the solid breeder concept. Tritium bred in the blanket but not released to the carrier gas does not contribute to the tritium fuel supply. The retained tritium inventory, if large enough, could reduce the released tritium rate to the point that it would not sustain the fusion reaction.

Figure 3

The major test parameters are shown in this slide. The four materials selected for this experiment have been under consideration as solid breeder materials. Li_4SiO_4 was evaluated in the INTOR design study, Li_2O was used in the recent DEMO study and $LiAlO_2$ was selected for the STARFIRE design. In blanket designs, solid breeders are expected to work between 400 and

1000°C. The temperatures of 500, 700 and 900°C attempt to span that temperature range. A density of 85% T.D. was selected for most of the materials in the irradiation, however, $LiAlO_2$ pellets at 95 and 60% T.D. have also been included. A density of 85% T.D. was selected since it was thought that open porosity is necessary for tritium release. Three exposure levels will be attained. At 300 full power days of operation in EBR-II a burnup of about 10×10^{20} captures/cm^3 will be reached which is comparable to one year of operation in the STARFIRE design.

Figure 4

The FUBR Experiment's test matrix is shown in this slide. It is worthwhile to note that there are 44 subcapsules in 11 pins. Seven pins will be in reactor at one time. In order to achieve 500°C, it was necessary to sodium bond those subcapsules.

Figure 5

The experimental pin design is shown in this slide. Four subcapsules are contained within an outer pin. Subcapsules operating at 700 and 900°C possess radial gaps which control heat transfer and increase the temperature. Those subcapsules contain a nickel liner which is swaged into a 316 stainless steel tube. The pellet column is .375 inches O.D. x 2.25 inches long. The getter tab is composed of cerium wrapped in titanium foil which is spot welded. The titanium is used for compatibility purposes.

Figurc 6

It should be emphasized that EBR-II is a fast neutron fission reactor with a spectrum closely approaching that of the blanket of a fusion reactor. Hence, it was selected in order to avoid the self-shielding that would occur in a thermal neutron reactor irradiation of natural or enriched lithium ceramics.

Figure 7

Tritium is actually released through the stainless steel into the reactor sodium. As T_2O is released from the crystallites it must be transported to the cerium getter where it is reduced to diatomic tritium. Tritium can diffuse rapidly through stainless steel. The rate controlling step, if the cerium is an active getter, is the T_2O gas phase transport to the getter. This is the same rate controlling step presently accepted for blanket tritium release.

Figure 8

This slide demonstrates the kinetics of cerium oxidation. With helium bubbled through ice water, complete oxidation to Ce_2O_3 occurred at 400°C in less than eight hours. Hence, cerium was selected for the getter in order that T_2O gas transport would be rate controlling for the tritium release rate of the subcapsule.

Figure 9

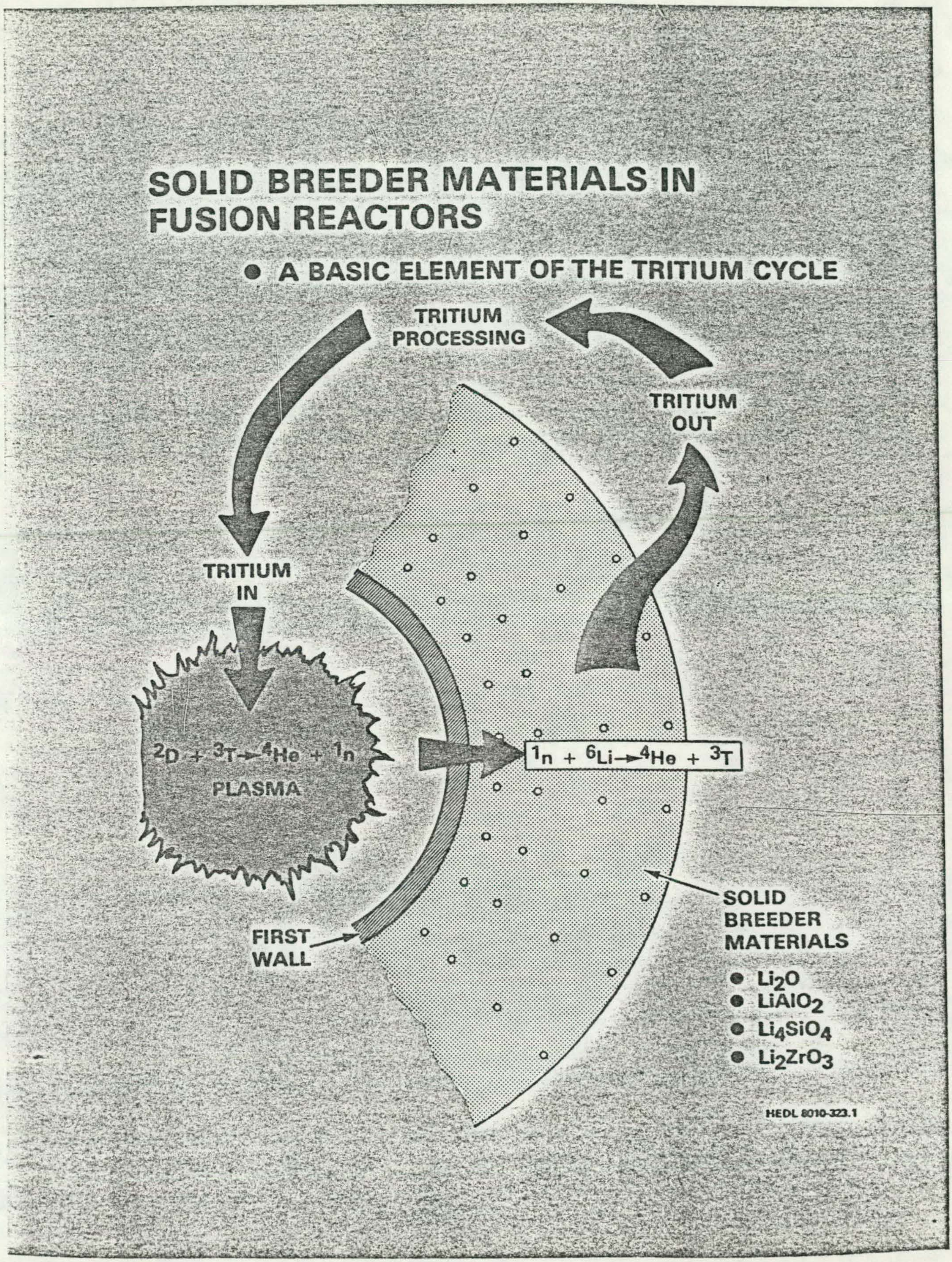
It is necessary to appreciate that the amount of tritium produced is exactly equal to the amount of helium produced. Since tritium is lost from the subcapsules, it is not possible to measure total tritium production. It is, however, possible to measure the amount of helium produced, which will then allow the calculation of tritium released from retained tritium measurements.

Figure 10

Grain growth and sintering are expected to occur in the Li_2O material during irradiation at 900°C. These phenomena are also expected to occur in a solid breeder blanket made from Li_2O. Hence, this will be viewed as a part of the Li_2O irradiation performance.

Figure 11

After irradiation, the post-irradiation examination will be conducted at INEL and at HEDL. The first insertion pins are expected to be removed from the EBR-II reactor in August 1982, while the higher burnup pins will remain in until July 1983.



SOLID BREEDER MATERIALS IN FUSION REACTORS

- A BASIC ELEMENT OF THE TRITIUM CYCLE

- Li_2O
- $LiAlO_2$
- Li_4SiO_4
- Li_2ZrO_3

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Figure 1

SOLID BREEDER PERFORMANCE

1. TRITIUM RELEASE
2. SWELLING
3. MICROSTRUCTURE STABILITY
4. THERMAL PERFORMANCE
5. HELIUM RELEASE

Figure 2

FUBR TEST PARAMETERS

- MATERIALS
  Li_4SiO_4, Li_2O, $LiAlO_2$, Li_2ZrO_3
- TEMPERATURES
  500°C, 700°C, 900°C
- DENSITY
  95%, 85% 60% T.D.
- EXPOSURE
  100 FPD, 200 FPD, 300 FPD

Figure 3

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FUBR TEST MATRIX

PIN SUBCAPSULES	MATERIAL	MATERIAL DENSITY (%TD)	TEMPERATURE (°C)	EXPOSURE (FPD)	PIN TO SUBCAPSULE BOND
1-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	500	100	Sodium
2-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	700	100	Helium
3-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	900	100	Helium
4-1	$LiAlO_2$	95	700	100	Helium
4-2	$LiAlO_2$	60	700	100	Helium
4-3	$LiAlO_2$	60	900	100	Helium
4-4	$LiAlO_2$	95	900	100	Helium
5-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	500	200	Sodium
6-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	700	200	Helium
7-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	900	200	Helium
8-1	$LiAlO_2$	95	700	200	Helium
8-2	$LiAlO_2$	60	700	200	Helium
8-3	$LiAlO_2$	60	900	200	Helium
8-4	$LiAlO_2$	95	900	200	Helium
9-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	500	300	Sodium
10-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	700	300	Helium
11-1,2,3,4	Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4	85	900	300	Helium

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Figure 4

FUBR EXPERIMENTAL PINS

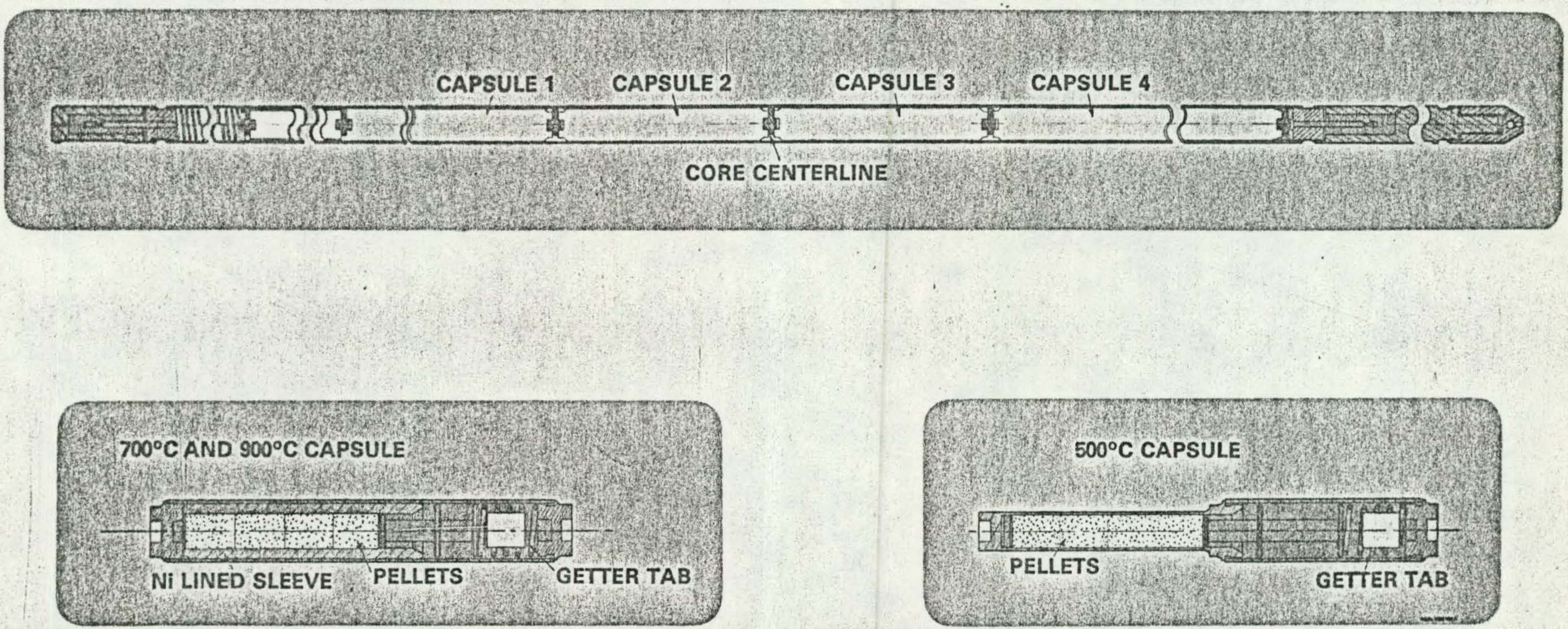


Figure 5

COMPARISON OF NEUTRON SPECTRUM IN FUSION BLANKET TO TEST REACTOR SPECTRA

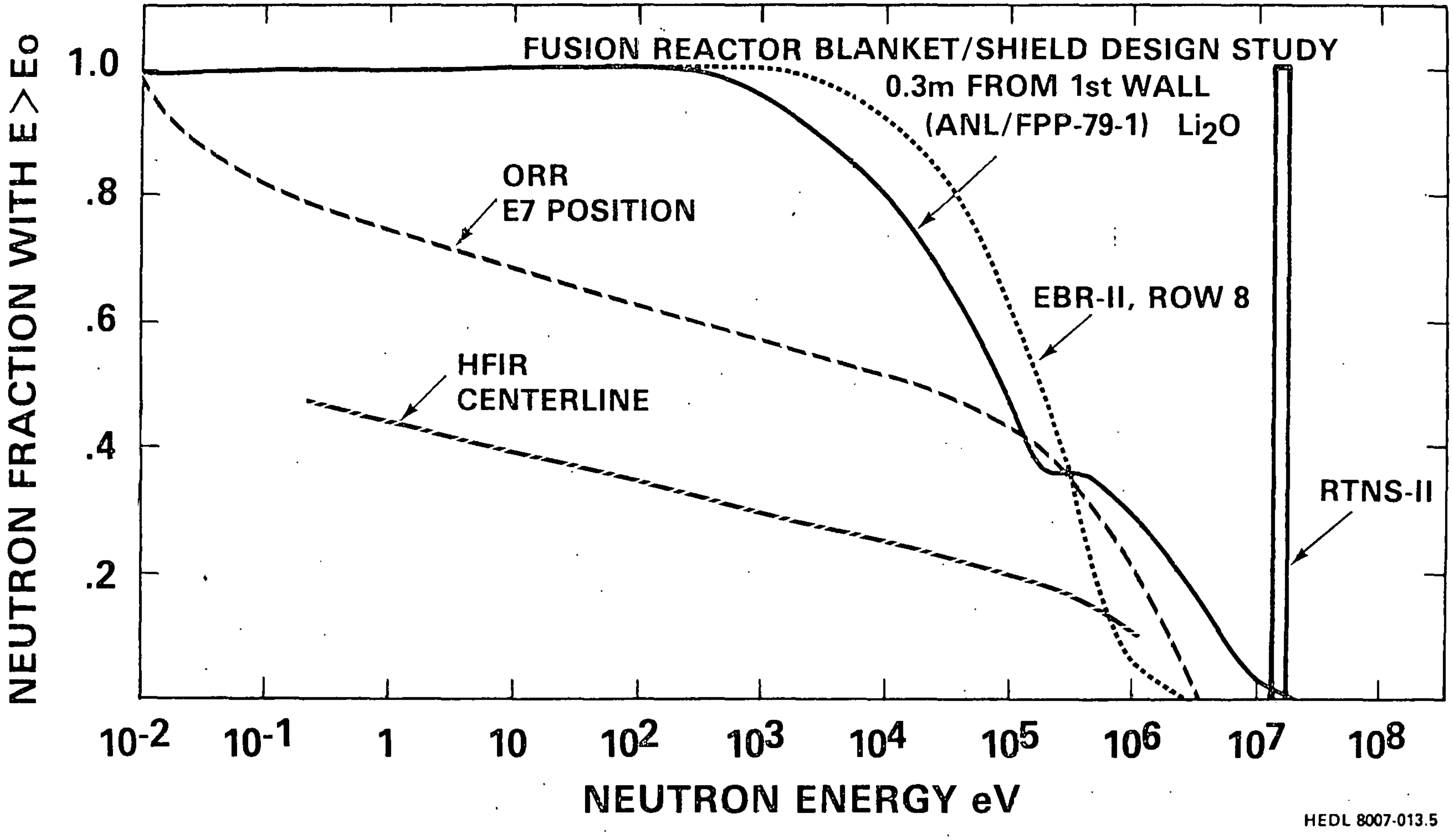
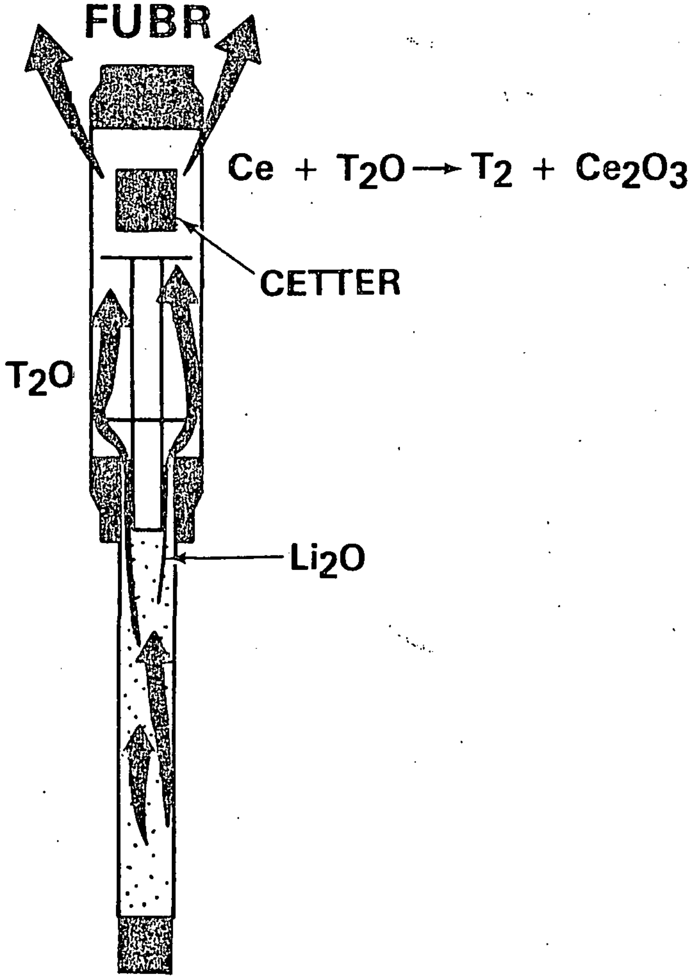
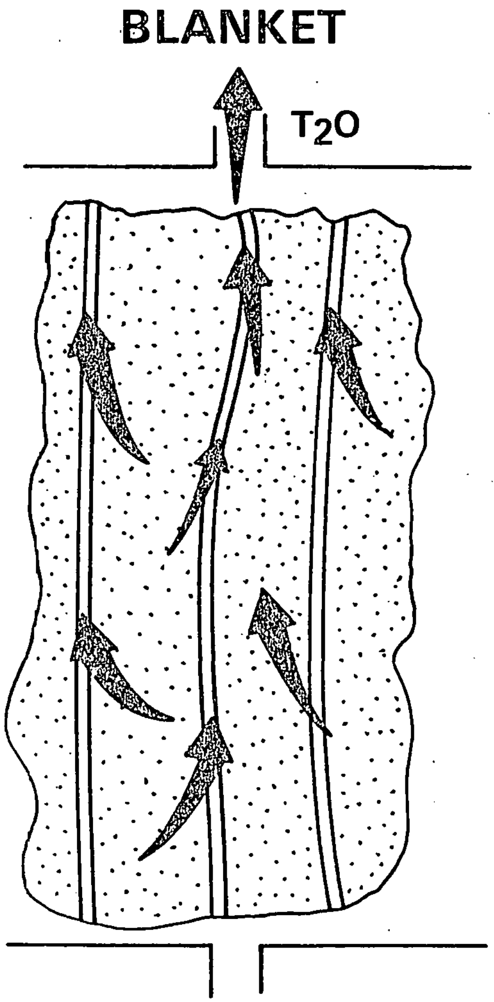


Figure 6

TRITIUM TRANSPORT



LIMITING PHENOMENON
T_2O TRANSPORT
IN POROSITY AND PLENUM



LIMITING PHENOMENON
T_2O TRANSPORT
IN POROSITY

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Figure 7

OXIDATION OF CERIUM METAL

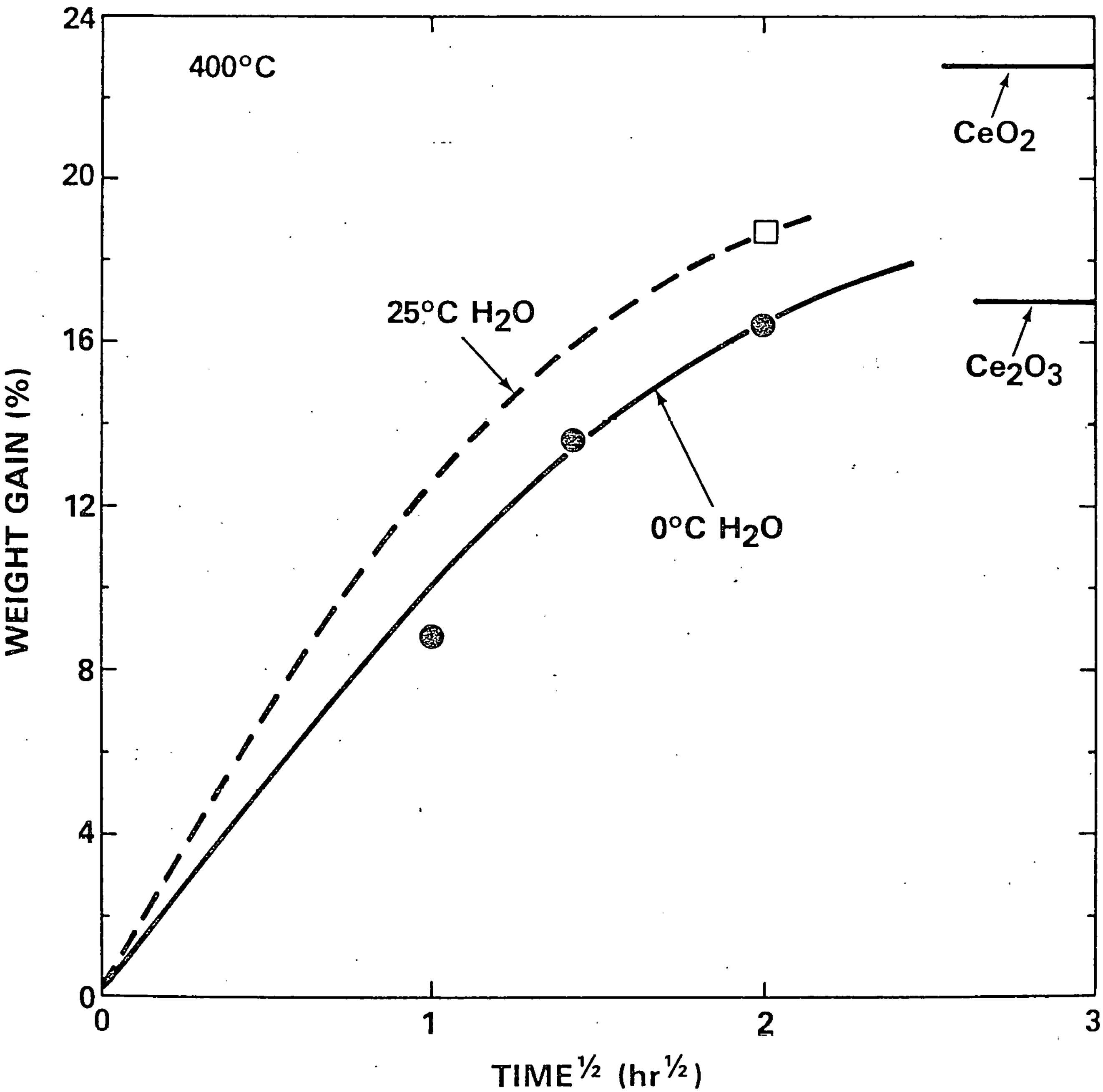

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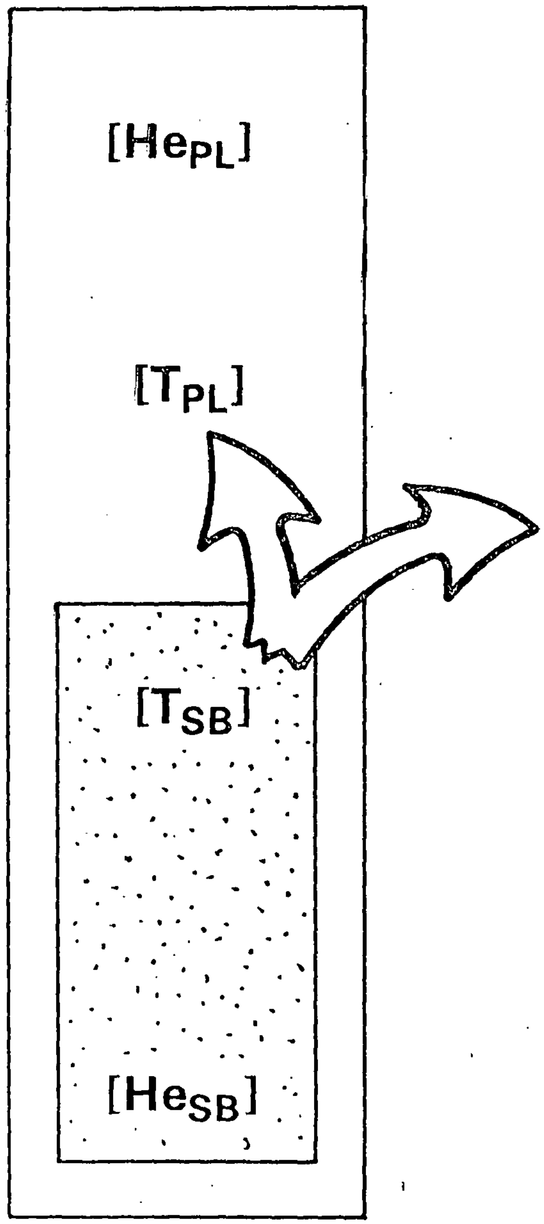
Figure 8

TRITIUM RELEASE MEASUREMENT



$$Li + n \rightarrow T + He$$

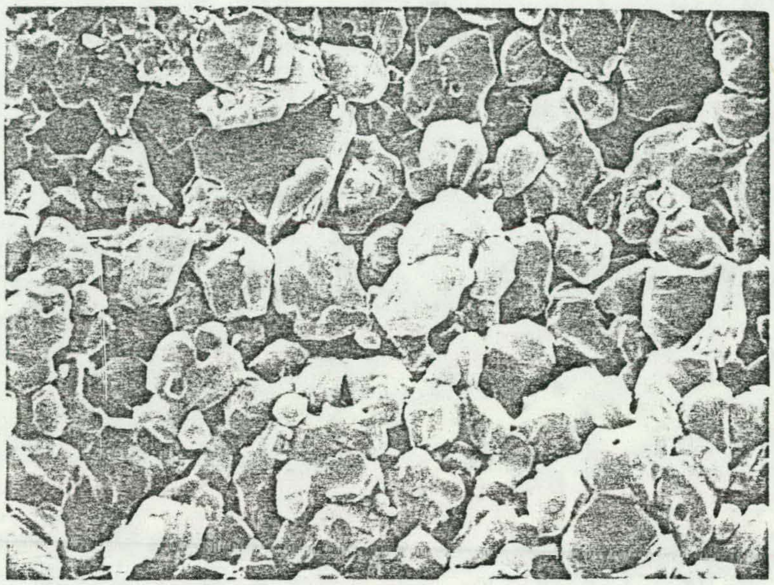
$$[T_{TOTAL}] = [T_{SB}] + [T_{PL}] + [T_{LOSS}]$$

$$[He_{TOTAL}] = [He_{SB}] + [He_{PL}]$$

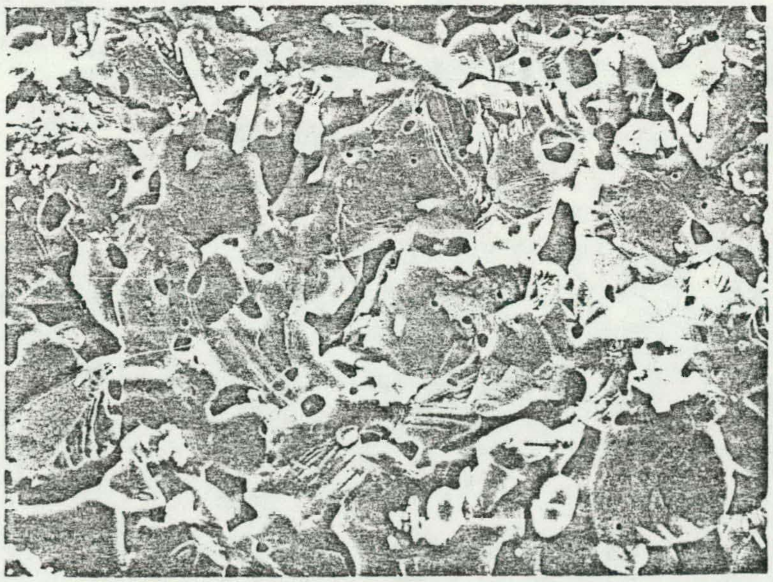
$$\frac{[T_{SB}]}{[T_{TOTAL}]} = \frac{[T_{SB}]}{[He_{TOTAL}]}$$

Figure 9

GRAIN GROWTH IN Li_2O



Li_2O AS HOT PRESSED



Li_2O AFTER ANNEALING
AT 900°C FOR 18 HOURS

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Figure 10

INITIAL FUBR POST-IRRADIATION CHARACTERIZATION

AT INEL

NEUTRON RADIOGRAPHY

LASER PUNCTURING

PROFILOMETRY

DISASSEMBLY

PELLET RECOVERY
VISUAL EXAMINATION

SHIPMENT TO HEDL

AT HEDL

SWELLING

RETAINED TRITIUM

RETAINED HELIUM

SURFACE AREA

MICROSTRUCTURE

X-RAY DIFFRACTION

THERMAL CONDUCTIVITY

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Figure 11