First Annual Progress Report

**BEATRIX-II Program
January 1988 to December 1988**

**ANNEX-III to IEA Implementing Agreement
for a Programme of Research and
Development on Radiation Damage
in Fusion Materials**

G. W. Hollenberg

March 1989

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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EXECUTIVE SUMMARY

During 1988, the BEATRIX-II program, Phase I was initiated by the signing of ANNEX-III and progressed through design efforts into either partial or complete fabrication of its systems in order to meet a scheduled beginning of irradiation in April 1989. Adequate funds were made available by Canada, Japan, and the U.S. to pursue the design and fabrication program at Pacific Northwest Laboratory (PNL), Westinghouse Hanford Company and Atomic Energy of Canada Limited (AECL). In addition, the Japan Atomic Energy Research Institute (JAERI) fabricated ceramic electrolysis cells (CEC) for incorporation into the sweep gas analysis lines. It appears that the final tasks before insertion into the reactor will be completed in time. Both the International Energy Agency (IEA) and Hanford site design review meetings have approved the final design of the system.

The purpose of BEATRIX-II is to conduct an in-situ tritium recovery experiment in the high energy neutron environment of the Fast Flux Test Facility (FFTF). During Phase I, two in-situ capsules containing Li_2O are being irradiated with higher tritium production levels than in previous experiments. One capsule possesses the capacity for temperature change experiments while the other possesses a temperature gradient for evaluating the stability of temperatures in an engineering blanket configuration. Nonvented capsules were included for measurement of irradiation damage, thermal diffusivity, PIE release kinetics, and beryllium compatibility.

Special materials and components were developed and adopted for BEATRIX-II including a channeled nickel layer, tritium barrier coatings, self-powered neutron detectors, tritium removal system, etc. Many of these materials and components could have application in future blanket systems. By December 1988, in-situ tritium recovery canisters had been fabricated and material for nonvented capsules were at Westinghouse Hanford. In December 1988, all sweep gas analysis system components had been received and were being installed into the glovebox before checkout.

A proposal was made to ship the tritium produced in the Phase I test and accumulated in the tritium removal system getter beds to the tritium system

test assembly (TSTA) at Los Alamos National Laboratory (LANL). The tritium will be processed into a form compatible with fusion fueling, thus demonstrating the fuel cycle. The scope of Phase II, i.e., Cycle 12, irradiations will be determined in February 1989.

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1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of the BEATRIX-II experiment is to design, conduct, and evaluate a collaborative, in-situ tritium-recovery experiment in the Fast Flux Test Facility (FFTF). Continuous monitoring of candidate solid breeder material's performance with respect to thermal conductivity, temperature stability, and tritium release is to be accomplished up to extended lithium burnup levels under simulated blanket environments.

1.2 SCOPE

The BEATRIX-II experiment as described in ANNEX-III is divided into Phase I and Phase II. The Phase I activities are directed specifically at the irradiation of material in the Cycle 11 of FFTF, beginning approximately on April 1989 and continuing to April 1990. Phase II will be irradiations conducted in Cycle 12 of FFTF, from approximately April 1990 to April 1991. Phase II activities are undefined at this time.

The Phase I scope includes the irradiation of two in-situ tritium recovery capsules containing Li_2O . The ring specimen or temperature-change capsule is designed to operate in a manner similar to previous tritium recovery experiments, i.e. TRIO, VOM, CRITIC, etc. The solid specimen capsule will provide performance data on a large mass of Li_2O irradiated under a temperature gradient. Nonvented capsules were selected for other canisters.

1.3 BACKGROUND

This report covers the first year of BEATRIX-II. A chronology of the International Energy Agency (IEA) major events is given in Table 1. Annex III, see Appendix I, was submitted by the Executive Committee to the IEA for approval during January 1988. Letters-of-intent preceded the actual transfer of funds to the operating agent, the U.S. Department of Energy (DOE). Events relative to the execution of the experiment and financial matters will be dealt with later in this report.

TABLE 1. 1988 Chronology of BEATRIX-II

<u>Date</u>	<u>Event/Location</u>	<u>Participant^(a)</u>	<u>Impact</u>
15 January 1988	Interim Design Review	BII Working Group	Technical Approval to proceed
22 January 1988	Annex III to IEA	IEA Executive Committee	Formal Authorization
8-9 March 1988	Final Design Review, Richland, WA, USA	BII Working Group plus experts	Design Approval/Modifications
19 April 1988	"Approval-in-Principle" granted	DOE	Authorization to use FFTF
19 April 1988	BII Meeting, Tokyo, Japan	BII Working Group	Review Status
20 July 1988	Solid Pellet Shipment	JAERI	Acceptance Testing
August 1988	Ring Specimen Fabrication	PNL	Acceptance Testing
10 September to 8 October 1988	Technical Meeting, Richland, WA, USA	T. Kurasawa, JAERI	CEC Checkout etc.
23 November 1988	TRS & Ion Chambers Arrive Hanford	AECL	Acceptance Review
28 November 1988	Nonvented Specimens Fabricated	PNL/JAERI	Acceptance Testing
7 December 1988	Program Review, Richland, WA, USA	Operating Agent, TC Reuther	Review of Program Status

(a) BII = BEATRIX-II

It is evident that many beyond the work scope at the Hanford site have contributed to the progress in this program. The BEATRIX-II Working Group conducted interim and final design reviews of the BEATRIX-II experiment proposals during 1988. In addition to experts from Japan Atomic Energy Research Institute (JAERI), Atomic Energy of Canada Limited (AECL), Pacific Northwest Laboratory (PNL)^(a), and Westinghouse Hanford Company, others from the tritium system test assembly (TSTA) at the Los Alamos National Laboratory (LANL), Argonne National Laboratory (ANL), and University of California Los Angeles (UCLA) also participated in these reviews. The delivery of CEC cells and Li₂O pellets from JAERI and the ion chambers and tritium removal system from AECL are examples of activities conducted off the Hanford site. The presence of T. Kurasawa during the checkout of the CEC cells specifically accelerated that procedure.

Design activities changed to fabrication and procurement activities after the March 1988 final design review. Li₂O test material for both capsules became available during the summer of 1988. The tritium analysis glovebox assembly was accelerated in October 1988. The tritium removal system from AECL was not delivered until November 1988 because of delays associated with obtaining an export license. Finally, at year's end, the in-reactor portions of the BEATRIX-II experiment were assembled and attached to the Materials Open Test Assembly (MOTA) stalk while the glovebox and its internal panels were being assembled for final inspection before installation in FFTF scheduled for the first week of February 1989. Intellectual property and documentations of BEATRIX-II in 1988 are listed in Appendices II and III.

1.4 RESPONSIBILITIES

The responsible parties associated with the BEATRIX-II experiment and ANNEX-III are shown in Table 2. The IEA executive committee has the responsibility for the approval and signing of Annex-III. According to ANNEX-III, the BEATRIX-II Working Group is a technical steering committee for preparation and supervision of budgets, schedules, and scientific activities of the tasks associated with BEATRIX-II. The operating agent for BEATRIX-II is DOE,

(a) Operated for the U.S. Department of Energy by the Battelle Memorial Institute.

TABLE 2. BEATRIX-II/ANNEX III Responsibilities

Office of Fusion Energy (OFE) (T. C. Reuther) which performs all legal actions required for ANNEX-III in addition to invoicing and accounting for funds. A PNL task manager at the Hanford site, Richland, WA, monitors the progress and coordinates activities between the participants. The funding provided by Japan, Canada (through the National Fusion Program, Canadian Fusion Fuels Technology Project and AECL) and the U.S. supports activities at the Westinghouse Hanford which operates the FFTF for the design, construction and operation of the BEATRIX-II experiment. Dr. R. J. Puigh is the experimenter's representative for this experiment. At the FFTF reactor, Mr. R. E. Redekopp is the site representative. J. M. Miller is responsible for the tritium removal system and ion chambers acquired from AECL. Dr. Kurasawa is responsible for the ceramic electrolysis cells (CEC) provided by JAERI. Post-irradiation examination will be the responsibility of Dr. O. D. Slagle. The responsibilities associated with the data analysis and reporting are to be decided by the BEATRIX-II working group.

1.5 SCHEDULE AND COSTS

The funding for BEATRIX-II has been divided into Phase I and Phase II activities. The funding requirements for BEATRIX-II, Phase I, were documented in ANNEX-III and are listed in Table 3. Also in Table 3 are the funds received from the participants during U.S. FY 1987 and 1988. It is anticipated that the Phase II will be defined at a BEATRIX-II Working Group Meeting scheduled for 13 February 1989 in Seattle, Washington. The scope of activities for Phase II, i.e. the Cycle 12 irradiation, will be defined at that time.

As reported in detail later, BEATRIX-II, Phase I, tasks are progressing at a rate consistent with insertion into FFTF for irradiation during Cycle 11. Projections for the beginning of Cycle 11 are now 29 April 1989 instead of January 1989. Because of the delayed insertion date, expenditure rates were less than estimated at the end of U.S. FY 1988 for the entire MOTA.

TABLE 3. Funding Requirements per ANNEX-III for BEATRIX-II, Phase I

<u>Participant</u>	<u>U.S. FY, USK\$</u>			
	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>
Canada	--	78	39	--
Japan	400	443	318	91
United States	180	524	327	220

Funds Received-to-Date (1 October 1988)

<u>Participant</u>	<u>U.S. FY, USK\$</u>			
	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>
Canada	--	60 ^(a)		
Japan	400	443		
United States	180	524	327	

(a) Note: Canada has not been invoiced for the additional 18K after an initial 60K contribution.

2.0 TECHNICAL STATUS

Liquid Metal reactor canisters will be inserted in the fusion MOTA on an exchange basis with the U.S. fusion program in order to avoid any irradiated materials during assembly of this MOTA.

2.1 DESIGN DESCRIPTION

The BEATRIX-II, Phase I, Cycle 11, will consist of both vented and non-vented capsules irradiated for approximately one year in the FFTF. These specimens have been loaded into canisters such as the ones shown in Figure 1 which will be irradiated in Cycle 11. The BEATRIX-II canister locations in the fusion MOTA are designated IEA in Table 4 in contrast to other MOTA users, Monbusho and the U.S. fusion program. The numerical designations refer to the axial row of the canister while the alphabetic designations refer to six different radial positions around the central MOTA stalk. The nonvented capsules of the BEATRIX-II, Phase I test will be loaded into standard MOTA canisters 1B, 1D, 5E, and 8B (see Table 4). The fusion MOTA will also contain two specialized canisters, 1C and 1E, for the two vented specimen geometries.

The ring specimen canister is designed to provide tritium release and thermal conductivity data on Li_2O . The canister's design (shown in Figure 2) allows temperature changes and has a sweep gas flow through the canister to recover the released tritium. The solid pellet specimen canister (shown in Figure 3) is designed to provide tritium release data for Li_2O under the large thermal gradient ($\sim 450^\circ\text{C}$) prototypic of many fusion blanket design. The sweep gas flow in the solid pellet geometry canister is routed around the pellets through a channeled nickel layer which is located next to the outer circumference of the solid Li_2O pellets. To minimize the permeation of tritium into the reactor sodium the canister walls and the exit, sweep gas lines for both in-situ recovery canisters are coated with a tritium barrier. A self-powered neutron detector (SPND) is located next to the vented canisters to provide information on temporal variations in the local neutron flux.

The major characteristics of the Li_2O specimens and their anticipated environment are summarized in Table 5. The ^6Li enrichment for both specimens

FIGURE 1. A Fusion MOTA Test Assembly Showing Canisters Attached to the Central Stalk and a Standard MOTA Canister with Temperature Control Capabilities Through Gas Cap Compositional Control. Some canisters (weeper) are maintained at reactor coolant temperatures. (Neg. 8405218-1CN)

TABLE 4. MOTA-2A (Fusion MOTA) Canister Matrix

	A	B	C	D	E	F
8	440°C FUSION [offset] W (HHF)	440°C FUS/MONB/ IEA W				
7		435°C FUS/MONB W				
6	430°C FUSION [offset] W (HHF)	430°C FUS/MONB W	430°C MONB [offset] W (HHF)			
5	600°C FUSION [offset] W (HHF)	425°C FUSION [offset] W (HHF)	600°C FUSION [offset] W (HHF)	800°C MONB	425°C IEA/MONB W	600°C MONB
4	425°C LMR W	600°C FUSION	600°C FUSION	425°C MONB W	520°C MONB	600°C MONB
3	605°C LMR	550°C LMR	420°C FUSION W	420°C MONB W	520°C MONB	600°C MONB
2	410°C LMR W	410°C LMR W	520°C FUSION	410°C MONB W	410°C MONB W	520°C MONB
1	390°C MONB W	390°C IEA W	900°C IEA [3 TCs] W	390°C IEA W	450-600°C IEA [3 TCs]	460°C MONB
BC	365°C FUSION W	365°C FUSION W	365°C LMR W	365°C LMR W	365°C MONB W	410°C MONB

W = Weeper Canisters
 FUSION = U.S. Fusion Program
 MONB = Japanese MONBUSHO Program
 IEA = I.E.A. BEATRIX-II Experiment
 LMR = Liquid Metal Reactor Program
 HHF = High Heat Flux Capsule
 [offset] = Offset Thermocouple

FIGURE 2. The Ring Specimen Canister Design with Temperature Control and In-situ Tritium Recovery (Neg. 88082331-2)

FIGURE 3. The Solid Specimen Canister Design with Centerline Temperature Stability Measurements and In-situ Tritium Recovery (Neg. 88082331-1)

TABLE 5. Characterization of the Li₂O Specimens and Anticipated Environment

Specimen	Ring Specimen	Solid Specimen
Physical Dimensions		
Outside Diameter (mm)	18.57	17.02
Wall Thickness (mm)	1.50	
Length (mm)	88.9	88.9
Lithium-6 Enrichment (%)	61.0	61.0
Density (%TD)	80	89
Grain Size (um)	5	45
Irradiation Temperature		
Inner Radius (°C)	500 - 685	863
Outer Radius (°C)	460 - 651	430
Maximum Gradient (°C)	28	433
Total Tritium Production (Ci)	2025	5300
Neutron Fluence (10 ²² n/cm ² E>0.1Mev)	3.9	3.9
Sweep Gas System		
Gas Composition	helium+(0 to 1%)H ₂	helium+(0 to 1%)H ₂
Flow rates (cm ³ /m)	10 - 800	10 - 800

was chosen to obtain a lithium atom burnup of 4% by the end of the irradiation (300 Equivalent Full Power Days). Monte Carlo neutronic calculations were performed to determine the reaction rate yielding the desired lithium atom burnup. Canisters are located near the bottom of the core in order to minimize the irradiation temperatures because the coolant is heated as it passes through the core. The dimensions of the ring geometry specimen were chosen to minimize the radial temperature gradient, maintain temperature control over an acceptable range and still generate significant tritium. The dimensions of the solid pellet geometry specimen were chosen to achieve an initial centerline temperature of approximately 900°C. The calculated radial temperature gradients in the two specimen types are shown in Figure 4. During the irradiation, the temperature of the ring specimen will be incrementally stepped from one temperature to another in order to observe the kinetics of tritium release from Li₂O. In the solid specimen, no external temperature changes will be made but the centerline thermocouple temperature will indicate the stability of thermal performance of Li₂O, thus establishing design margins.

FIGURE 4. Predicted Radial Temperature Gradients in the Ring and Solid Specimens (Neg. 88090922-2)

The tritium production rate in the ring geometry specimen is calculated to be 7 Ci/day which will provide 2025 Ci by the end-of-life. The calculated tritium production gradients in the ring geometry specimen are calculated to be quite low (<5%) because of lithium's relatively low average cross section for neutron reactions in FFTF's fast neutron environment. The calculated tritium production rate is 17 Ci/day which will provide 5300 Ci by the end-of-life. The calculated radial and axial tritium production rate gradients in the solid pellet geometry specimen are shown in Figure 5. As seen in the figure, both the axial and radial gradients are less than 7%. Because of the higher tritium production rates in the BEATRIX-II experiment, it is possible to achieve 50 ppm of tritium in the sweep gas at 100 cm³. Higher tritium partial pressures are typical for the recoverable levels in an actual blanket and should reduce the influence of minor impurities present in gasses (1 ppm).

FIGURE 5. Tritium Production Gradients in the Solid Pellet Specimen

The sweep gas flow for the BEATRIX-II, Phase I test is shown in Figure 6. The sweep gas flow for the vented canisters originates at the inlet monitoring system and flows to the inlet pressure control system before routing to the MOTA. These two systems comprise the gas inlet system. This design offers the flexibility of routing a separate sweep gas composition to each vented canister in the fusion MOTA. The sweep gas from each canister is routed out of the MOTA and to the gas analysis system where the flow stream from each canister is split into two paths. One path measures the total tritium in the sweep gas line; the second path measures the tritium gas ($HT + T_2$) in the sweep gas line. The sweep gas flow from the two vented canisters is combined and processed through the tritium removal system which removes the tritium from the sweep gas before it is exhausted into the cell atmosphere processing system (CAPS) which is used by many systems in FFTF. Both the gas analysis system and the tritium removal system are located within a glovebox which provides environmental control and secondary containment for the tritium systems.

FIGURE 6. Sweep Gas Flow in the BEATRIX-II Experiment

2.2 ACCOMPLISHMENTS

The schedule of activities performed on the BEATRIX-II experiment during calendar year 1988 are summarized in Table 6. Design work continued during the first part of the calendar year until the final design review by the IEA working group occurring in March 1988. An internal, Westinghouse Hanford design review was held in May 1988. The major efforts in 1988 were in the assembly of the vented canisters and the tritium handling system. Specimens for both the vented capsules were provided on schedule. The assembly of the solid pellet canister was completed in October and the assembly of the ring specimen canister was completed in December. Difficulties in obtaining qualified weld procedures caused some delays in the assembly of these capsules. However, work then proceeded with the assembly of the fusion MOTA and the schedule remains viable for completion of the fusion MOTA before the start of the FFTF Cycle 11 which is presently planned for May 1989. The assembly of the MOTA instrumentation and control (I&C) system has been completed and installation initiated at FFTF. The assembly of the tritium handling system (THS) is 95% completed. Canada completed the design, pretest characterization, and assembly of the tritium removal system and ion chambers required for the gas analysis system. These components were received at Westinghouse Hanford in November 1988. Initial checkout of the system is scheduled for January, before its shipment to FFTF for installation. Final installation checkout will occur in March and April of next year.

2.3 COMPONENTS

The in-reactor components will be attached to the MOTA test assembly; these components include the ring specimen and solid specimen canisters, nonvented canisters, and associated components.

2.3.1 Ring Specimen

A drawing of the ring specimen canister was presented in Figure 2. This canister has been fabricated and attached to the MOTA stalk. The ring specimen canister will allow temperature changes between 460°C and 650°C on a thin ring of Li_2O in a manner similar to earlier experiments. In Figure 7, the ring specimen is shown before loading into the canister. It was noted that

TABLE 6. BEATRIX-II, Phase I, Cycle 11 Test Schedule 1988

Major Tasks	CY 1988											
	J	F	M	A	M	J	J	A	S	O	N	D
Design												
Final Design Review												Δ
Specimen Preparation												
Solid Li ₂ O Specimen Delivery (JAERI)												Δ
Ring Li ₂ O Specimen Delivery (PNL)												Δ
Nonvented Specimen Delivery (JAERI/PNL)											(JAERI)Δ	Δ(PNL)
MOTA Assembly												
Channeled Nickel Layer												
Barrier Coated Stainless Steel												
Solid Specimen Capsule Assembly												Δ
Ring Specimen Capsule Assembly												Δ
MOTA I&C System												
System Assembly												Δ
FFTF Installation												
Tritium Handling System												
Glovebox Modification (WHC)												Δ
Vendor Supplied Components (WHC)												Δ
CEC Cells (JAERI)												Δ
Inlet Monitoring System Assembly (WHC)												Δ
Inlet Pressure Control System Assembly (WHC)												Δ
Tritium Recovery System Assembly (AECL)												Δ
Tritium Ion Chamber (AECL)												Δ
Data Acquisition System (WHC)												Δ
Gas Analysis System Assembly (WHC)												Δ
Glovebox Cleanup System Assembly (WHC)												Δ
Glovebox System Assembly (WHC)												Δ
FFTF Installation (WHC)												Δ
Checkout (WHC)												Δ

FIGURE 7. The Thin-walled Li_2O Specimens for Ring Specimen Canister
(Neg. 88102806-5CN)

localized areas of higher zirconium concentration caused a spotty discolorization of the specimen. These specimens were used because specimen's average zirconium concentration did not exceed the specification and because resynthesis of the powder could be done fast enough to meet the original delivery schedule.

The ring specimen was fabricated by Dr. O. D. Slagle (PNL) from powder synthesized by Dr. R. B. Poeppel (ANL) from enriched lithium carbonate. The specimen fabrication was accomplished by isostatic pressing in a special mold so that the precise tolerances could be maintained on the external surface

and yet avoid grinding of the delicate thin-walled ring specimen. In Figure 8, the loading of the thin-walled Li_2O specimen in an inert gas glovebox is presented. After the closure weld on this inner container, it was sealed in an outer container which was then filled with sodium for heat conduction. Finally, the outside container was positioned and sealed.

FIGURE 8. Loading of the Ring Specimen into the Inner Cladding in an Inert Gas Glovebox (Neg. 88112240-16CN)

2.3.2 Solid Specimen

The solid specimen canister was shown in Figure 3. This canister was fabricated and attached to the MOTA stalk. To limit tritium loss during irradiation, it was necessary to not only barrier coat the outer stainless steel cladding of the capsule but also to insert a tungsten rhenium alloy sheath down the central thermocouple hole. Tungsten rhenium alloys possess a lower tritium permeation rate at high temperatures than many other materials. The flow of the sweep gas down the center of the Li_2O pellets (900°C) could result in significant LiOT transport so the gas was routed to the circumference of the pellets. If a gas gap was provided, a significant temperature increase would result. To avoid a temperature increase due to a gas gap between the solid pellet and canisters, a coarse, porous, nickel-powder layer was developed to provide adequate heat transfer and yet allow gas flow.

In Figure 9, the loading in an inert gas glovebox of the solid pellets into the outer cladding is shown. After the closure weld on the canister, it was attached to the MOTA stalk.

2.3.3 Barrier Coating

Initial calculations indicated that tritium permeation through the cladding and tubing into the reactor's sodium coolant could result in significant errors in the tritium sweep gas measurement. A tritium permeation barrier (Figure 10) was applied to the stainless steel components to measure this error. Tritium permeation will also be a challenge for containment of tritium in actual fusion power plants. Calculations indicated that less than 1% of the tritium will be lost to the coolant in this experiment.

The coating applied to the stainless steel is a 0.01-cm thick aluminized coating which was originally developed for the reduction of tritium permeation in liquid metal reactors. It was applied to the canister components and tubing by a U.S. vendor using a qualified process.

2.3.4 Channeled Nickel Layer

The solid pellet design required a porous metal region around the Li_2O pellet to provide a gas flow path and high heat conduction. A process was

FIGURE 9. Loading of the Solid Pellets into the Solid Pellet Canister for BEATRIX-II, Cycle 11 (Neg. 88113015-2CN)

FIGURE 10. Micrograph of Tritium Barrier Coating Applied to Ring Specimen Canister (Neg. 88102113.2)

developed which provided a large-grained nickel layer which is sintered to the external cladding. Originally, isostatic pressing was used to press the nickel powder in place but too dense a product was formed to allow adequate flow. By modifying of the forming process, a product of appropriate density was obtained as shown in Figure 11. Machining of the internal surface of the nickel layer allowed for a precision fit with the Li_2O pellet. Nickel was used because of its compatibility with Li_2O .

A patent disclosure on the channelled nickel layer was written by Westinghouse Hanford and will be processed in accordance with ANNEX-III (see Appendix II).

FIGURE 11. Micrograph of Channelled Nickel Layer on Cladding of Solid Specimen (Neg. 88102113.1)

2.3.5 Nonvented Specimens

In Table 7 the nonvented test matrix for BEATRIX-II, Phase I, is given. Specimens can be grouped according to the purpose of the testing. Specimens B4, B5, and B6 are Li_2O single crystals of varying enrichment which will be examined by ESR, TEM, and SEM in order to evaluate the build up of irradiation damage by both neutrons and transmutation products. Specimens in capsule B7 will be used to measure the effect of irradiation on the thermal conductivity of Li_2O during PIE. Specimens in capsule B8 will be returned to JAERI for isothermal tritium release measurements to be conducted.

TABLE 7. BEATRIX-II Nonvented Capsule Matrix

ID Capsule/ Canister	As Fab Dimensions			Material Description	ENR	Temp. (°C)	Purpose
	OD(in)	L(in)	WT(gm)				
B4 / 1B	0.275 0.275	0.2214 0.1761	0.3917 0.309	Li_2O crystal	61%	390	ESR/Anneal/TEM/SEM
B5 / 1B	0.314 0.314	0.2089 0.1735	0.5045 0.4012	Li_2O crystal	1.8%	390	ESR/Anneal/TEM/SEM
B6 / 1B	0.314 0.314	0.2633 0.1518	0.6335 0.3407	Li_2O crystal	0.07%	390	ESR/Anneal/TEM/SEM
B7 / 1D	0.3616	0.03252	0.0859	Li_2O : 83.5% TD	61%	390	Thermal Diff.
B7 / 1D	0.36325	0.03398	0.0959	Li_2O : 87.4% TD	61%	390	Thermal Diff.
B7 / 1D	0.3639	0.03617	0.1097	Li_2O : 93.6% TD	61%	390	Thermal Diff.
B8 / 1D	0.314 0.314	0.7394 0.3978	1.8119 0.9313	Li_2O crystal	0.07%	390	Tritium Release
B9 / 5E	0.1268	0.12	0.0404	$\text{Li}_2\text{O}/\text{Be}$	61%	425	Compatibility
B10 / 5E	0.1268	0.1185	0.0872	$\text{Li}_2\text{ZrO}_3/\text{Be}$	69%	425	Compatibility
B11 / 5E	0.127	0.1174	0.0531	LiAlO_2/Be	95%	425	Compatibility
B12 / 5E	0.1276	0.1191	0.0481	$\text{Li}_4\text{SiO}_4/\text{Be}$	68%	425	Compatibility
B13 / 5E	0.1278	0.1184	0.0385	$\text{Li}_2\text{O}/\text{Be}$	0.2%	425	Compatibility
B14 / 5E	0.1273	0.118	0.0885	$\text{Li}_2\text{ZrO}_3/\text{Be}$	2%	425	Compatibility
B15 / 5E	0.1271	0.1175	0.0548	LiAlO_2/Be	2%	425	Compatibility
B16 / 5E	0.1288	0.1194	0.0483	$\text{Li}_4\text{SiO}_4/\text{Be}$	2%	425	Compatibility
B17 / 5E	0.1269	0.1076	0.0346	$\text{Li}_2\text{O}/\text{Be}$	0.2%	425	Compatibility
B18 / 5E	0.1272	0.1182	0.0882	$\text{Li}_2\text{ZrO}_3/\text{Be}$	2%	425	Compatibility
B19 / 5E	0.1266	0.1176	0.0547	LiAlO_2/Be	2%	425	Compatibility
B20 / 5E	0.1262	0.1165	0.0451	$\text{Li}_4\text{SiO}_4/\text{Be}$	2%	425	Compatibility
B21 / 8B	0.1273	0.116	0.0389	$\text{Li}_2\text{O}/\text{Be}$	61%	440	Compatibility
B22 / 8B	0.1271	0.1186	0.0872	$\text{Li}_2\text{ZrO}_3/\text{Be}$	69%	440	Compatibility
B23 / 8B	0.1269	0.1175	0.0529	LiAlO_2/Be	95%	440	Compatibility
B24 / 8B	0.1282	0.1139	0.0458	$\text{Li}_4\text{SiO}_4/\text{Be}$	68%	440	Compatibility
B25 / 8B	0.1263	0.1183	0.0378	$\text{Li}_2\text{O}/\text{Be}$	0.2%	440	Compatibility
B26 / 8B	0.1271	0.1168	0.0877	$\text{Li}_2\text{ZrO}_3/\text{Be}$	2%	440	Compatibility
B27 / 8B	0.127	0.1187	0.0551	LiAlO_2/Be	2%	440	Compatibility
B28 / 8B	0.1276	0.1155	0.0473	$\text{Li}_4\text{SiO}_4/\text{Be}$	2%	440	Compatibility

In capsules B9 through B28, disks of beryllium are layered between samples of Li_2O , Li_4SiO_4 , Li_2ZrO_3 , and LiAlO_2 . The purpose of these capsules is to evaluate the effect of irradiation and burn up on the compatibility of these lithium ceramics and beryllium. Burn up and neutron dose are evaluated separately by the variation of enrichment in these samples. Samples in canister 8B are not expected to receive any significant neutron exposure or burnup and thus act as control samples.

Mechanical interaction test specimens were to have been irradiated in capsules B1, B2, and B3. However, it was not possible to arrive at a rational design in time for Cycle 11. Consequently, the mechanical interaction test specimens are deferred to Cycle 12 irradiations. The purpose of these specimens was to identify the compressibility of the swelling of Li_2O because it is anticipated that dilational creep can internally accommodate the unrestrained swelling previously observed. At first, the design of this specimen focused on almost isothermal specimens. But Li_2O does swell significantly at the low temperatures which are appropriate for cladding. Higher temperatures which initiate swelling in Li_2O are not appropriate for the cladding. A temperature gradient configuration such as the in-situ solid specimen is more appropriate. However, the high thermal expansion coefficient of Li_2O makes it necessary to very precisely configure the specimen geometry in order to differentiate swelling effects from thermal expansion effects. Thermal control experiments in the laboratory may be required to distinguish these effects.

2.3.6 Self-Powered Neutron Detector

The SPND chosen for the BEATRIX-II Phase I test uses rhodium as the sensitive element. This type of SPND is similar to the design used in earlier instrumented tests in the FFTF. The SPND will provide real time information on the local neutron flux near the vented canisters. For the Phase I test, the SPND has been mounted next to the ring specimen geometry canister. Instrumentation for the SPND will be mounted in the FFTF head compartment which is adjacent to the MOTA instrumentation penetrations through the reactor vessel.

2.3.7 Instrument and Control System

The I&C for the MOTA system will monitor the temperatures in the instrumented canisters and provide temperature control for the gas-gapped canisters, i.e. the ring specimen and some of the nonvented samples. Figure 12 shows the completed system ready for shipment to the FFTF site. The system is completely automated with both a primary subsystem and a secondary subsystem which is needed to assure uninterrupted operation. The computer automatically adjusts gas mixtures for each temperature. This system was operated in a simulation mode for 3 weeks before being shipped to FFTF for installation.

FIGURE 12. The Instrument and Control System (I&C) Before Shipment to FFTF (Neg. 88090660-3CN)

2.3.8 MOTA Assembly

Beyond the fabrication of the two BEATRIX-II in-situ recovery canisters, it is necessary to attach all of the other canisters to the central stalk with full instrumentation and to provide appropriate quality assurance. The fabrication and assembly of the entire fusion MOTA assembly is approximately 50% complete. Figure 13 shows the present status of the fusion MOTA irradiation vehicle assembly. All canister components have been fabricated and assembled into canisters. The test train which holds the canisters has been assembled and all canisters have been mounted to the test train. Assembly has started on the upper portions of the irradiation vehicle.

FIGURE 13. Fusion MOTA Test Vehicle Fabrication Status During December 1988
(Neg. 89010336-6CN)

2.4 TRITIUM HANDLING SYSTEM

The tritium handling system consists of a gas analysis system and a tritium removal system contained within a glovebox. The glovebox will be installed on the main operating deck of FFTF.

2.4.1 Glovebox Modifications

The glovebox provides the secondary containment for the tritiated sweep gas as it flows through the gas Analysis and tritium removal systems. The glovebox is shown in Figure 14 before significant modifications had occurred. The glovebox inner dimensions are 7 ft (wide) x 9 ft. (high) x 2.5 ft.(deep). This glovebox provides sufficient space for the equipment to be used in the Cycle 11 test and has some additional room which could be used for additional analytical systems required for the Cycle 12 test. The modifications to the glovebox included the fabrication of a base to hold the glovebox, the machining of penetrations for the gas and instrument leads, and the attachment of an airlock for transfer of equipment in and out of the glovebox. The glovebox system will provide the necessary environment to assure accurate instrument performance, preclude release of tritium into reactor containment, allow for equipment transfers into the glovebox, and minimize the release of tritium to CAPS, the reactor gas processing system. The glovebox will operate with a nitrogen atmosphere so as to avoid instrument calibration issues associated with the operation of instrumentation in other gases such as argon. The glovebox atmosphere will be continuously purged to CAPS at a rate of approximately 0.3 cu ft./min. to minimize the buildup of tritium and moisture in the glovebox. The glovebox is equipped with a refrigeration unit to maintain the instrument sensor temperatures within it. In Figure 15, the fabrication status of the glovebox during the Operating Agent's on-site review in early December 1988 is shown. Since to that review, all components except for the tritium removal system have been placed into the glovebox.

2.4.2 Glovebox Cleanup System

The glovebox is equipped with a glovebox cleanup system. This system consists of a molecular sieve to remove moisture, a metal getter system (SAES-ST198) to remove the tritiated gas, and a pump to circulate the glovebox atmosphere through the cleanup system. The system is sized to reduce the

FIGURE 14. Tritium Glovebox Before Being Modified for BEATRIX-II
(Neg. 88092966-5CN)

FIGURE 15. Tritium Handling System Including Glovebox and Data
Acquisition System During Operating Agent On-site Review,
During Early December 1988 (Neg. 88120736-22CN)

tritium concentrations in the glovebox atmosphere to levels below 1 mCi/m³. (Hydrogen must be present or introduced into the glovebox atmosphere to reach these tritium levels.) Cleanup of the glovebox atmosphere could take approximately 72 hrs. During this period the glovebox atmosphere would be isolated from the FFTF cell atmosphere processing system.

2.4.3 Gas Analysis System

The gas analysis system provides a parallel flow path for each canister's sweep gas in order to continuously measure both the total and tritium gas releases from each vented canister. The valving pattern for the analysis system for one canister is shown in Figure 16. During the operation of the test these valves will be operated only to take gas samples (calibration of the ion chambers) or to remove and repair any sensors which malfunction. The instrumentation required to operate the gas analysis system is shown in Figure 17.

2.4.4 Ceramic Electrolysis Cells

JAERI provided two CECs for the reduction of any moisture in the gas streams into tritium/hydrogen and oxygen gases. The two CECs were received by Westinghouse Hanford on July 18, 1988. These CECs were tested and calibrated during Dr. T. Kurasawa's visit to Hanford in September and October. The setup used to calibrate them is shown in Figure 18. During their testing and calibration, the optimum operating parameters were established. One of the CECs had developed a leak which was located near the ceramic-to-metal seal. JAERI shipped a replacement for use in the Cycle 11 test. Based on these results, we can anticipate the CECs to be approximately 95% efficient in converting any moisture in the gas stream to hydrogen/tritium and oxygen gas.

2.4.5 Inlet Monitoring and Control System

The inlet monitoring system (IMS) provides the source for the sweep gas used in the BEATRIX-II experiment and is shown in Figure 19. The design allows for as many as two different sweep gas compositions (reference and alternate) to be used simultaneously (one in each vented canister). The IMS also permits the oxygen concentration in the sweep gas to be checked before

FIGURE 16. Valving Pattern for the Gas Analysis System of BEATRIX-II
(Neg. 88112240-4CN)

FIGURE 17. Tritium Handling System Instrumentation Which Includes the Data Acquisition System (Neg. 88112240-3CN)

FIGURE 18. Testing of BEATRIX-II's Ceramic Electrolysis Cells from JAERI in October 1988 (Neg. 88090966-3CN)

FIGURE 19. Inlet Monitoring System in December 1988 (Neg. 88112240-2CN)

its use as a sweep gas which flows through the vented canisters. The IMS provides a gas purifier on each gas stream before the flow is sent to the inlet pressure control system.

The inlet pressure control system (IPCS) provides inlet pressure control of each gas stream before to its insertion into the MOTA. The IPCS is shown in Figure 20. The moisture concentration in both gas streams is continuously monitored. The IPCS also serves the function of routing the different sweep gas compositions available into each of the vented canisters.

2.4.6 Tritium Removal System

The tritium removal system was designed and fabricated in Canada under the direction of the AECL. This system is shown in Figure 21 as it is being unloaded from the shipping crates. The system uses metal getter material (SAES 707) to remove the tritium from the sweep gas streams in the BEATRIX-II experiment. Dr. Miller measured detritiation factors with tritium for the SAES 707 getter and found factors greater than required by FFTF (2500). Each getter bed will be limited to less than 1000 Ci to facilitate burial and/or shipment and to avoid saturation. One valve was found missing from the system and was installed at Hanford. This system will provide a demonstration of sweep gas technology which could have direct applications to a fusion fuel cycle.

2.4.7 Tritium Ion Chambers

The ion chambers used in the gas analysis system were designed and fabricated by Canada under the direction of the AECL. These ion chambers were designed to provide both rapid response to changes in the tritium release rate and to provide the necessary accuracy for the anticipated tritium concentrations in the BEATRIX-II sweep gas lines. The active volume in these ion chambers is approximately 100 cm^3 so as to reduce the measurement time constant.

2.4.8 FFTF Installation

Progress has been made during the last year to ready the FFTF site for the installation of the BEATRIX-II experiment's glovebox. An area on the main entrance level of the reactor was identified and unused equipment

FIGURE 20. Inlet Pressure Control System in December 1988
(Neg. 88101939-1CN)

FIGURE 21. Photograph of Tritium Removal System in November 1988. Valve modifications were accomplished in December 1988. (Neg. 89010438-4CN)

removed to make room for the THS. The routing path for the sweep gas lines has been identified and work has been initiated in laying these gas lines into FFTF. The bases for the THS instrument racks have been welded to the FFTF floor. The MOTA I&C system has been mounted onto its base in FFTF and the IMS has been shipped to FFTF for installation.

2.4.9 BEATRIX-II Data Acquisition System

The data acquisition system (DAS) is designed to record the necessary data channels, provide operational information, and provide alarm condition indications to FFTF. The system consists of a dual computer system where each computer can operate as the primary system if the other computer should fail. This system was shown in Figure 15 mounted with the instrumentation for the gas analysis system. The DAS has the capability of recording up to 60 channels of data every 10 seconds. This capability is readily expandable to over 300 channels if required for Cycle 12. In performing its operational

to over 300 channels if required for Cycle 12. In performing its operational function, it provides the operator the capability of monitoring the various channels coming into the computer, and it keeps a running log on the accumulated tritium in each of the various trapping sites for tritium within the sweep gas system. Should an abnormal condition arise, the computer activates an alarm in the control room in FFTF to indicate the system is not performing as designed.

2.5 DATA ANALYSIS

Data from the BEATRIX-II experiment will be compiled at FFTF on a Hewlett Packard computer, i.e the Data Acquisition System. It will then be transferred to an IBM personal computer at PNL where it will be broken into run files and distributed by either disk or MFE network to the working group members for analysis. A test data set was sent to JAERI to confirm the compatibility of these systems with JAERI hardware. It is anticipated that the participants will individually analyze the resulting data and then meet to collaborate on the conclusions to be made from these results.

Data Channels for BEATRIX-II are given in Table 8. Data is broken chronologically into runs as changes are made to the operating environment. In Table 9, a projection of parameter changes are presented for the first 100 EFPD of operation. Parameters to be changed include the temperature, flow rate, and sweep gas composition. Because each run will be continued until steady-state tritium release is observed, an exact time based schedule cannot be arrived at before irradiation. Flexibility in establishing the next run is required to take advantage of the results obtained. FFTF is expected to run at full power for three 100 EFPD periods except for the initial startup sequence, power coefficient testing (down to 75% power), and reactivity feedback testing (down to 75% power). The latter two events are short in duration, i.e., less than one day.

At the beginning and end of each 100 FFPD period (runs 11A, 11B, and 11C) sampling chambers will be removed from the gas analysis system and analyzed in order to calibrate the ionization chambers.

TABLE 8. Experimenter BEATRIX-II Channels

Subject	Measurement	Location	Channel No.
BEATRIX-II Analysis System Data Channels			
1.0 General			
Reactor	Time	PST	0
Reactor	Flux (SPND)	Level I	35
Reference Gas	Moisture	Inlet	3
Alternate Gas	Moisture	Inlet	4
Ring Sweep Gas	Pressure	Inlet	1
Solid Sweep Gas	Pressure	Inlet	2
2.0 Ring Specimen			
2.1 General			
Sweep Gas	Pressure	Outlet	11
Sweep Gas	Flow Rate	Outlet	17
Sweep Gas	Moisture	Outlet	5
Li ₂ O	Temperature	OD	47
Li ₂ O	Temperature #1	ID	48
Li ₂ O	Temperature #2	ID	49
2.2 CEC Line			
Sweep Gas	Flow Rate	CEC Line	18
Sweep Gas	Tritium Conc	CEC Line	1001
2.3 Mol Sieve Line			
Sweep Gas	Flow Rate	MS Line	19
Sweep Gas	Tritium Conc	MS Line	1002
3.0 Solid Specimen			
3.1 General			
Sweep Gas	Pressure	Outlet	12
Sweep Gas	Moisture	Outlet	8
Sweep Gas	Flow Rate	Outlet	20
Li ₂ O	Temperature	OD	44
Li ₂ O	Temperature #1	ID	45
Li ₂ O	Temperature #2	ID	46
3.2 CEC Line			
Sweep Gas	Flow Rate	CEC Line	21
Sweep Gas	Tritium Conc	CEC Line	1003
3.3 Mol Sieve Line			
Sweep Gas	Flow Rate	MS Line	22
Sweep Gas	Tritium Conc	MS Line	1004
4.0 Tritium Handling System Parameters			
Sweep Gas	Pressure	Exit Solid System	23
Sweep Gas	Pressure	Exit Ring System	24
Getter Bed	Temperature	TRS #1	37

TABLE 8. (contd)

<u>Subject</u>	<u>Measurement</u>	<u>Location</u>	<u>Channel No.</u>
Getter Bed	Temperature	TRS #2	38
Getter Bed	Temperature	TRS #3	39
Exhaust Gas	Tritium	Outlet TRS	1006
Exhaust Gas	Tritium	Inlet TRS	1005
Exhaust Gas	Pressure	Outlet TRS	25
Ring Specimen	Temperature	CEC	50
Ring Specimen	Temperature	CEC	51
Sweep Gas	CEC Potential	Ring Specimen	13
Sweep Gas	CEC Current	Ring Specimen	14
Sweep Gas	Moisture	Ring Specimen	
		After CEC	6
Sweep Gas	CEC Potential	Solid Specimen	15
Sweep Gas	CEC Current	Solid Specimen	16
Sweep Gas	Moisture	Solid Specimen	
		After CEC	9
Sweep Gas	Moisture	Solid Specimen	
		After MS	10
Sweep Gas	Moisture	Ring Specimen	
		After MS	7
Solid Specimen	Temperature	CEC	52
Solid Specimen	Temperature	CEC	53
Glove Box	Pressure-	Control	26
	differential		
Glove Box	Pressure-	Measurement	27
	differential		
Glove Box	Pressure-absolute	Measurement	28
Glove Box	Argon Flow	Inlet	29
Glove Box	Tritium	Monitor	30
Glove Box	Tritium	Range 0	31
Glove Box	Tritium	Range 1	32
Glove Box	Tritium	Range 2	33
Glove Box	Moisture	Monitor	34
Glove Box	Temperature	Getter Bed	40
Glove Box	Temperature	Inlet	41
Glove Box	Temperature	Outlet	42
Glove Box	Temperature	Static	43

TABLE 9. BEATRIX-II, Cycle 11, Preliminary Test Scenario

<u>Run ID</u>	<u>Power</u>	<u>Ring Specimen Temp (°C)</u>	<u>Ring Specimen Gas/Flow(cc/m)</u>	<u>Solid Specimen Gas/Flow(cc/m)</u>	<u>Comments</u>
11-1a	0 to 100	450/575	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 Moisture Cleanup Calibration
11-2	100	625	0.1%H ₂ /200	0.1%H ₂ /100	
11-3	100	625	0.1%H ₂ /100	0.1%H ₂ /800	
11-4	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-5	100	625	0.1%H ₂ /50	0.1%H ₂ /50	
11-6	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-7	100	625	0.01%H ₂ /100	0.1%H ₂ /100	
11-8	100	625	0.1%H ₂ /100	0.01%H ₂ /100	
11-9	100	625	0.0%H ₂ /100	0.1%H ₂ /100	
11-10	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-11	100	550	0.1%H ₂ /100	0.1%H ₂ /100	
11-12	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-13	100	500	0.1%H ₂ /100	0.1%H ₂ /100	
11-14	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-15	100	450	0.1%H ₂ /100	0.1%H ₂ /100	
11-16	100	625	0.1%H ₂ /100	0.1%H ₂ /100	
11-17					Establish RR Calibration

2.6 TRITIUM SYSTEMS TEST ASSEMBLY INTERFACE

The TSTA at Los Alamos National Laboratory is intended to demonstrate the safe and effective processing of tritium in fusion facilities. To this end, Dr. J. L. Anderson, TSTA project manager, has proposed (see Appendix IV) that tritium removed by the BEATRIX-II tritium removal system be transferred to TSTA instead of the original plans for burial as tritiated waste.

The proposal is to be considered by the Working Group in a meeting on February 1989. The proposal has merit in terms of the overall fuel cycle of a fusion facility, i.e. the demonstration of tritium production all the way from sweep gas recovery from a solid breeder blanket to processing of a usable DT fuel. With this combination of facilities, a model of the overall blanket tritium processing can be obtained.

2.7 PLANNED ACTIVITIES

The planned activities for the Phase I (Cycle 11) test in calendar years 1989 and 1990 are shown in Table 10. Assembly of the fusion MOTA-2A will be completed in February 1989 and the vehicle shipped to FFTF. Installation of the MOTA I&C system and the tritium handling system into FFTF will be occurring in January and February 1989. The checkout of these systems will occur in March and April 1989. The checkout of the tritium handling system will include a test with tritium gas to confirm the response of the gas analysis and tritium removal systems. Irradiation of the fusion MOTA is scheduled to begin in April 1989.

TABLE 10. BEATRIX-II Phase I, Cycle 11, Planned Activities

<u>Major Tasks</u>	<u>CY 1989</u>				<u>CY 1990</u>	
	<u>(10C)</u>	<u>(11A)</u>	<u>(11B)</u>	<u>(11C)</u>	<u>(12A)</u>	<u>(12B)</u>
FFTF Cycles						
MOTA Assembly						
Vehicle Assembly	—Δ					
Specimen Loading	—Δ					
Ship to FFTF	Δ					
MOTA I&C System						
FFTF Installation	—Δ					
Acceptance Checkout	—Δ					
Tritium Handling System						
FFTF Installation	—Δ					
Acceptance Checkout	—Δ					
Irradiation						
Postirradiation Examination						

5.7 PLANNED ACTIVITIES

The planned activities for Year 1 (Cycle II) test in calendar years 1988 and 1989 are shown in Table 5.1. Assembly of the fusion WTA-2A will be completed in February 1988 and the vehicle shipped to FTRF. Installation of the WTA-2A system and the fusion handling system then FTRF will be occurring in January and February 1988. The checkout of these systems will occur in March and April 1988. The checkout of the fusion handling system will occur in May with the fusion gas to confirm the response of the gas analysis and fusion removal system. Irradiation of the fusion WTA-2A is scheduled to begin in May 1989.

TABLE 5.1. PLANNED ACTIVITIES - Cycle II, Year 1

Activity	1988	1989
WTA-2A Assembly	Jan - Feb	
Vehicle Assembly	Feb - Mar	
System Loading	Mar - Apr	
Shipment to FTRF	Apr - May	
WTA-2A System	May - Jun	
FTRF Installation	Jun - Jul	
System Checkout	Jul - Aug	
Fusion Handling System	Aug - Sep	
FTRF Installation	Sep - Oct	
System Checkout	Oct - Nov	
Irradiation	Nov - Dec	
Post Irradiation Examination	Jan - Feb	

3.0 PHASE II, CYCLE 12, PROPOSALS

The scope and estimated cost of the BEATRIX-II, Phase II, Cycle 12 irradiation was not exactly defined in ANNEX-III. It is anticipated that the scope will be defined in a meeting of the BEATRIX-II Working Group on 13-14 February 1989. As in Cycle 11, IEA's partners (U.S. Fusion and Monbusho) are anticipating that 33% of the funding and available in-core space (10 canisters) will be associated with BEATRIX-II.

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APPENDIX I

ANNEX-III

FAST FLUX NEUTRON IRRADIATION OF CANDIDATE FUSION

BREEDER BLANKET MATERIALS

(Subject to final approval of the Executive Committee)

IEA Implementing Agreement on a Programme of Research and Development on
Radiation Damage in Fusion Materials

ANNEX III January 29, 1988

FAST FLUX NEUTRON IRRADIATION OF CANDIDATE FUSION BREEDER BLANKET MATERIALS

1. Background and Objective

- (a) Background. Following the successful pursuit of Breeder Exchange Matrix ("BEATRIX-I"), it is necessary to continue the collaborative effort to measure and evaluate the neutron irradiation effects, tritium release, and thermal properties of candidate fusion breeder blanket materials in a high flux, fast neutron environment ("BEATRIX-II"). The Fast Flux Test Facility ("FFTF") at Hanford, Washington, a multipurpose research reactor operated by the Westinghouse Hanford Company for the United States Department of Energy ("USDOE"), shall be used as the source for neutron irradiation of the candidate materials. In order to perform the planned experimental task, Materials Open Test Assemblies ("MOTAs") shall be specially designed, built, and operated as irradiation vehicles to be inserted into FFTF.
- (b) Objectives. The objectives of this Task are to collaborate in:
- (i) The overall planning, design, fabrication, and assembly of the MOTA tritium system;
 - (ii) The formulation of the experimental matrix;
 - (iii) The fabrication, insertion, and irradiation of the MOTAs in FFTF;
 - (iv) The disassembly of the MOTAs;
 - (v) The postirradiation examination at FFTF and other sites; and
 - (vi) The reporting of results.

2. Means

- (a) Programme. Cooperation between the Participants in this Annex (referred to in this Annex as the "Participants") in the activities to be conducted under this Annex shall include:
- (i) The testing of candidate solid breeder materials in a fast neutron environment, including temperature, time and burn-up variations, to study the effects of this environment on material behavior, chemical stability, in particular, tritium trapping and swelling;
 - (ii) The evaluation by continuous monitoring of the tritium release, thermal conductivity and temperature stability of these materials, up to high burn-up levels of the lithium isotopes;
 - (iii) The evaluation of the compatibility of these materials with the surrounding structures; and
 - (iv) This Task consists of the Phases I and II. Phase I is scheduled to begin with Cycle 11 of FFTF in U.S. FY 1989 and

continue through Phase II, FFTF Cycle 12 which is planned to conclude in U.S. FY 1991. Schedules for sample preparation and MOTA design and construction shall be consistent with the initiation of Cycles 11 and 12; schedules for postirradiation testing shall be consistent with the conclusion of those cycles. Subsequent testing may be considered by the Participants.

- (b) Working Group. The Participants shall establish a Working Group to be composed of one representative designated by each Participant. In addition, each Participant may have additional technical advisers attend the meetings of the Working Group, including persons from appropriate facilities. The Working Group, which shall be convened by the Operating Agent at least annually or at intervals mutually agreed upon, shall report to the Executive Committee through the Operating Agent. Decisions of the Working Group shall be made by unanimity except that where unanimity is not achieved, each Participant's representative on the Working Group shall be entitled to have his views presented to the Executive Committee. The Working Group will act as a steering committee for the conduct of the Task and will be responsible for the preparation and supervision of the budget, schedule and scientific activities of the Task. The Working Group shall develop a Program of Work and Budget which the Participants shall review and recommend to their respective authorities and to the Executive Committee for approval. This Work Plan will cover the full term of this Task supplemented annually with updated details of the budget, schedule, and scientific activities for the next twelve month period. The Program of Work and Budget shall also specify the contributions to be provided by each participant. (c) Task Manager. The Operating Agent shall appoint a Task Manager who shall be responsible to the Operating Agent in coordination with the Working Group for the conduct of the work under this Task as specified in the Program of Work and Budget.

3. Responsibilities of the Participants and the Working Group

- (a) Exchange of Information. Each Participant shall provide to the Operating Agent for transmission to the Working Group information dealing with neutron irradiation effects, tritium release and thermal properties of candidate fusion breeder blanket materials in a high flux, fast neutron environment. Based on such information, the Working Group shall review and adopt a common technical framework to be utilized in the work of each Participant undertaken pursuant to this Annex.
- (b) Reference Materials. Each Participant shall provide to the Operating Agent for transmission to the Working Group information dealing with reference materials for neutron irradiation effects, tritium release and thermal properties of candidate fusion breeder blanket materials in a high flux, fast neutron environment. Using this information the Working Group shall adopt reference materials to provide a common basis for comparison of experimental results in these areas.

- (c) Resulting Information. The Participants shall exchange information on neutron irradiation effects, tritium release and thermal properties of candidate fusion breeder blanket materials in a high flux, fast neutron environment arising from this Task.
- (d) Symposia. The Participants shall arrange symposia when mutually agreed to discuss selected topics in neutron irradiation effects, tritium release and thermal properties of candidate fusion breeder blanket materials in a high flux, fast neutron environment.
- (e) Assignment of Experts. The Participants shall assign experts in neutron irradiation effects, tritium release and thermal properties of candidate fusion breeder blanket materials to the Pacific Northwest Laboratories of USDOE (the site of FFTF), and if necessary, to other facilities of the Participants in accordance with agreements between the concerned Participants. The procedures to be followed in assigning experts shall be as follows:
 - (1) Each Participant desiring to assign an expert shall through the Operating Agent submit its nomination to the Participant in whose country the facility is located (the Recipient Participant), as a rule, at least four months prior to the expected assignment date. Each such nomination shall specify the qualifications of the expert, his work during the assignment and the length of the assignment. The Recipient Participant shall, as soon as possible, notify the nominating Participant of the acceptability of the assignment. The nominating Participant and the Recipient Participant shall, in consultation with the Operating Agent, as required, attempt to reach agreement upon the specific terms applicable to such assignments, after which the assignments may be implemented;
 - (2) The duration of each assignment shall normally be one year, except as may otherwise be agreed between the concerned Participants;
 - (3) Publication resulting from theoretical or experimental investigation carried out in connection with this Annex and the assignment hereunder shall normally be issued in the form of joint reports of the concerned Participants or individuals who contributed to the investigation;
 - (4) All personal expenses associated with an assignment shall be borne by the assigning Participant. Such expenses shall include, but not be limited to, costs of salary, travel, insurance and living expenses of the assigned personnel. Assigned personnel shall in no way be deemed to be employees of the Recipient Participant by virtue of this assignment. Assigned personnel shall adhere to all safety and other operating procedures of the Recipient Participant;
 - (5) The Recipient Participant or its contractor shall provide office space and related administrative support and facilities and access to laboratory space, shops, and equipment which are required to carry out the agreed assignment. The Recipient Participant will provide assistance and advice to assignees and their families in regard to housing, community services, and general familiarization with the community;

- (6) The assigning Participant agrees to indemnify and hold harmless the Recipient Participant, its contractor, and any person acting on their behalf for any damages, liabilities, or costs arising out of gross negligence or willful misconduct of personnel assigned under an agreement entered into in accordance with the provisions of this Annex; provided, however, that this provision shall not apply to damages, liabilities, or costs insofar as and to the extent that they arise out of gross negligence or willful misconduct of the Recipient Participant, contractor, or persons acting on their behalf;
 - (7) Each expert on assignment may be accompanied by instrumentation or other such equipment necessary as part of his assignment to assist in data collection or diagnosis of experiments. The terms and conditions for transportation and use of such instrumentation and equipment shall be agreed upon in writing between the concerned Participants. USDOE shall confirm to US customs authorities that the equipment provided by Participants is of a scientific character and not of a commercial character. USDOE shall make its best effort to obtain tax-free clearance from US customs authorities for such equipment.
- (f) Further Cooperation. The Working Group shall, through the Operating Agent, recommend to the Participants other joint cooperative efforts, including experiments. On the basis of such recommendations, the Participants shall decide upon further joint activities.

4. Specific Responsibilities of the Working Group

In addition to the responsibilities mentioned above, the Working Group shall assist the Operating Agent in providing periodic technical reports and a final scientific report on the progress of work under this Annex to all Participants as well as supervising the preparation of the Program of Work and Budget. A Chairman selected by the Working Group shall also attend the meetings of the Executive Committee. The Working Group shall be responsible for the overall management of the work under the Annex.

5. Information and Intellectual Property

- (a) Executive Committee's Powers. The publication, distribution, handling, protection and ownership of information and intellectual property arising from activities conducted under this Annex shall be determined by the Executive Committee, acting by unanimity, in conformity with this Agreement.
- (b) Right to Publish. Subject only to the patents and copyright restrictions of this Annex, the Participants in this Annex shall have the right to publish all information provided to or arising from this Annex except proprietary information, but they shall not publish it with a view to profit, except as agreed by the Executive Committee, acting by unanimity. Neither the Participants nor personnel designated by them shall introduce into this Task any proprietary

information unless such information is specifically identified and the terms and conditions for its introduction are agreed upon in writing by the concerned Participants.

- (c) Proprietary Information. The Participants shall take all necessary measures in accordance with this Annex, the laws of their respective countries and international law to protect proprietary information. It is recognized that certain information made available to the Task may include industrial property of a proprietary nature. Such property, which may include trade secrets, inventions, patent information and "know-how", and which was acquired by a Participant prior to or outside the course of activities conducted under this Task shall be defined for the purposes of this Task as information which:
- (1) Is of a type customarily held in confidence by commercial firms;
 - (2) Is not generally known or publicly available from sources other than the Programme;
 - (3) Has not previously been made available to others by the Participant supplying it except under an agreement protecting its confidentiality; and
 - (4) Is not already in the possession of the recipient Participant or its contractor.

It shall be the responsibility of each Participant supplying proprietary information to identify the information as such and to ensure that it is appropriately marked.

- (d) Information. Each Participant agrees to provide to the other Participants and to the Operating Agent all information utilized in the activities under this Annex. All information developed in connection with and during activities carried out under this Annex (arising information) shall be provided to each Participant and to the Operating Agent by the Participant performing the work, subject only to the need to retain information concerning patentable inventions in confidence until appropriate action can be taken to protect the rights to such inventions in accordance with paragraph (e) below. Reports containing arising information and pre-existing information necessary for and used in the activities under this Annex, including proprietary information in accordance with paragraphs (b) and (c) above, shall be provided to the Operating Agent and to the Participants by the Participant performing the work. The Operating Agent shall provide summary reports of work performed under this Annex and arising information therefrom, other than proprietary information, if any, to the Executive Committee. In addition, the Operating Agent shall provide management reports to all Participants on a quarterly basis and to the Executive Committee and the agency on an annual basis. The management reports shall include an accounting of task funds for the previous period. Information regarding inventions on which patent protection is to be obtained by the Participants shall not be published or publicly disclosed by the other Participants or the Operating agent until a patent application has been filed, provided, however, that this restriction on publication or disclosure shall not extend beyond six months from the date of receipt of such information. It shall be the responsibility of the inventing Participant to

appropriately mark reports which disclose inventions that have not been appropriately protected by the filing of a patent application.

- (e) Licensing of Inventions. With respect to any invention or discovery made or conceived in the course of or under this Annex:
- (1) If made or conceived by personnel of one Participant (the Assigning Participant) or its contractors while assigned to the other Participant (Recipient Participant) or its contractors in connection with exchanges of scientists, engineers and other specialists:
 - (i) The Recipient Participant shall acquire all right, title and interest in and to any such invention or discovery in its own country and in third countries, subject to a non-exclusive, irrevocable, royalty-free license in all such countries to the Assigning Participant, and to its nationals designated by it;
 - (ii) The Assigning Participant shall acquire all right, title and interest in and to any such invention or discovery in its own country, subject to a non-exclusive, irrevocable, royalty-free license to the Recipient Participant, and to its nationals designated by it.
 - (2) If made or conceived during the course of or under this Annex by personnel of a Participant other than in accordance with subparagraph (1), the Participant making the invention shall acquire all right, title and interest in and to any such invention or discovery in all countries, provided however that the other Participants and its nationals designated by it shall be granted a non-exclusive, irrevocable, royalty-free license in all other countries.
- (f) Copyright. Each Participant may take appropriate measures necessary to protect copyrightable material generated under the Task. Copyrights obtained shall be the property of that Participant, provided, however, that Participants may reproduce and distribute such material, but shall not publish it with a view to profit.
- (g) Inventors and Authors. Each Participant shall, without prejudice to any rights of inventors or authors under its national laws, take all necessary steps to provide the cooperation from its authors and inventors required to carry out the provisions of this paragraph. Each Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the laws of its country.
- (h) Determination of "National". The Participants may establish guidelines to determine what constitutes a "national" of a Participant provided, however, in recognition of the fact that all fusion power research and development programmes of the individual Member States of the European Atomic Energy Community (EURATOM) are carried out jointly in the framework of EURATOM, and that EURATOM acts on behalf of itself and its fusion power research and development associated national organizations in the EURATOM Member States, and that Sweden and Switzerland are associated with the EURATOM Fusion Programme, the

countries referred to in this paragraph shall, with respect to EURATOM, be understood to be the countries of the Member States of EURATOM, Sweden and Switzerland.

6. Operating Agent

The Operating Agent for this Task shall be the United States Department of Energy. The Operating Agent shall perform all legal acts required to carry out the objectives of this Annex on behalf of the Participants, including the receipt, disbursement and accounting of funds and other contributions of the Participants required to perform the work of this Task. The Operating Agent shall prepare, verify, and distribute the minutes of the Working Group; shall assist personnel assignments as agreed by the Participants; and shall act as the central repository for all reports, publications and other information as collected and developed under this Annex, and shall be responsible for their distribution to all Participants and Members of the Executive Committee, and to others as directed by the Executive Committee. The cost for this administrative activity shall be funded from the Common Funds set forth in paragraph 7 below.

7. Funding

- (a) A common fund shall be established for this Task by the Participants. The annual amount of this fund shall be determined by the Participants on the basis of the annual Program of Work and Budget developed by the Working Group and approved by the Executive Committee for the purpose of funding the obligations of the Operating Agent for this Task under Article 6(b) of the Agreement. The Operating Agent is not obligated to proceed without an approved Program of Work and Budget and funding allocation.
- (b) The Participants will jointly fund the expenditures incurred by the Operating Agent in fulfilling its responsibilities for Phase I (FFTF Cycle #11) of this Task in accordance with the following Table of Contributions:

Table of Contributions
Planned for the IEA BEATRIX-II Phase I Experiment
(thousand US dollars)

<u>Participant /</u>	<u>Period</u>	<u>0</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>Total</u>
	<u>[US FY]</u>		<u>[1988]</u>	<u>[1989]</u>	<u>[1990]</u>	
Canada		0	78 + *	(39)	0	(117.+ *)
Japan		400**	443	(318)	(91)	(1252)
United States		180	524	(327)	(220)	(1251)
TOTAL						(2620) + *

Note: 1) The values shown in parenthesis are subject to the availability of appropriated funds for each Participant in future years.

Note (Continued)

- 2) The asterisk (*) indicates in-kind contribution in the form of expertise and experience in the design, construction and operation of experimental systems for tritium measurement and recovery.
 - 3) The double asterisk (**) indicates that the contribution shall be made before the end of March, 1988.
-

- (c) The expenditure is not expected to exceed 2 620 000 US Dollars at 1st January, 1988 price levels for the initial Phase (FFTF Cycle #11) and may not exceed such level except upon the unanimous decision of the Participants. If significant changes in price levels or in the scope of activities under this Task occur, the Participants, acting by unanimity, shall decide whether to adjust the Program of Work and Budget to the available funds or to increase the budget;
- (d) Contributions in kind or services may be accepted in lieu of cash. The value of any such contribution shall be fixed by the Participants, acting by unanimity, in the Executive Committee;
- (e) The contributions shall be made as provided in Article 6(b) and (g) of the Agreement at such times and in such amounts as shall be fixed by the Participants, acting by unanimity, in the Executive Committee.

8. Schedule

- (a) This Annex shall enter into force on March 1, 1988, and shall remain in force for a period of five years subject to the effectiveness of the Agreement. It may be extended by agreement of two or more Participants acting in the Executive Committee. Extensions shall apply only to those Participants who agree to the extension and who notify the IEA Secretariat of their decision to continue to participate.

9. Participation

- (a) The Contracting Parties which are the initial Participants in this Task are the following:
 - Atomic Energy of Canada, Limited (AECL)
 - The Japan Atomic Energy Research Institute (JAERI)
 - The United States Department of Energy (USDOE)

APPENDIX II

INTELLECTUAL PROPERTY OF BEATRIX-II PROGRAM

APPENDIX II

INTELLECTUAL PROPERTY OF BEATRIX-II PROGRAM

A patent disclosure was drafted by Roger Bauer entitled "Thermal Conducting Porous Layer." It describes the channeled nickel layer that surrounds the solid pellet specimen which allows the sweep gas to flow around the specimen and still allows heat to be dissipated radially away from the pellets.

APPENDIX III

DOCUMENTATION OF BEATRIX-II PROGRAM

APPENDIX III

DOCUMENTATION OF BEATRIX-II PROGRAM

Two papers were presented on BEATRIX-II at international conferences with proceeding forthcoming:

1. "A Fast Neutron, In-Situ Tritium Recovery Experiment on Solid Breeder Materials," G. W. Hollenberg, T. Kurasawa, H. Watanabe, S. E. Berk, I. J. Hastings, J. Miller, D. E. Baker, R. E. Bauer, and R. J. Puigh, Eighth topical Meeting on the Technology of Fusion Energy, October 9-13, 1988, Salt Lake City, Utah.
2. "BEATRIX-II: In-Situ Tritium Recovery from a Fast Neutron Irradiation of Solid Breeder Materials," R. J. Puigh, G. W. Hollenberg, T. Kurasawa, H. Watanabe, I. J. Hastings, J. M. Miller, S. E. Berk, R. E. Bauer, and D. E. Baker, 15th Symposium on Fusion Technology, 19-23 Sept 1988, Utrecht, the Netherlands.

Design documents necessary for irradiation in FFTF are as follows:

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

APPENDIX IV

TSTA PROCESSING OF BEATRIX-II TRITIUM

APPENDIX IV

TSTA PROCESSING OF BEATRIX-II TRITIUM

Proposal by TSTA for processing of BEATRIX-II gettered tritium.

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DATE: November 29, 1988
IN REPLY REFER TO: MST-3/TSTA-173-88
MAIL STOP: C348
TELEPHONE: (505) 667-1410
(FTS) 843-1410

Glenn W. Hollenberg
Battelle Pacific Northwest Laboratories
Battelle Boulevard
Richland, WA 99352

Dear Glenn:

I would like to propose that the BEATRIX II project consider the possibility that the tritium extracted from the solid breeder materials be sent to the Tritium Systems Test Assembly (TSTA) at Los Alamos for recovery. My understanding is that the extracted tritium will be collected in getter canisters with the intent of burying these canisters.

Since the getter material is regenerable it would be relatively straightforward for us to recover the tritium from these beds. We would need to know the history of the canisters, estimated quantities of hydrogen isotopes, including tritium, estimates of other species collected on the getter, and the total number of canisters to be used. We would then plan to regenerate the getters, collect the hydrogen isotopes, purify and separate the hydrogens using our plasma exhaust gas processing loop, thus demonstrating the applicability of the TSTA technology for this purpose. Based on our previous discussions, I estimate that the total quantity of tritium to be collected is about 7000 Ci. We would then use the tritium and canisters in our work at TSTA.

This recovery of tritium from the getter material would be done at no cost to BEATRIX II other than the cost of packaging and shipping the material to TSTA. I suspect that this cost would be no more than the cost of packaging the tritium contaminated getter for burial.

If there is interest in this proposal, I suggest that a meeting of key TSTA and BEATRIX II personnel could begin to work out the details on schedules, timing, and interfacing between BEATRIX II and TSTA.

I look forward to your response to this proposal and the opportunity for possible collaboration between TSTA and BEATRIX II.

Sincerely,

A handwritten signature in black ink, appearing to read 'James L. Anderson', with a stylized, flowing script.

James L. Anderson, Project Manager
Tritium Systems Test Assembly

JLA/dv

Cy: G. Haas, DOE/OFE
G. Nardella, DOE/OFE
S. Berk, DOE/OFE
E. Walker, DOE/AL
R. Linford, ADET/MFE
G. Wewerka, MST-DO
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