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BEATRIX-II PROGRAM

JANUARY 1989 TO DECEMBER 1989

ANNEX-III TO IEA IMPLEMENTING AGREEMENT
FOR A PROGRAMME OF RESEARCH AND
DEVELOPMENT ON RADIATION DAMAGE
IN FUSION MATERIALS

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EXECUTIVE SUMMARY

BEATRIX-II is an International Energy Agency (IEA) sponsored collaborative experiment among Japan, Canada, and the United States. The purpose of the experiment is to evaluate the performance of ceramic solid breeder materials in a fast neutron environment. To do this, an in-situ tritium recovery experiment is being conducted in the Fast Flux Test Facility (FFTF), located on the Hanford site near Richland, Washington, and operated by Westinghouse Hanford Company (WHC). The Pacific Northwest Laboratory (PNL), Richland, Washington, together with the Japan Atomic Energy Research Institute (JAERI) and Atomic Energy of Canada Limited (AECL) are responsible for conducting the experiment.

The work is divided into two phases: Phase 1 will be irradiated from January 1990 until approximately February 1991, in what is called Cycle 11 of FFTF, while Phase 2 is tentatively scheduled to begin in April 1991 and continue for 300 EFPD in what is called Cycle 12 of FFTF.

PHASE 1 - INSTALLATION AND STARTUP

During 1989, the work focused on the fabrication of the material open test assembly (MOTA) Vehicle and installation of the tritium handling system at the FFTF--culminating in the startup of Phase 1. Fabrication of the MOTA Vehicle involved installation of the vented canisters, fabrication and assembly of the nonvented canisters, and the final assembly of the MOTA Vehicle. The assembly of the MOTA vehicle was completed and shipped to the reactor in June 1989.

Installation of the supporting equipment for the experiment included both the instrumentation and control (I&C) system for temperature control of the canisters and the tritium gas handling system. The I&C system was shipped to the FFTF in November 1988; installation and hookup occurred during 1989. Installation was completed in August 1989. Installation of the tritium gas handling system involved installing a glovebox to serve as secondary containment for the tritium, installing associated instrumentation for monitoring the tritium recovery, and assembling a computer facility for data collection,

conversion, and storage. The installation and final check out of the supporting equipment was completed in October 1989.

The MOTA vehicle was installed in the FFTF core in October 1989. The readiness review, which permits the operation of the test, was then completed. In December 1989, approval to start the experiment was granted by FFTF management. The experiment started on January 4, 1990 when the FFTF started its ascent to full power.

PHASE 2 - EXPERIMENT PLAN

The scope and funding for Phase 2 was approved by the IEA Executive Committee at its December 1989 meeting in Tokyo. The scope of Phase 2 will include a temperature change canister with an Li_2O specimen and a temperature gradient canister with an Li_2ZrO_3 specimen for performance studies. Funding is consistent with that given in ANNEX-III of the Implementation Agreement (Hollenberg 1989).

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1.0 INTRODUCTION

The BEATRIX-II experiment is an International Energy Agency (IEA) sponsored collaborative experiment among Japan, Canada, and the United States. The purpose of the experiment is to evaluate the performance of ceramic solid breeder materials in a fast neutron environment at high burnup levels. The experiment is being conducted in the Fast Flux Test Facility (FFTF), located on the Hanford site near Richland, Washington, and operated by Westinghouse Hanford Company (WHC). The Pacific Northwest Laboratory (PNL), Richland, Washington, together with the Japan Atomic Energy Research Institute (JAERI) and Atomic Energy of Canada Limited (AECL) are responsible for conducting the experiment.

1.1 OBJECTIVE

The objective of the BEATRIX-II experiment is to design, conduct and evaluate the in-situ recovery of tritium from solid breeder materials during neutron irradiation in the FFTF. During the experiment, the performance of candidate solid breeder materials is continuously monitored with respect to thermal conductivity, temperature stability, and tritium release. The experiment is to be carried out to extended lithium burnups under simulated blanket conditions.

1.2 SCOPE

The BEATRIX-II experiment as described in ANNEX-III (Hollenberg 1989) is divided into Phase 1 and Phase 2. Phase 1 activities are directed toward FFTF Cycle 11 and irradiation began January 4, 1990. Phase 1 irradiation is expected to continue until February 1991 at which time the accumulated exposure would nominally be 300 EFPD. Phase 2 irradiations will be carried out in Cycle 12 of the FFTF from approximately April 1991 to June 1992.

1.2.1 Phase 1 Scope

The Phase 1 scope of the experiment includes the irradiation of two Li_2O in-situ tritium recovery canisters. One canister contains a ring specimen having a nearly uniform temperature profile which is capable of temperature

changes that make possible the study of temperature transients on tritium release. The other canister will provide performance data on a solid specimen of Li_2O under a thermal gradient. Nonvented capsules are used to characterize radiation damage in single crystals, the effect of radiation on thermal conductivity, and the compatibility of beryllium with solid breeder materials.

1.2.2 Phase 2 Scope

The Phase 2 scope of the experiment will again include the irradiation of two in-situ tritium recovery canisters containing a Li_2O ring specimen, and a solid Li_2ZrO_3 specimen composed of 1 to 1.5 mm spheres. The ^6Li enrichment will be increased to increase the total burnup. Nonvented capsules will include barrier-coated stainless steel specimens for tritium permeation studies at high temperatures and solid breeder-beryllium compatibility capsules from Phase 1 that will be irradiated to higher burnups.

2.0 BACKGROUND

This report covers the period from January 1, 1989 until January 3, 1990. This period is from the end of the previous annual report until the start of the irradiation of BEATRIX-II when the FFTF reactor started its ascent to full power on January 4, 1990. The chronology of events during 1989 is listed in Table 2.1.

The primary focus of the work this year was on the installation of the BEATRIX-II experiment in the FFTF. This work started in the previous year with the shipment of the MOTA instrumentation and control (I&C) system to the FFTF in November 1988, followed by the shipment of the glovebox system in February 1989. Considerable effort was directed toward the actual installation of the experiment at the FFTF together with the development of operational procedures and the acceptance tests.

The last major step in this installation was the tritium testing of the system that was completed in October 1989. Installation of the MOTA Vehicle in the reactor and final hookup was performed in October and November 1989. A readiness review of the system was carried out and approval to begin irradiation was granted in December 1989. Irradiation began on January 4, 1990.

2.1 STATUS REVIEW

During the year, a number of meetings were held with the BEATRIX-II Working Group and participants to review the status of the experiment, the installation of experiment in the reactor, and the operational plan for the initial irradiation cycle. D. O. Coffin visited Hanford to establish the procedures for transferring the getterbeds from the FFTF to Los Alamos National Laboratory (LANL). S. B. Bokwa, Atomic Energy of Canada, Limited (AECL), visited the FFTF to review the results of the tritium test and discuss operational procedures for the tritium handling system. At the December Working Group meeting in Tokyo the scope of Phase 2 was defined.

TABLE 2.1. 1989 Chronology of Events for BEATRIX-II

<u>Date</u>	<u>Event/Location</u>	<u>Participants</u>	<u>Impact</u>
6 February	Shipment of glovebox to the FFTF/Richland, Washington, USA	WHC	--
14-15 February	Working Group Meeting/ Seattle, Washington, USA	Working Group	Review Status
25 May	Status of BEATRIX-II/ Tokai Mura, Japan	G. W. Hollenberg H Watanabe JAERI Staff	Test Scenario and Procedures
6 June	MOTA Vehicle shipped to the FFTF/Richland, Washington, USA	WHC	--
20 June	Transfer of getter beds to TSTA/Richland, Washington, USA	D. O. Coffin WHC and PNL	Procedures Established
8 September	B-II Status/Richland, Washington, USA	T. Kurasawa WHC and PNL	Data Transfer
10-12 October	B-II tritium test/ Richland, Washington, USA	WHC	Acceptance Test
October	Review of B-II tritium handling system/Richland, Washington, USA	S. B. Bokwa	--
21 October	MOTA insertion in the FFTF	WHC	--
11 December	Working Group Meeting/ Tokyo, Japan	Working Group	Phase 1 Review Phase 2 Plans
12 December	Status of BEATRIX-II/ Tokyo, Japan	IEA Executive Committee	Approval of Phase 2

2.2 REVISED RESPONSIBILITIES

The basic organization of the BEATRIX-II experiment was similar to that described in the 1988 Annual Report with some minor revisions as indicated in the updated organization diagram shown in Table 2.2. The IEA Executive committee, which had the responsibility for approval and signing of ANNEX-III, is

TABLE 2.2. Responsibilities under BEATRIX-II, ANNEX III

also responsible for any changes or additions. The BEATRIX-II Working Group is a technical steering committee for the preparation and supervision of budgets, schedules and scientific activities. During the past year, H. Watanabe served as the chairman of the BEATRIX-II Working Group.

At the December Working Group Meeting, S. E. Berk was appointed chairman for the coming year while O. D. Slagle was designated as interim BEATRIX-II Task Manager during the reassignment of G. W. Hollenberg to another project. G. W. Hollenberg is expected to resume his role as Task Manager during the first quarter of CY 1990 and then remain in that role, as shown in Table 2.2. With the pending retirement of T. C. Reuther, R. J. Price will assume the role as Operating Agent, Office of Fusion Energy, U.S. Department of Energy (OFE/DOE).

3.0 COSTS AND SCHEDULES

The projected start of Cycle 11 MOTA given in the 1988 Annual report was April 29, 1989. A combination of problems encountered during installation and increased administrative controls, however, resulted in the experiment being delayed beyond that date. The installation and check out of the tritium handling system was completed in October and the MOTA vehicle was installed in the reactor in October. Reactor approval was obtained in December to begin the experiment at the start of Cycle 11B which occurred on January 4, 1990. Completion of the irradiation of MOTA-2A is projected to be in February 1991.

Funding for BEATRIX-II is divided into Phase 1 and Phase 2. Phase 1 is the first test series in Cycle 11 of the FFTF/MOTA while Phase 2 is the second test series planned for Cycle 12.

3.1 PHASE 1 FUNDING

Phase 1 funding for BEATRIX-II was documented by ANNEX-III and is given in Table 3.1. Also listed in Table 3.1 are the funds received to date. The rate of spending for Phase 1 is behind schedule on a time basis but is currently over spent on the basis of accomplishments. The reason for this

TABLE 3.1. Funding for BEATRIX-II, Phase 1

As-Specified in ANNEX-III (1988 U.S. \$ in Ks)

<u>Participant</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>Total</u>
Canada		78	39		117
Japan	400	443	318	91	1252
United States	180	524	327	220	1251

Funds Received to December 1989 (actual)

<u>Participant</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>Total</u>
Canada		60			60
Japan	400	443	442		1285
United States	180	497	397		1074

Inflation Factor

1989	1.045
1990	1.036

budgetary situation is attributed to the increased documentation and acceptance testing required for installation in the FFTF. These requirements were put in place after the initial cost analysis was performed. Column 1 in Table 3.2 lists the expenditures on Phase 1 through FY 1989.

Because BEATRIX-II shares equally in the cost of MOTA fabrication and operation with the other two partners (NIMS and MONBUSHO), one third of the total canisters are assigned to BEATRIX-II. The experimental scope of BEATRIX-II for cycle 12 does not require that all of the canisters be used, so the excess canisters are available for reassignment to other projects. At the IEA Executive committee meeting held on April 6, 1989, the BEATRIX-II Task Manager requested that the excess canisters be sold and the funds obtained be used to cover the increased costs of Phase 1. This proposal was approved and customers for the excess canisters have been identified. The amount and schedule of the cost recovery associated with the sale of these canisters is shown in the bottom row of Table 3.2. Because the canisters which are to be sold are associated with Cycle 12, the bulk of the cost recovery occurs in FY 1990 and FY 1991. The projected total cost of Phase 1 in Table 3.2 corresponds to the projected total actual dollars available for Phase 1.

3.2 PHASE 2 FUNDING

The scope and funding for Phase 2 and the funding for post-irradiation examination was presented to the IEA Executive Committee at the December Meeting in Tokyo. Approval was granted for both proposals. The level of funding for Phase 2 is shown in Table 3.3 and is consistent with that given in ANNEX-III. The scope of Phase 2 is given in Section 4.2. The funding for the post-irradiation examination in both Phases 1 and 2 is shown in Table 3.4.

TABLE 3.2. To-Date and Projected Costs for BEATRIX-II, Phase 1; Fusion MOTA IEA Breeder Experiment
(U.S. \$ in Ks)

	Expenditures Through FY 1989	Projected Cost	
		FY 1990	FY 1991
Design	250		
Fabrication and Assembly	640		
MOTA I&C System	137		
Sweep/Purge Gas System	1278	45	
MOTA Irradiation			
Operation	0	206	62
FFTF Charges	134	50 + 278	31 + 83
Disassembly	0		54
Engineering Support	92		
Cost Recovery	-120	-240	-300
Subtotal	2421	339	-70
			2690

TABLE 3.3. Funding for BEATRIX-II, Phase 2 (1989 U.S. \$ in Ks)

<u>Participant</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>Total</u>
Canada		60 ^(a)	60 ^(a)	120
Japan	511	457		968
United States	511	458		<u>969</u>
				2057

(a) Actual U.S. Dollars for 1990 and 1991.

TABLE 3.4. Funding for BEATRIX-II, Phase 1 and 2; Post-Irradiation Examination (1989 U.S. \$ in Ks)

<u>Participant</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>Total</u>
<u>PHASE 1</u>				
Canada				
Japan		100	100	200
United States		100	100	200
<u>PHASE 2</u>				
Canada			(a)	
Japan			200	200
United States			200	<u>200</u>
Total				800

(a) Contribution is the examination of the ternary vented canister.

4.0 TECHNICAL STATUS

The BEATRIX-II experiment as described in ANNEX-III is divided into Phase 1 and Phase 2. Phase 1 activities are directed toward Cycle 11. Irradiation began January 4, 1990 and is expected to continue until February 1991 at which time the accumulated exposure will nominally be 300 EFPD. Phase 2 irradiation is to be carried out in Cycle 12 of the FFTF between April 1991 and June 1992. The uncertain future of the FFTF at this time, however, makes this schedule tentative.

4.1 PHASE 1 - INSTALLATION AND STARTUP

The Phase 1 scope includes the irradiation of two Li_2O in-situ tritium recovery canisters. One canister contains a ring specimen having a nearly uniform temperature profile which is capable of temperature changes that make possible the study of temperature transients on tritium release. The other canister will provide performance data on a solid specimen of Li_2O under a thermal gradient. Specimens in nonvented capsules will be used to characterize the following: 1) radiation damage in single crystals, 2) the effect of radiation on thermal conductivity, and 3) the compatibility of beryllium with ceramic breeder materials.

4.1.1 Vented Canisters

Fabrication, specimen loading, and closure of the two vented canisters were completed last year. This year's activity involved incorporating these canisters into the MOTA assembly and final attachment of the gas and thermocouple leads. Shown in Figure 4.1 is one of the vented canisters, Canister 1E, being attached to the MOTA vehicle during the final assembly. Canister 1E is the ring specimen canister. Canister 1C containing the solid specimen is the darker canister to the right of canister marked 1D. The physical and chemical specifications of the specimens are given in Appendix A.

4.1.2 Nonvented Capsules

The nonvented capsules include Li_2O single crystals for radiation damage study, sintered pellet specimens for thermal conductivity measurements, and lithium ceramic-beryllium compatibility specimens. The specimen matrix along

FIGURE 4.1. A Vented Canister Being Attached to the MOTA Vehicle During Final Assembly. Canister 1E, the ring specimen, is shown being latched to the assembly. Canister 1C containing the solid specimen is the darker canister to the right of the canister marked 1D (Neg. 89051166-16CN).

with the physical and chemical specifications of the specimens are given in Appendix A. During the present period, the nonvented capsule design and fabrication together with specimen loading and closure were completed. For capsules containing enriched lithium, plenum volumes were provided to accommodate the helium generated. Cerium getter tabs were included in these capsules to reduce any HTO or T₂O and allow the release of the generated tritium from the capsule by diffusion of HT or T₂ through the stainless steel as in EBR-II testing (Siagle, Hollenberg, and Baldwin 1989).

4.1.3 Completion of the MOTA Vehicle

Assembly of the MOTA irradiation vehicle occurred through the end of May. In Table 4.1 is shown the actual schedule for the assembly and preparation of the irradiation vehicle. The finished assembly was shipped to the FFTF during June and placed in storage at the reactor site awaiting insertion. Weld preparation work on the fusion MOTA Vehicle during final assembly is shown in Figure 4.2. In Figure 4.3 the assembled fusion MOTA (right) is shown next to the completed liquid metal reactor (LMR) MOTA. BEATRIX-II is in the fusion MOTA.

4.1.4 Tritium Generation Rates

The predicted tritium generation rates for the two in-situ canisters were recalculated and the resulting revised rates are compared in Table 4.2 with the previous rates. The results are compared on the basis of release rates per day and for the nominal 300 EFPD cycle. The revised rates are approximately one half the initially predicted rates.

4.1.5 Experiment Test Plan

The proposed test plan presented in the last annual report was revised through extended discussions with the participants; the updated test plan for the first 100 days of operation is outlined in Table 4.3. The primary change to the previous test plan is the addition of temperature changes from the reference temperature of 625°C to 500°C during the initial tests of flow rate and gas composition changes.

All test parameter changes will be made while the reactor is at full power. The specified conditions for the ring specimen include the specimen

TABLE 4.1.1. Schedule for Preparation of MOTA-2A Irradiation Vehicle

Activity	1989										
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov
Vehicle Assembly											
Specimen Loading											
Shipment Preparations											
Ship to FFTF											
Move to Storage

FIGURE 4.2. Weld Preparation Work on the Fusion MOTA Test Vehicle During Final Assembly.
The upper portion of the MOTA vehicle is being assembled (Neg. 89010336-5CN).

FIGURE 4.3. The Assembled Fusion MOTA-2A (Right) Shown Next to the Completed Liquid Metal Reactor (LMR) MOTA (Left). The assembled MOTA-2A has all of the canister in place. MOTA-2A has the thermocouple and gasline connections completed, the outer hexagonal duct installed, and the upper assembly in place (Neg. 89010437-1CN).

TABLE 4.2. Tritium Generation Rates (Curies) for BEATRIX-II,
Cycle 11; In-situ Vented Canisters

<u>Description</u>	<u>Revised Tritium Production Rates</u>
Ring Specimen	3.4 Ci/EFPD 1013 Ci/300 EFPD
Solid Specimen	9.3 Ci/day EFPD 2800 Ci/300 EFPD

TABLE 4.3. Test Plan for BEATRIX-II, Cycle 11; First
100 Days of Reactor Operation

<u>Run ID</u>	<u>Reactor Power, %</u>	<u>Ring Specimen</u>		<u>Solid Specimen</u>	<u>Comments</u>
		<u>Temp, °C</u>	<u>Gas/Flow, cc/m</u>	<u>Gas/Flow, cc/m</u>	
11-1a	75 to 100	575	0.1%H ₂ /100	0.1%H ₂ /100	Startup
11-1	100	625	0.1%H ₂ /100	0.1%H ₂ /100	Establish RR ^(a) Moisture Cleanup Calibration
11-2	100	500	0.1%H ₂ /100	0.1%H ₂ /100	Temperature Change
11-3	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-4	100	625	0.1%H ₂ /200	0.1%H ₂ /100	Flow Rate and Temperature Change
11-5	100	500	0.1%H ₂ /200	0.1%H ₂ /100	
11-6	100	625	0.1%H ₂ /200	0.1%H ₂ /100	
11-7	100	625	0.1%H ₂ /100	0.1%H ₂ /800	Solid Specimen Flow Rate
11-8	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-9	100	625	0.1%H ₂ /50	0.1%H ₂ /50	Flow Rate and Temperature Change
11-10	100	500	0.1%H ₂ /50	0.1%H ₂ /50	
11-11	100	625	0.1%H ₂ /50	0.1%H ₂ /50	Effect of Gas Composition
11-12	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-13	100	625	0.01%H ₂ /100	0.1%H ₂ /100	
11-14	100	625	0.1%H ₂ /100	0.01%H ₂ /100	Temperature Transients
11-15	100	625	0.0%H ₂ /100	0.1%H ₂ /100	
11-16	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-17	100	550	0.1%H ₂ /100	0.1%H ₂ /100	
11-18	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-19	100	500	0.1%H ₂ /100	0.1%H ₂ /100	
11-20	100	625	0.1%H ₂ /100	0.1%H ₂ /100	Establish RR ^(a) Calibration
11-21	100	450	0.1%H ₂ /100	0.1%H ₂ /100	
11-22	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-23					

(a) "RR" stands for steady-state release rates.

temperature, the amount of H_2 in the helium sweep gas, and the flow rate. For the solid specimen, the specified conditions involve the amount of H_2 in the helium sweep gas and the flow rate. The first test after startup, 11.1, will be used to establish the generation/release rate (RR) of the tritium, to condition the system with respect to moisture and gas retention, and to finalize calibration. It is anticipated that, after the initial test series, the results may require a change in the proposed test plan.

Each individual test is to be run until steady-state conditions for tritium release are achieved or the test is terminated by the experimenter. Guidelines have been developed that can be used to determine whether steady-state conditions have been reached. These conditions will be defined by either of two conditions (whichever occurs first) that can be determined using the diagram shown in Figure 4.4.

When the run conditions such as temperature are changed, as shown in Figure 4.4, the tritium release rate changes sharply from R_0 to R_1 . The

FIGURE 4.4. Definition of Parameters used for Determining Whether Steady-State Conditions for Tritium Generation Have Been Met

change in the release rate is then $R_1 - R_0$. The first condition for steady state will be when the tritium release rate has returned to within 5% of the initial tritium release rate (R_0).

The alternative condition for return steady state is defined relative to the time involved to return to a specified release rate. When the release rate has returned to within 30% of the change from the initial tritium release rate (R_0), a time t_1 is defined (see Figure 4.4). The run should then be continued for a total time of $3t_1$ from the start of the transient.

In the event that equilibrium is not achieved in three days, a decision will be made as to when the run will be terminated. This would be the case if, as shown in Figure 4.4, $3t_1$ is greater than three days or if after three days, then the release rate has not returned to within 5% of the original release rate.

4.1.6 Data Handling/Analysis

The experiment is continuously monitored using a data acquisition system that records the specified data channels, provides operational information for assessing the performance of the test and sends an alarm signal to the reactor control room if selected signals exceed limits. In the previous annual report, a listing was provided of the 59 data channels that will be monitored during the experiment. From these 59 data channels, 25 were chosen to be included in the prime data set that will be sent to the experimenters for data analysis. These were selected on the basis that they were the data which will be needed to characterize the behavior of the vented canisters during operation as opposed to those channels more concerned with the operation of the experimental system itself. The prime data set and the units in which they are supplied by WHC are given in Table 4.4.

The complete data set is continuously monitored and stored on a data disc at the experiment site at the FFTF. When the disc is full, or at shorter intervals as requested by the experimenter (PNL), WHC segregates the prime data set from the total data set and stores the prime data set on a separate data disc in a compressed form. The data is formatted appropriately so that

TABLE 4.4. Prime Data Set for BEATRIX-II, Cycle 11

Channel	Units	Description
1	atm	Ring specimen inlet gas pressure
2	atm	Solid specimen inlet gas pressure
3	ppm	Reference gas inlet moisture
4	ppm	Alternate gas inlet moisture
5	ppm	Ring specimen sweep gas moisture
8	ppm	Solid specimen sweep gas moisture
11	atm	Ring specimen sweep gas pressure
12	atm	Solid specimen sweep gas pressure
17	cc/min(STP)	Ring specimen injection sweep gas flow
18	cc/min(STP)	Ring specimen sweep gas flow #1
19	cc/min(STP)	Ring specimen sweep gas flow #2
20	cc/min(STP)	Solid specimen injection sweep gas flow
21	cc/min(STP)	Solid specimen sweep gas flow #1
22	cc/min(STP)	Solid specimen sweep gas flow #2
35	Relative Intensity	Self-powered neutron detector
44	°C	Solid specimen outer temperature
45	°C	Solid specimen center temperature - top
46	°C	Solid specimen center temperature - bottom
47	°C	Ring specimen outer temperature
48	°C	Ring specimen inner temperature #1
49	°C	Ring specimen inner temperature #2
1001	Ci/m ³	Ring specimen sweep gas tritium #1
1002	Ci/m ³	Ring specimen sweep gas tritium #2
1003	Ci/m ³	Solid specimen sweep gas tritium #1
1004	Ci/m ³	Solid specimen sweep gas tritium #2

it can be imported into a Lotus 1-2-3® spreadsheet. This data disc is transferred to PNL. Using software provided by WHC, the data is read from the data disc and "decompressed." The data is then read into Lotus 1-2-3 spreadsheet. Using the capabilities of Lotus 1-2-3 and a series of "macros" specifically developed for this application, a series of calculations are carried out to compile and correct the data. The basic calculations carried out are as follows:

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1. From the measured tritium concentrations (Ci/m^3) and flow rates (m^3/sec), the tritium recovery rate (Ci/sec) is determined for both the ring and the solid. This tritium recovery rate is partitioned into the categories of total tritium, elemental tritium/hydrogen, and tritium in the form of water.
2. The amount of water deposited on the molecular sieve in the tritium handling systems of both specimens is calculated to ensure that these remain functional throughout the experiment. Also the deposition of tritium and hydrogen in the getterbeds is followed. The accumulated tritium is used as a cross check for the accumulated tritium on the getterbeds calculated at the reactor. The total amounts of tritium and hydrogen in each getterbed is data requested by the LANL for processing the getterbeds at the tritium system test assembly (TSTA) located at LANL.
3. A series of plots are made showing the change of the prime data set versus time. In addition a series of plots are made to compare the tritium recovery rates with the related experimental parameters such as specimen temperature, sweep gas moisture, and sweep gas flow rate.

It is planned that the data transfer from PNL to JAERI will occur in the form of the final Lotus 1-2-3 spreadsheets with the associated plots stored on multiple data discs.

4.1.7 Component Installation

The associated instrumentation that is used to monitor and control the test parameters in the experiment must be located in close proximity to the MOTA vehicle during irradiation. Therefore, the equipment must be installed in the primary containment of the FFTF.

4.1.7.1 Installation at the FFTF

The installation of all systems into the FFTF facility must follow a prescribed set of development and acceptance procedures. Although these procedures may vary slightly, depending on the individual system, basically the installation of any system follows these steps:

1. Operational Procedure Development
2. Installation Package Development
3. Physical Installation

4. Calibration, Grooming and Alignment (C/G&A) - ensures that all the mechanical and electrical interconnections are according to the design and that the system can be calibrated.
5. Acceptance Testing - ensures that the system performs according to the design specifications and verifies that the operating procedures (Step 1 above) are correct.

4.1.7.2 Instrument and Control System

The I&C system monitors the temperatures in the instrumented MOTA canisters and in particular controls the temperature in the ring specimen canister. There is one I&C system that is dedicated to the fusion MOTA. Temperature control is by computer controlled mixing of Ar-He to adjust the thermal conductance in the specially designed gas-gapped canisters. The equipment was shipped to the FFTF in November 1988. The actual MOTA I&C installation schedule in the FFTF is shown in Table 4.5. Installation was completed in August 1989. The MOTA I&C system is shown in Figure 4.5 installed at the FFTF.

4.1.7.3 Tritium Handling System

The tritium handling system comprises the following:

1. the inlet gas system which selects the types of sweep gas to be used and includes provisions for sampling, conditioning, and pressure control
2. the gas analysis system which is used to control and characterize the sweep gas coming from the vented canisters
3. the tritium cleanup system which reduces the tritium concentration in the sweep gas to a level that can be vented to the ventilation system at the FFTF.

A glovebox serves as the secondary containment for that section of the sweep gas system which contains tritium and could be a source of tritium during maintenance operations when connections are broken. The gas analysis system was initially assembled and installed in the glovebox in the 306 East Laboratory WHC and then shipped to the FFTF.

Glovebox Installation. The first major step in the installation of the sweep gas system involved placement of the primary components in the glovebox in the 300 Area at the Hanford site. The glovebox was shipped to the FFTF in February 1989, and Table 4.6 outlines the major activities involved in the

TABLE 4.5. Schedule for Installation of MOTA Instrumentation and Control (I&C) System

Activity	1989										
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov
Equipment Shipped to FFTF (November 1988)											
Physical Installation Completed (January 1989)											
Plant Wiring/Piping											
C/G&A											
Documentation											
Testing											
Acceptance Testing											
Documentation											
Testing

FIGURE 4.5. The MOTA Instrumentation and Control (I&C) System Installed in the FFTF. Personnel are using the computer system to make a temperature change for the ring specimen. All control and monitoring of the temperature is done using these two computer systems (Neg. 90060622-44CN).

TABLE 4.6. Schedule for Installation of Glovebox System

Activity	1989										
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov
Equipment Shipped to FFTF (February 1989)		▽									
Physical Installation											
Plant Wiring/Piping											
C/G&A											
Documentation											
Testing											
Acceptance Testing											
Documentation											
Testing											

installation. The tritium glovebox, shortly after being moved to the FFTF, is shown in Figure 4.6. The physical installation was completed in May; the wiring and piping were completed in June. Then C/G&A was completed in July with final acceptance testing in August. Because of the physical height of the glovebox, two mechanical lifts are used to facilitate access to the gloveports when work is being carried out in the glovebox. Figures 4.7 and 4.8 show the front and back of the glovebox, as installed, and the use of the lifts for access to the higher gloveports.

Acceptance testing involved verification of the integrity of the glovebox by demonstrating that a negative pressure could be maintained in the glovebox for an extended period of time. Atmospheric control was tested by flowing nitrogen at 9300 cc/min while maintaining a moisture level as low as 125 ppm. The pressure control system for the glovebox was shown to be able to respond to expected changes in the containment pressures. The operation of the airlock for entering and removing material from the glovebox was verified.

Sweep Gas System. The schedule for the installation of the sweep gas system is shown in Table 4.7. The system was shipped to the FFTF in January. Physical installation of the system was completed in March while the associated piping and wiring was completed in May. The C/G&A documentation and testing continued into August. Acceptance testing was completed in September. Shown in Figure 4.9 is the instrumentation for the sweep gas system as installed at the FFTF.

Acceptance testing involved confirmation that the gas supply and inlet monitoring system were working correctly. The flow controllers were tested and found operational. The sweep gas pressure controllers were set to the operational levels of 2070 Torr for the inlet pressure, 1138 Torr for the ionization chambers, and 930 Torr for the outlet pressure. It was verified that these pressures could be controlled for extended periods of time. It was also verified that the moisture levels in the system could be reduced and maintained at dew-point levels below -80°C .

The final acceptance test for the sweep gas system was the demonstration of its operation using a simulated sweep gas containing tritium. The

FIGURE 4.6. The Tritium Glovebox Installed at the FFTF. The tritium glovebox is shown shortly after it was moved to the FFTF in February 1989. Installation is in progress (Neg. 89021341-4CN).

FIGURE 4.7. The Front of the Tritium Glovebox, Installed at the FFTF, with lifts to Facilitate Access. The lift is extended to give access to the upper gloveports. The gloveports on the front of the glovebox provide access to the valves used in making routine changes in the sweep gas flow (Neg. 90060622-35CN).

FIGURE 4.8. The Back of the Tritium Glovebox, Installed at the FFTF, with lifts to Facilitate Access. Gloveports on the back of the glovebox are used when access is needed to the calibration samples and getterbeds (Neg. 90060622-39CN).

TABLE 4.7. Schedule for Installation of Sweep Gas System

Activity	1989											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Dec	
Equipment Shipped to FFTF (January 1989)	▽											
Physical Installation		■										
Plant Wiring/Piping		■	■	■								
C/G&A												
Documentation			■	■								
Testing					■							
Acceptance Testing												
Documentation						■	■	■				
Testing							■	■				
Final Acceptance Testing												
Documentation									■	■		
Testing										■	■	

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FIGURE 4.9. The Instrumentation for the Sweep Gas System, Installed at the FFTF. The operator is adjusting a valve to change the flow of the sweep gas. Other instrumentation indicates moisture levels in the sweep gas and the operating parameters of the CEC cells (Neg. 90060622-26CN).

objectives of the test were 1) to verify the operability of the tritium removal system, 2) to provide a calibration check on the ionization chambers, and 3) to demonstrate the gas sampling/calibration system. Testing was performed at flow rates from 10 to 1000 SCFM at two tritium concentration levels: 9 and 47 Ci/m³. All objectives were met. However, the results of the test did indicate that there was a discrepancy between the tritium concentration in the sweep gas as indicated by the ionization chambers and the concentration as determined by sampling the sweep gas and performing an analysis of the total contained tritium. This discrepancy will be addressed in the future when the sweep gas in the system is sampled for calibration.

4.1.8 Reactor Startup

The completion of the tritium test in October, represented the last major acceptance test for the tritium handling system. The MOTA-2A vehicle was inserted into the reactor during October. The sweep gas lines were then connected and helium sweep gas was used to condition the lines. During November and December, the results of the acceptance testing were reviewed and the system was approved for startup. In Figure 4.10 is shown an overview of the BEATRIX-II instrumentation as installed in the reactor. The reactor head compartment cover plate is shown in the bottom left-hand corner of the figure. The reactor started on January 4, 1990.

4.2 PHASE 2 - EXPERIMENT PLAN

The Phase 2 scope will include the irradiation of two in-situ tritium recovery canisters containing a Li₂O ring specimen and a solid Li₂ZrO₃ specimen composed of 1 to 1.5 mm spheres. The ⁶Li enrichment will be increased to increase the total possible burnup. Nonvented capsules will include barrier-coated stainless steel specimens for tritium permeation studies at high temperatures and solid breeder-beryllium compatibility capsules from Phase 1 that will be irradiated to higher burnups.

4.2.1 Vented Canisters

At the December Working Group Meeting, it was decided that there would be two in-situ recovery canisters included in BEATRIX-II Phase 2:

FIGURE 4.10. An Overview of the Instrumentation for BEATRIX-II, Installed at the FFTF. Shown is the opposite side of the reactor containment. The center of the reactor core is located beneath the lower left region of the photo (Neg. 90032334-24CN).

1. High Burnup Li_2O Temperature Change Canister. The design of this canister will be nearly identical to the one used in Phase 1. The only change will be an increase in the ^6Li enrichment from 61 at% to 95 at% in order to achieve an 8% burnup during the 300 EFPD irradiation. JAERI will fabricate the specimen and deliver it in September 1990.
2. Pebble Bed Li_2ZrO_3 Temperature Gradient Canister. The test requirements for the Li_2ZrO_3 canister were discussed extensively. Specifically, the maximum allowable centerline temperature was an important subject. The recommendation of the Working Group was to establish a peak goal centerline temperature of 1200°C for the Li_2ZrO_3 material with a specification of $+0^\circ\text{C}$ and -200°C for design purposes. Thermocouples in the Li_2ZrO_3 should be designed to determine the peak temperature and have a high probability of surviving the life of the experiment (300 EFPD). Two different type thermocouples should be used in either end of the specimen: 1) chromel-alumel which has a high probability of failure when operated above 1000°C but does not decalibrate due to transmutation and 2) tungsten-rhenium which will be more resistant to failure at the higher temperatures but will decalibrate during irradiation. An additional consideration in operating the thermocouples is to position them off-center so that they are not at the peak temperature. Fabrication of this canister is dependent on AECL delivering the spheres in a timely manner. If problems arise in the fabrication, such that the spheres cannot be produced when needed, the alternate specimen will be solid Li_2ZrO_3 .

4.2.2 Tritium Permeation Experiment

The permeation of tritium through the stainless steel sweep gas tubing and canister walls is a possible source of error in the BEATRIX-II results. It has been proposed to conduct some experimental testing to determine the significance of these permeation losses on the initial tritium recovery results. At the December 1989 Working Group Meeting in Tokyo, it was decided that the tritium loss prediction in BEATRIX-II was the only justification for tritium permeation measurements because the objective of any supporting experimentation must fall under the charter of ANNEX-III. The primary permeation issues that should be considered are the effects of sodium, the loss of surface integrity from deformation of the barrier coated specimen, cumulative irradiation damage, and pseudo-equilibrium defects from the neutron flux. Tritium losses from permeation through the barrier coated components were predicted to be low (approximately 1%), but the uncertainty in this analysis is a prime issue. It was decided that of the options available the laboratory

measurement of tritium permeation was the most reasonable choice, considering feasibility, usefulness and cost.

4.2.3 Mechanical Interaction Canister

A mechanical interaction canister had been previously proposed for inclusion in the BEATRIX-II test matrix. The purpose of this canister was to determine whether mechanical interaction of Li_2O with the stainless steel cladding will be a design problem for blanket applications. Attempts to design a discriminating test have been unsuccessful. Considering the difficulty in designing a meaningful mechanical interaction experiment which will provide discriminating results from a non-prototypic configuration, it was decided to eliminate this canister from the nonvented matrix.

4.3 TRITIUM SYSTEMS TEST ASSEMBLY INTERFACE

The BEATRIX-II tritium getter beds will be transferred to LANL for processing and use in the Tritium Systems Test Assembly (TSTA). This processing will demonstrate the overall fuel cycle of a fusion facility where the tritium produced is processed to usable D-T fuel.

The transfer of the BEATRIX-II tritium getterbeds to LANL for processing and use in the TSTA was the topic of a meeting held at WHC on June 20, 1989. The LANL representative, DO Coffin, met with WHC and PNL to discuss 1) the BEATRIX-II experiment, 2) the details concerning the operation, and 3) the expected condition of the getterbeds to be shipped to TSTA. As a result of the discussions on the handling and movement of the getterbeds within the FFTF and the interim storage at the Hanford site, it was concluded that there should be no problems. The total tritium on each getterbed will be limited to less than 1000 Ci which will classify them as Type A quantities under U.S. Department of Transportation (DOT) guidelines. These requirements should not pose any difficulty with the packaging and shipment of these getterbeds to LANL. Shipments will be limited to one getterbed per shipping container and will be made directly from the FFTF to LANL.

During operation of BEATRIX-II, the getterbeds will be filled with tritium on a fairly routine basis, every thirty to forty days. The getterbeds

will be kept at the FFTF in interim storage and shipped to LANL in either one or two shipments. Details on the schedule of these shipments is to be determined. The legal authority to transfer ownership of the getterbeds to LANL remains an issue due to the export license agreements with Canada.

5.0 REFERENCES

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Slagle, O. D., G. W. Hollenberg, and D. L. Baldwin. 1989. "The FUBR-1B Irradiation Experiment--Tritium Release and Physical Stability of Solid Breeder Materials." Presented at the Fourth International Conference on Fusion Reactor Materials, Kyoto, Japan, December 4-8, 1989. PNL-SA-16939, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

SPECIFICATIONS/CHARACTERISTICS OF THE BEATRIX-II SPECIMENS

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SPECIFICATIONS/CHARACTERISTICS OF THE BEATRIX-II SPECIMENS

A series of pellet acceptance test measurements have been carried out on the solid Li_2O pellets received from JAERI, the ring specimens prepared at PNL, the nonvented specimens prepared from material supplied by JAERI, and the beryllium compatibility specimens prepared at PNL. The chemical acceptance data is summarized in Tables A.1 and A.2. (All tables for this appendix are at the end.) The mensuration data is given in Tables A.3, A.4 and A.5, respectively. All the pellets were accepted as received.

A.1 LITHIUM ASSAY

A lithium assay by induction coupled plasma (ICP) was performed on a sample from a section of the JAERI characterization solid pellet, archive #9, and on a sample from a section of the ring specimen archive. The weight percent of lithium was determined to be 41.30% for solid specimen archive #9 and 41.60% for the ring specimen archive. The theoretical weight percent of lithium in 61% enriched Li_2O is 44.47%. This deviation is assumed to be due to moisture contamination during the measurement process. There was no specification for this lithium assay, and the purpose of the analysis was for information only.

A.2 PHASE PURITY

An X-ray diffraction analysis was performed on samples from a section of the solid pellet archive #9 and a section from the ring specimen archive. The compounds identified in JAERI #9 were 94% Li_2O , 4% LiOH , and 1% gamma LiAlO_2 . The compounds identified in the ring specimen were 91% Li_2O , 8% LiOH , and 1% gamma LiAlO_2 . It is proposed that the LiOH was formed during the analysis procedures. However, its occurrence poses no problem because, in the actual sample, it was decomposed during the outgassing procedure at the time of canister loading. The observation of the LiAlO_2 is confusing because aluminum

was not found to be a major impurity in either of the samples. It is suggested that the archive material be used as a control material in any post-irradiation determination of the phases present. There was no specification for the phase purity, but the analysis was performed to characterize the as-irradiated sample condition.

A.3 LITHIUM ISOTOPIC

Three individual samples of JAERI characterization samples and the ring specimens were analyzed for Li-6/Li-7 ratio. The data are listed in Table A.1 and all the results are within the specified $61 \pm 2\%$.

Two determinations were made on the Li-6/Li-7 ratio of the powder used for fabricating the insulator pellets. The results in atom percent Li-6 were $0.37\% \pm 0.01\%$ and $0.13\% \pm 0.3\%$. The specified ratio was "depleted" and therefore the pellets are within specification.

For the nonvented specimens, only one sample each was analyzed for Li-6/Li-7 ratios. The specified enrichments are listed in Table A.2 along with the results. All the specimens enrichments are in agreement with the specifications to within $\pm 2\%$.

A.4 MENSURATION

The diameters, lengths, hole sizes and weights of the JAERI solid samples were measured and found to agree with the data supplied by JAERI. A comparison of the measurements is given in Table A.3.

The dimensions and weights of the ring specimen are given in Table A.4. During assembly of the temperature change canister, the diameter of the ring specimen 5T was reduced to facilitate insertion of the sample into the canister. NOTE: This resulted in a reduction in weight from the original 4.8501 g to 4.8314 g.

The dimensions and weights of the nonvented specimens are given in Table A.5. The only critical dimension in the nonvented specimens is the diameter which was specified to be $0.128 +.000/-0.002$ in. for the beryllium compatibility specimens. All the pellets except LS-D-3-1 and LS-E-2-3 were

within the specifications. Even though these pellets were oversized, they were accepted as-is because they fit easily into the cladding used to fabricate the capsules.

A.5 MICROSTRUCTURE

Microstructural characterization involved determining the grain size and density. Both these properties are used in the analysis/modeling of the tritium release from ceramic solid breeder materials.

A.5.1 Grain Size

The grain size was determined from optical microstructures of polished surfaces of JAERI #9. Five different micrographs were analyzed using the line intercept technique, and the grain size was determined to be 46 microns. This grain size was calculated from an intercept length of 32.2 microns using a factor of 0.925 to correct for porosity and a factor of 1.56 to convert intercept to grain size (Mendelson 1969).

Grain size of the ring specimen was determined from an analysis of the SEM microstructures. The grain size of the ring specimen was determined from a line intercept analysis of five different microstructures. The resultant grain size was determined to be 5.5 microns using the same procedure as above to convert line intercept to grain size.

The grain sizes of the solid breeder specimens for the beryllium compatibility capsules was determined from an SEM analyses of the samples. The resulting grain sizes are given in Table A.1. The enriched silicate had a bimodal grain size of 1 and 5 microns. This would not be expected to affect the interpretation of the final beryllium interaction.

There was no specification on grain size, and the analysis was intended for information purposes only; is to be used for interpretation of the data generated by the test.

A.5.2 Density

The densities of the samples were calculated from the measured dimensions and weights are included in Tables A.3, A.4 and A.5. The specified density

for the vented solid pellets was 85% TD. The pellets as-received from JAERI ranged from 84.5 to 92.6% TD. To accommodate this change, the specification was changed to $89 \pm 5\%$ TD.

The nominal density specified for the ring specimen was 85% TD. The two sections of Li_2O tube supplied had densities of 78.5 and 80.5% TD. These lower density specimens were accepted as-fabricated because the wall thicknesses of the specimens were at the upper limit of design. The lower densities together with the larger wall thicknesses offset each other to give the required ^6Li per unit length. The ^6Li per unit length determines the heat generation/unit length and is an important design variable.

The densities of the nonvented specimens as calculated from the dimensions and weight are given in Table A.5. The single crystals are expected to have densities equal to the theoretical densities. The difference from theoretical density is due to a deviation from a cylindrical shape which results in a calculated volume which is larger than actual. The resultant low calculated densities are due to the uncertainties in the dimensions.

A.6. PURITY

The chemical purity of the specimens was characterized by measuring the total metallic impurities in all the specimens and the residual carbonate in the Li_2O specimens. The residual carbonate results because the Li_2O powder is made by decomposing Li_2CO_3 powder at high temperatures in a vacuum.

A.6.1 Metallic Impurities

A spark source mass spectrometer analysis was performed on samples from two solid specimen archives (#8 and #9), on two samples from the fabricated ring specimen, on the powders used to fabricate the insulator pellets, on the beryllium compatibility samples, and on the ring specimens. The results are listed in Tables A.1 and A.2 under impurities.

The specifications for the vented samples were that the total metallic impurities be less than 2000 ppm and that no single element impurity be greater than 300 ppm. These specifications were met for all the analyses associated with the vented samples except one. There were two analyses made

TABLE A.1. Chemical Analyses of Specimens for BEATRIX-II;
Vented Specimen Acceptance

<u>Analysis</u>	<u>Ring</u>	<u>Solid</u>	<u>Insulator</u>
1.0 LITHIUM			
1.1 Lithium Assay (wt %)	41.6	41.3	--
1.2 Phase Purity			
% Li ₂ O	91	94	--
% LiOH	8	4	--
% LiAlO ₂	1	1	--
1.3 Lithium Isotopic			
Li-6 (at)	61.0 61.1 60.7	60.5 60.3 60.5	0.37 0.13 --
3.0 MICROSTRUCTURE			
3.1 Grain Size (microns)	5.5	46	--
4.0 PURITY			
4.1 Metallic Impurities			
Total (ppm)	<1500	<500	<600
Major Element (ppm)	Ca(400) V(300) Mn(200) Cr(100) Ge(100)	Ca(100) V(100) Si(70) Mn(50)	Ca(100) S(90) Fe(80) V(80)
4.2 Moisture/Carbonate			
Moisture (ppm)	515	5	--
Carbonate (wt%)	0.01	0.13	0.15

on the fabricated ring specimen and one on the powder. One of the analyses on the fabricated ring specimen was much higher than either of the other two analyses and is the one listed in the Table A.1. It is believed that these high impurity levels are associated with dark spots observed on the ring specimen surface and that they do not represent the overall impurity content of the ring specimens.

The specification for the nonvented samples was that the total metallic impurities be less than 3000 ppm. This was met by all the specimens except for the depleted silicate. The large amount of aluminum was due to the presence of approximately 10% each of alumina and lithium aluminate in the starting powder. No measurements were made of the impurities in the thermal conductivity and single crystal specimens because there was insufficient material available. The impurities given for the single crystal specimens are from an analysis of the starting powder. It is expected that the impurities will be reduced during the floating zone melting process used for growing the single crystals.

A.6.2 Moisture/Carbonate

The solid specimen archive pellet #9 and a sample from an archive ring sample were wrapped in nickel foil and outgassed with the respective canister outgas procedures before assembly. After the 600°C outgas, the specimens were then analyzed for moisture and carbonate to characterize the pre-irradiated material. The moisture in solid pellet archive was 5 ppm while in the archive ring specimen it was 515 ppm. The carbonate for the two specimens was determined to be 0.13 and 0.01 wt% CO₂, respectively. Carbonate analysis of a spare insulator pellet after sintering gave a value of 0.15 wt% CO₂.

The carbonate analyses of the enriched and depleted Li₂O nonvented specimens are identical to the ring and solid insulator specimens, respectively.

A.7 REFERENCES

M. I. Mendelson. 1969. "Average Grain Size in Polycrystalline Ceramics." J. Amer. Cer. Soc., 52(8):445-446.

TABLE A.2. Chemical Analyses of Specimens for BEATRIX-II; Nonvented Specimen Acceptance

	Single Crystals			Beryllium Compatibility									
	XL-1	XL-2	XL-3, 4 & 5	Therm Cond.	DEP		ENR		DEP		ENR		ENR SIL
					OX	OX	OX	AL	AL	ZR	ZR	SIL	
Lithium Isotopic Li-6 (at %)													
Specification	61	1.8	0.07	61	0.2		61	2.0		2	69	2	68
Measured	59.7	1.795	0.074	59.4	0.3		60.9	1.92		1.82	59.3	1.79	68.3
Grain Size (microns)					10		10	0.5		7	7	3	1 & 5
PURITY													
Metallic Impurities													
Total (ppm)	<200	<200	<700		<600		<1500	<120		<600	<500	12000	<500
Major Element (ppm)	Na(30) V(30) Fe(30)	Ag(80)	Ca(520) Si(120)		Ca(100) S(90) Fe(80) V(80)		Ca(400) V(300) Mn(200) Cr(100) Ge(100)	Si(80) Fe(10) Ni(10)		Ti(100) Sm(100) Eu(100) Dy(100)	Ti(100) Fe(80) Al(80)	Al (10000) Mg (2000)	Zr(100) Al(80) Fe(80)
Carbonate (wt%)					0.15		0.01						

TABLE A.3. Dimensions and Weights of Specimens for BEATRIX-II; Vented,
Temperature Gradient Canister; Supplied by JAERI

As supplied by JAERI

B-II ID	JAERI ID	Weight, g	Length, cm	Diameter, cm	ID, cm	Density, % TD
S-2	4	3.0546	0.837	1.700	0.27	84.5
S-3	12	3.1773	0.838	1.700	0.27	87.9
S-4	13	3.1858	0.832	1.701	0.27	88.6
S-5	14	3.1878	0.836	1.701	0.27	88.2
S-6	3	2.8594	0.743	1.702	0	86.7
S-7	1	2.8393	0.746	1.702	0	85.9
S-8	10	3.0652	0.745	1.703	0	92.6
S-9	15	3.1903	0.836	1.701	0.27	88.3
S-10	16	3.1827	0.836	1.702	0.27	88.0
S-11	18	3.2723	0.838	1.701	0.27	90.4
S-12	19	3.2524	0.836	1.702	0.27	89.9

As measured at PNL

S-2	4	3.0589	0.838	1.700	0.27	84.5
S-3	12	3.1809	0.838	1.700	0.27	87.9
S-4	13	3.1876	0.833	1.701	0.27	88.6
S-5	14	3.1902	0.837	1.701	0.27	88.1
S-6	3	2.8633	0.743	1.702	0	86.8
S-7	1	2.8449	0.745	1.702	0	86.0
S-8	10	3.0651	0.745	1.703	0	92.6
S-9	15	3.1921	0.836	1.703	0.27	88.1
S-10	16	3.1858	0.837	1.701	0.27	88.1
S-11	18	3.2728	0.838	1.702	0.27	90.3
S-12	19	3.2702	0.838	1.702	0.27	90.2

Insulators

S-1	1.8526	0.619	1.550	0.246	80.1
S-13	1.9391	0.644	1.550	0.246	80.6

TABLE A.4. Dimensions and Weights of Ring Specimens for BEATRIX-II; Vented, Temperature Change Canister

B-II ID	Sample ID	Wall Thickness, in.		Diameter, in.		Length, in.	Weight, g	Density, % TD
		End #1	End #2	End #1	End #2			
R-1 (Bottom)	6T	0.0642	0.065	0.7255	0.7261	2.0493		
		0.064	0.0667	0.7256	0.7259	2.0505		
		0.0641	0.0673	0.7249	0.7262	2.0515		
	Average=	0.0652		Average=		2.0504	7.1158	80.17
R-2 (Top)	5T	0.0643	0.0631	0.7265	0.7237	1.4518		
		0.0651	0.0632	0.7255	0.7265	1.452		
		0.0664	0.0623	0.7263	0.723	1.4503		
	Average=	0.0641		Average=		1.4514	4.8501(a)	78.49

(a) During capsule loading tube 5T was ground to fit. The final weight was 4.8314 grams.

**TABLE A.5. Dimensions and Densities of Specimens for BEATRIX-II;
Nonvented Specimens**

Cap ID	Can ID	Specimen ID	FABR ID	As-Fabricated Dimensions					Material Description	Li-6 ENR
				Diameter, in	Length, in	Weight, g	Density, % TD	Th Dens, g/cm ³		
B4	1D	1D-B4-1	LO-XL-1-1	0.275	0.2214	0.3917	93.14	1.9515	Li2O crystal	61%
B4	1D	1D-B4-2	LO-XL-1-3	0.275	0.1761	0.309	92.38	1.9515		
B5	1D	1D-B5-1	LO-XL-2-1	0.314	0.2089	0.5045	93.70	2.031	Li2O crystal	1.8%
B5	1D	1D-B5-2	LO-XL-2-3	0.314	0.1735	0.4012	89.72	2.031		
B6	1D	1D-B6-1	LO-XL-3-1	0.314	0.2633	0.6335	93.22	2.034	Li2O crystal	0.07%
B6	1D	1D-B6-2	LO-XL-3-2	0.314	0.1518	0.3407	86.96	2.034		
B7	1B	1B-B7-1	LO-TC-1-2	0.3616	0.03252	0.0859	80.43	1.9515	Li2O: 83.5% TD	61%
B7	1B	1B-B7-2	LO-TC-3-1	0.3632	0.03398	0.0959	85.16	1.9515	Li2O: 87.4% TD	61%
B7	1B	1B-B7-3	LO-TC-5-1	0.3639	0.03617	0.1097	91.19	1.9515	Li2O: 93.6% TD	61%
B8	1D	1D-B8-1	LO-XL-4-1	0.314	0.7394	1.8119	94.94	2.034	Li2O crystal	0.07%
B8	1D	1D-B8-2	LO-XL-5-2	0.314	0.3978	0.9313	90.70	2.034		
B9	5E	5E-B9	LO-E-12-2	0.1268	0.12	0.0404	83.37	1.9515	Li2O/Be	61%
B10	5E	5E-B10	LZ-E-2-1	0.1268	0.1185	0.0872	86.31	4.12	Li2ZrO3/Be	69%
B11	5E	5E-B11	LA-E-2-1	0.127	0.1174	0.0531	84.48	2.579	LiAlO2/Be	95%
B12	5E	5E-B12	LS-E-2-1	0.1276	0.1191	0.0481	82.19	2.345	Li4SiO4/Be	68%
B13	5E	5E-B13	LO-D-10-1	0.1278	0.1184	0.0385	76.09	2.033	Li2O/Be	0.2%
B14	5E	5E-B14	LZ-D-2-1	0.1273	0.118	0.0885	86.52	4.156	Li2ZrO3/Be	2%
B15	5E	5E-B15	LA-D-3-1	0.1271	0.1175	0.0548	85.75	2.616	LiAlO2/Be	2%
B16	5E	5E-B16	LS-D-3-1	0.1288	0.1194	0.0483	79.01	2.398	Li4SiO4/Be	2%
B17	5E	5E-B17	LO-D-10-2	0.1269	0.1076	0.0346	76.32	2.033	Li2O/Be	0.2%
B18	5E	5E-B18	LZ-D-2-2	0.1272	0.1182	0.0882	86.22	4.156	Li2ZrO3/Be	2%
B19	5E	5E-B19	LA-D-3-2	0.1266	0.1176	0.0547	86.20	2.616	LiAlO2/Be	2%
B20	5E	5E-B20	LS-D-3-2	0.1262	0.1165	0.0451	78.76	2.398	Li4SiO4/Be	2%
B21	8B	8B-B21	LO-E-12-3	0.1273	0.116	0.0389	82.39	1.9515	Li2O/Be	61%
B22	8B	8B-B22	LZ-E-2-2	0.1271	0.1186	0.0872	85.83	4.12	Li2ZrO3/Be	69%
B23	8B	8B-B23	LA-E-2-2	0.1269	0.1175	0.0529	84.23	2.579	LiAlO2/Be	95%
B24	8B	8B-B24	LS-E-2-3	0.1282	0.1139	0.0458	81.06	2.345	Li4SiO4/Be	68%
B25	8B	8B-B25	LO-D-10-3	0.1263	0.1183	0.0378	76.55	2.033	Li2O/Be	0.2%
B26	8B	8B-B26	LZ-D-2-3	0.1271	0.1168	0.0877	86.90	4.156	Li2ZrO3/Be	2%
B27	8B	8B-B27	LA-D-3-3	0.127	0.1187	0.0551	85.48	2.616	LiAlO2/Be	2%
B28	8B	8B-B28	LS-D-3-4	0.1276	0.1155	0.0473	81.50	2.398	Li4SiO4/Be	2%

APPENDIX B

DOCUMENTATION OF BEATRIX-II PROGRAM

APPENDIX B

DOCUMENTATION OF BEATRIX-II PROGRAM

The following papers have been presented on the design and fabrication of BEATRIX-II:

1. Hollenberg, G. W., T. Kurasawa, H. Watanabe, S. E. Berk, I. J. Hastings, J. Miller, D. E. Baker, R. E. Bauer, and R. J. Puigh. 1988. "A Fast Neutron, In-Situ Tritium Recovery Experiment on Solid Breeder Materials." Fusion Technology. 15:1349-1354.
2. Puigh, R. J., G. W. Hollenberg, T. Kurasawa, H. Watanabe, I. J. Hastings, J. M. Miller, S. E. Berk, R. E. Bauer, and D. E. Baker. 1989. "BEATRIX-II: In-Situ Tritium Recovery from a Fast Neutron Irradiation of Solid Breeder Materials." In Proceedings of the 15th Symposium on Fusion Technology, ed. AM van Inger, A. Nigsen-Vis, and H.P. Klippel, pp. 1282-1286. September 19-23, 1988, Utrecht, the Netherlands. Elsevier, Netherlands.
3. Slagle, O. D., K. Noda, and T. Takahashi. 1989. "Fabrication of Lithium Ceramic Pellets Rings and Single Crystals for Irradiation in BEATRIX-II." Presented at The American Ceramic Society Meeting, April 24-25, 1989, Indianapolis, Indiana. PNL-SA-16869, Pacific Northwest Laboratory, Richland, Washington.

Design documents necessary for irradiation in FFTF are as follows:

1. Bauer, R. E. 1988. "Test Design Description for the Fusion Materials Open Test Assembly (Fusion MOTA-2A) Specifications," Vol. 1B, Part 1 and 2. WHC-SP-0255, Westinghouse Hanford Co., Richland, Washington.
2. Bauer, R. E. 1988. "Test Design Description for the Fusion Materials Open Test Assembly (Fusion MOTA-2A)," Parts 1 and 2. WHC-SP-0224, Westinghouse Hanford Co., Richland, Washington.

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