THE MONBUSHO/U.S. SHIELDED HFIR IRRADIATION EXPERIMENT: HFIR-MFE-RB-11J AND 12J (P3-2 AND P3-3) — M. L. Grossbeck, K. E. Lenox, and M. A. Janney (Oak Ridge National Laboratory), T. Muroga (National Institute for Fusion Science), D. W. Heatherly and K. R. Thoms (Oak Ridge National Laboratory)

SUMMARY

This experiment is a joint project between the Japanese Monbusho, the Japan Atomic Energy Research Institute, and the U.S. Fusion Energy Sciences Program. It is the first of a series of experiments using europium oxide as a thermal neutron shield to minimize transmutations in vanadium alloys and ferritic/martensitic steels. The europium oxide shields were developed using ceramic processing techniques culminating in cold pressing and sintering. This experiment, which is a prototype for future fast neutron experiments in the HFIR, contains approximately 3200 specimens of 18 different types. The experiment began operating at 300 and 500°C in February 1997 and is projected to attain its goal fluence of ~5 dpa in February 1998.

PROGRESS AND STATUS

Introduction

This experiment is a low exposure irradiation containing a large variety of specimens primarily for microstructural analysis and mechanical properties of a wide variety of materials. It consists of two irradiation vehicles, one at 300°C (HFIR-MFE-RB-11J) and the other at 500°C (HFIR-MFE-RB-12J). Vanadium transmutes to chromium by thermal neutron absorption with an absorption cross section of 80 barns. As a result, initially pure vanadium will contain 10% Cr after an exposure of 5 dpa in a HFIR reflector position. For the low activation ferritic-martensitic steels, transmutation of tantalum and tungsten, which have thermal absorption cross-sections of 25 and 19 barns, respectively, could significantly perturb alloy composition. To minimize these transmutation effects, a europium oxide shield was developed for this experiment that reduces the thermal flux by a factor of about 100.

To maintain controlled specimen temperatures and minimize radiative heat transfer, the specimens are held in carefully designed racks of aluminum alloy. The specimens had to be machined to close tolerances in order to fit into the racks and to achieve good thermal contact. Twenty-one thermocouples are positioned along the length of each capsule, some near the centerline, and the remainder toward the periphery of the holders. Temperature is maintained by surrounding the specimen chamber with an annulus of inert gas which can be varied in composition from pure helium to neon or argon, or a mixture of helium and one of the other gases. An automatic computer-controlled system uses an average thermocouple temperature for control and adjusts the gas mixture to maintain the design temperature.

Experiment Goals

The irradiation vehicles contain many varied experiments for fusion materials research. Only a few examples will be stated. Pressurized tubes of low Cr-Ti-vanadium alloys are being irradiated for the first time to evaluate irradiation creep in this alloy class. Pressurized tubes of ferritic/martensitic alloys are also included to evaluate the newer low-activation ferritic/martensitic steels. A large portion of the space is devoted to ceramic materials, including ceramic/metallic braze joints. Advanced SiC/SiC fiber composites using low-oxygen SiC are being irradiated to study irradiation-induced densification. Alumina and silicon nitride bend bars of different thicknesses are included to study size effects on fracture of irradiated ceramics. There is also a series of TEM disks with varying minor element chemistry to study the effects of transmutation on microstructure. Mechanical test samples of tensile, compact tension, and Charpy bars as well as bend bars are included to evaluate mechanical properties of several classes of alloys and ceramics. Table 1 presents the specimen loading by material and type of specimen.

Table 1. Specimen Loading for HFIR-MFE-RB-11J (300°C)

Alloy	PRZ Tubes JP/US	1.5 mm CVN (JP)	SS-J (JP)	DCT (JP/ US)	TEM (JP/ US)	U.S. SS-3	U.S. CVN	U.S. PCVN	Bend Bar 1 2x2x15mm (JP)	Bend Bar 2 1x2x15 (JP)	Bend Bar 3 0.5x2x15 (JP)	Bend Bar 4 .25x2x15 (JP)	Bend Bar 5 .6x1.4x9 (JP)	Bend Bar 7 0.7x1x10 (JP)	Bend Bar 8 3x2.5x25 (ORNL)	Fiber Bundle Tube 2od x 50mm	Thermal Diffusivity 10dx2mm (US)
JLF-1	5	9	8	5/2	15/0	10	5	5									
JLF-1B	4	9	5		6/0												
JLF-1Mn1	4	8	5		6/0												
JLF-1Mn2	4	8	5		6/0												
JLF-1LS			5														
JLF-1LM			5														
JLF-1LSM			5														
F82H	5	9	5		10/0												
Kimura (ferritic)					30/0												
ODSHK (ferritic)		9	5		6/0												
9Cr-2WVTa																	
V-4Cr-4Ti-.1Si(JP)			7		10/0												
V-4Cr-4Ti(JP)			7		10/0												
V-5Cr-4Ti(JP)			7		10/0												
V-4Cr-3Ti(JP)			7		10/0												
V-5Cr-3Ti(JP)			7		10/0												
V-5Cr-5Ti(JP)			7		10/0												
V-4Fe-4Ti-.1Si			7		10/0												
V-4Fe-4Ti			7		10/0												
V-4Fe-3Ti			7		10/0												
V-4Cr-4Ti-.1SiR			7		10/0												
V-4Cr-4Ti-SiAlY-x			40		50/0												
V-4Cr-4Ti 832665 (Partial rxl)					0/3	3		4									
V-4Cr-4Ti 832665 (Full rxl)					0/3	3											
V-5Cr-5Ti					0/4	3											
V-4Cr-4Ti-Si					0/4	3											
V-3Cr-3Ti					0/4	3											
V-6Cr-3Ti					0/4	3											
V-6Cr-6Ti					0/4	3											
V-4Cr-4Ti-B					0/4	3											
SiC/SiC					0/4	3									20		
SiC (B,Be,N)					6/0				3								
Al_2O_3					6/0				7	7	7	6					
AlN					6/0				4								
MgO/xAl_2O_3					6/0				3								
SiO_2									3								
TiCx					9/0												

Table 1. Specimen Loading for HFIR-MFE-RB-11J (cont'd)
(300°C)

Alloy	PRZ Tubes (JP)	1.5 mm CVN (JP)	SS-J (JP)	DCT (JP/ US)	TEM (JP/ US)	U.S. SS-3	U.S. CVN	U.S. PCVN	Bend Bar 1 2x2x15mm (JP)	Bend Bar 2 1x2x15 (JP)	Bend Bar 3 0.5x2x15 (JP)	Bend Bar 4 .25x2x15 (JP)	Bend Bar 5 .6x1.4x9 (JP)	Bend Bar 7 0.7x1x10 (JP)	Bend Bar 8 3x2.5x25 (ORNL)	Fiber Bundle Tube 2od x 50mm	Thermal Diffusivity 10dx2mm (US)
C/Cu Joints									8								
V/ceramics					6/0								6				
SiC Fiber																	
<u>Transmutation Series</u>																	
V			6		30/15												
V-xCr			6		40/20												
V-4Ti-4Cr			6		40/20												
Cu			4		20/20												
Cu-xNi-yZn			4		40/20												
Cu-xNi-yZnNi			4		40/20												
Fe			6		40/20												
Fe-W&Mn			6		30/15												
ODS			6		20/10												
Fe-Cr-Ni			6		30/15												
Fe-Cr-Ni-x			6		40/20												
316/TiN			6		30/15												
TiAl					10/5												
SiC					20/10												
Al, Al-Si					20/10												
Mo alloys					20/10									46			
Irradiated Cu alloys					9/0												
JAERI/U.S.																	
F82H (HT-1)				6	10	12	6	5									
F82H (HT-2)				2	10	8	5	5									
F82H Ni doped				2	10	5	5										
F82H weld				2	10	4	5										
F82H weldment				2		4	5										
F82H HAZ						4											
9Cr-2WVTa				2	10	6	5	5									
Ferritic Alloys TBD					50												

2 Temp Monitors
(Same as Ti)

Table 1. Specimen Loading for HFIR-MFE-RB-12J
500°C

Alloy	PRZ Tubes JP/US	1.5 mm CVN (JP)	SS-J (JP)	DCT (JP/ US)	TEM (JP/ US)	U.S. SS-3	U.S. CVN	U.S. PCVN	Bend Bar 1 2x2x15mm (JP)	Bend Bar 2 1x2x15 (JP)	Bend Bar 3 0.5x2x15 (JP)	Bend Bar 4 .25x2x15 (JP)	Bend Bar 5 .6x1.4x9 (JP)	Bend Bar 6 2x4x25 (PNL/ORNL)	Bend Bar 7 0.7x1x10 (JP)	Bend Bar 8 3x2.5x25 (ORNL)	Fiber Bundle Tube 2od x 50mm	Thermal Diffusivity 10dx2mm (US)
JLF-1	5/0	6	3	3/3	15/0	10	5	5										
JLF-1B	3/0	6	3		6/0													
JLF-1Mn1	3/0	6	2		6/0													
JLF-1Mn2	3/0	6	2		6/0													
JLF-1LS																		
JLF-1LM																		
JLF-1LSM																		
F82H	5/0	6	2		10/0													
Kimura (ferritic)					30/0													
ODSHK (ferritic)		6	2		6/0													
9Cr-2WVTa																		
V-4Cr-4Ti-.1Si(JP)			9		10/0													
V-4Cr-4Ti(JP)			9		10/0													
V-5Cr-4Ti(JP)			9		10/0													
V-4Cr-3Ti(JP)			9		10/0													
V-5Cr-3Ti(JP)			9		10/0													
V-5Cr-5Ti(JP)			9		10/0													
V-4Fe-4Ti-.1Si			9		10/0													
V-4Fe-4Ti			9		10/0													
V-4Fe-3Ti			9		10/0													
V-4Cr-4Ti-.1SiR			9		10/0													
V-4Cr-4Ti-SiAlY-x			40		50/0													
V-4Cr-4Ti 832665 (Partial rxl)	0/6				0/3	3	5											
V-4Cr-4Ti 832665 (Full rxl)					0/3	3												
V-5Cr-5Ti					0/4	1												
V-4Cr-4Ti-Si					0/4	1												
V-3Cr-3Ti					0/4	2												
V-6Cr-3Ti					0/4	2												
V-6Cr-6Ti					0/4													
V-4Cr-4Ti-B					0/4	2												
SiC/SiC														24		10		7
SiC (B,Be,N)					6/6				9									
Al_2O_3					6/0				10	8	10	10	1					
AlN					6/0				16									
MgO/xAl_2O_3					6/0				9									
SiO_2									3									
TiCx					9/0													

1 Temp Monitors
(Same as Ti)

Table 1. Specimen Loading for HFIR-MFE-RB-12J (cont'd)
500°C

Alloy	PRZ Tubes (JP)	1.5 mm CVN (JP)	SS-J (JP)	DCT (JP/ US)	TEM (JP/ US)	U.S. SS-3	U.S. CVN	U.S. PCVN	Bend Bar 1 2x2x15mm (JP)	Bend Bar 2 1x2x15 (JP)	Bend Bar 3 0.5x2x15 (JP)	Bend Bar 4 .25x2x15 (JP)	Bend Bar 5 .6x1.4x9 (JP)	Bend Bar 6 2x4x25 (PNL/ORNL)	Bend Bar 7 0.7x1x10 (JP)	Bend Bar 8 3x2.5x25 (ORNL)	Fiber Bundle Tube 2od x 50mm	Thermal Diffusivity 10dx2mm (US)
C/Cu Joints									8									
V/ceramics					6/0								19					
SiC Fiber																	10	
Transmutation Series																		
V			6		30/0													
V-xCr			4		40/0													
V-4Ti-4Cr			4		40/0													
Cu			4		20/0													
Cu-xNi-yZn			4		40/0													
Cu-xNi-yZnNi			4		40/0													
Fe			6		40/0													
Fe-W&Mn			6		30/0													
ODS			6		20/0													
Fe-Cr-Ni			12		30/0													
Fe-Cr-Ni-x			12		40/0													
316/TiN			12		30/0													
TiAl					10/0													
SiC					20/0													
Al, Al-Si																		
Mo alloys					20/0										59			
Irradiated Cu alloys					18/0													
JAERI/U.S.																		
F82H (HT-1)	8			6	10	11	6	5										
F82H (HT-2)				2	10	5	6	5										
F82H Ni doped				2	10	4	5											
F82H weld				2	10	4	5											
F82H weldment						4												
F82H HAZ						4												
9Cr-2WVTa				2	10	4	6	5										
Ferritic Alloys TBD					50													

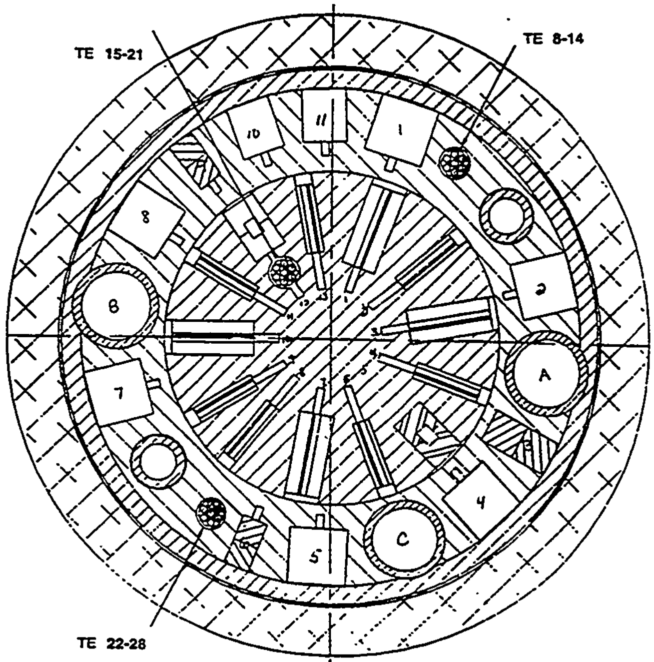
Specimen Loading Configuration

The specimens are loaded into round holes and square or rectangular slots along the longitudinal axes of the capsules. Figure 1 shows the center sections of the capsules identifying the holes and slots. The upper and lower sections of each capsule are shown in Fig. 2. In HFIR-MFE-RB-11J, which will be referred to as 11J, the upper and lower sections contain disc compact tension specimens (DCT). In HFIR-MFE-RB-12J, which will be referred to as 12J, the upper and lower sections contain Charpy v-notch specimens (CVN), bend bar specimens (BB), and DCT specimens. The overall geometry of the specimens is shown in Table 2.

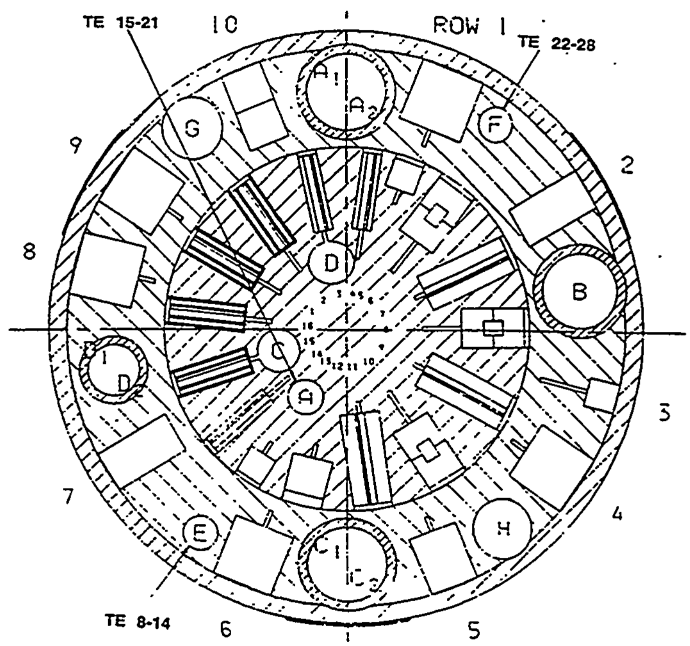
Table 2. Specimen Types and Overall Sizes
(The experimenter is the person who may be contacted to obtain drawings.)

Specimen Type	Designation	Overall Dimensions (mm)	Experimenter
Trans. Elect. Micros.	TEM	3 x 0.15-0.25	
Tensile	SSJ	16 x 4 x 0.25	Kohno
Tensile	SS-3	25 x 4.95 x 0.76	Grossbeck
Pressurized Tube		22.4 x 4.57 dia	Kohno
Compact Tension	DCT	9.6 dia x 3.93	Kimura
Compact Tension	DCT	12.5 dia x 4.62	Grossbeck
Charpy	1.5 CVN	20 x 1.5 x 1.5	Kohno
Charpy	CVN	25 x 3.33	Grossbeck
Bend Bar	BB1	15 x 2 x 2	Satou
Bend Bar	BB2	15 x 2 x 1	Satou
Bend Bar	BB3	15 x 2 x 0.5	Satou
Bend Bar	BB4	15 x 2 x 0.25	Satou
Bend Bar	BB5	9.0 x 1.4 x 0.6	Satou
Bend Bar	BB6	25 x 4 x 2	Satou
Bend Bar	BB7	10 x 1 x 0.7	Satou
Bend Bar	BB8	25 x 3 x 2.5	Snead
Fiber Tube	SiC Tube	48 x 2 dia	Satou
Thermal Cond.	TD	10 dia x 2	Satou

The specimen loading for the upper and lower sections of 11J is shown in Table 3. Tables 4 and 5 contain the specimen loading for 12J. Since specimens are loaded side by side in a given slot, two columns are allotted for each row (slot). As can be seen in Fig. 1, there is an inner and an outer specimen holder in the center section of each capsule. The two holders are separate and fit concentrically together very tightly so as not to impede radial heat transfer. The specimen loading for the 11J inner holder is given in Table 6. The specimens are listed top to bottom as

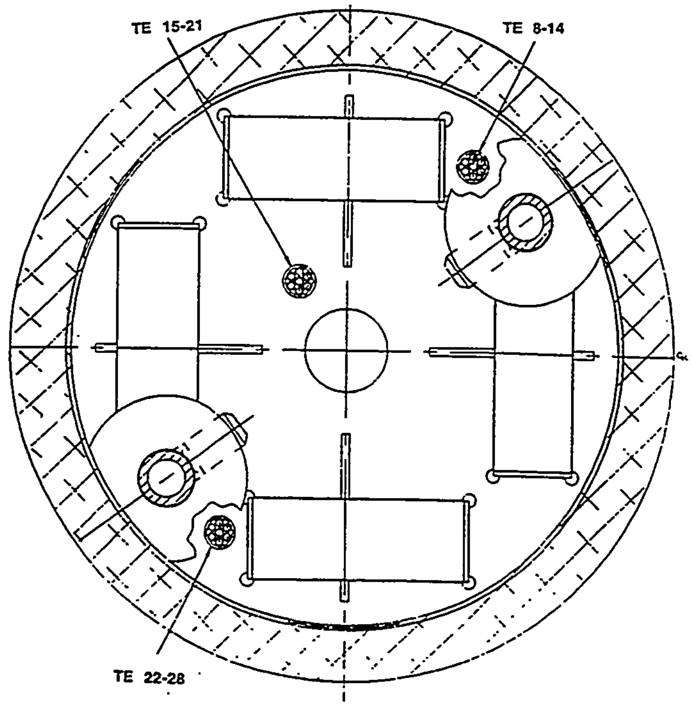


(A) HFIR-MFE-RB-11J

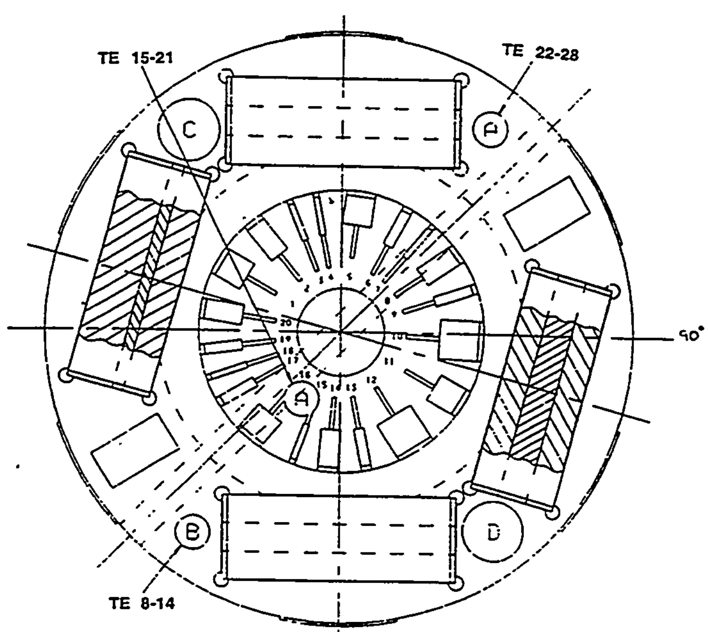


(B) HFIR-MFE-RB-12J

Fig. 1. Cross section through the central portion of the irradiation capsules indicating the designations for the holes and slots.



(A) HFIR-MFE-RB-11J



(B) HFIR-MFE-RB-12J

Fig. 2. Cross section through the end sections of the irradiation capsules.

Table 3. Specimen Loading for the End Sections of HFIR-MFE-RB-11J

Upper Section				
Specimen Type	**DCT**	**DCT**	**DCT**	**DCT**
Row	**1**	**2**	**3**	**4**
	Z106	LFV5	N202	FA13
	FA01	LFV4	TJO2	FA12
	M1	LFV3	TWO2	FA11
Lower Section				
	TWO1	LFW2	LFV2	FA10
	TJ01	LFW1	LFV1	FA09
	N201	FA00	Z105	FA08

Table 4. Specimen Loading for the Upper Section of HFIR-MFE-RB-12J

Upper Section									
Specimen Type	DCT		DCT, DT	TD	DCT, TD	TD	DCT, TD		1.5 CVN, BB1, BB2, BB3, BB4
Row	1		2		3		4		Inner
	M2	Spacer	B1	D2	P1	D1	P2	Spacer	LDW6
	TWO4		Z108		FA03		N204		DY59
	TW03		Z107		FA02		N203		DY73
									DY78
									LDW5
									DY92
									DY72
									DY56
									DY70
									DY41
									LHW2
									DY50
									DY71
									DY57
									DY35
									LDW4
									DY69
									DY36
									DY68
									DY58

Table 5. Specimen Loading for the Lower Section of HFIR-MFE-RB-12J

Lower Section									
	DCT	BB6	DCT		DCT		DCT	BB6	1.5 CVN, BB1-BB4
Row	1		2		3		4		Inner
	LFTF	D3	LFTH	Spacer	FA16	Spacer	FA19	D4	LHW1
	LFTD		LFTG		FA15		FA18		DY60
	LFTA		LFTB		FA14		FA17		DY74
									DY75
									LDW1
									DY28
									DY79
									DY63
									DY64
									DY42
									LDW3
									DY51
									DT66
									DY61
									DY76
									LDW2
									DY67
									DY65
									DY62

Table 6. Specimen Loading for the Central Inner Holder for HFIR-MFE-RB-11J

Center Section													
Inner Holder													
Row	1		2		3		4		5	6		7	
Specimen Type	SS-3		SS-J		SS-3		SS-4		BB5, BB7	SS-J		SS-3	
	FA12	FA11	AV52	AV46	70	70	LFV6	LFV7	D--5	F5AH	F4AR	TJ03	TJ04
	FA09	FA10	F2AG	F247	UC15	70	LFV4	LFV5	D--4	F5AK	F641	TW03	TW04
	FA07	FA08	AV53	AV44	ST05	ST06	LFV2	LFV3	D--3	TD74	F8AL	TW02	TW01
	FA05	FA06	F34M	F340	ZC13	ZC14	LFV1	LBV5	D--2	F7A9	F5A0	ZH40	ZH41
	A025	A026	AV38	AV41	UC13	UC14	LBV3	LBV4	D--1	TD90	F5A6	Z140	Z141
	A024	A023	AV50	AV48	XC15	ZC15	LBV1	LBV2	C--5	F4AB	TD73	Z142	Z142
	A022	A012	AV51	AV49	XC13	XC14	LDV4	LDV5	C--4	F5AL	F4AH	ST07	N205
	A010	A011	F4A1	F2A2	71	71	LDV2	LDV3	C--3	TD91	TD92	71	72
	A006	A008	AV15	AV43	72	71	LFV8	LDV1	C--2	F8A0	F4A9	ST03	ST04
	A002	A003	F4A3	F34R	72	72	GF38	GF39	C--1	F6AH	F7D0	ST01	STO2
			AV47	AV40			GF30	GF37	FY3	F6AM	TD75		
			AV39	AV37			L1V4	L1V5	FY2	F7AD	F6A6		
			AV54	AV42			L1V2	L1V3	FY1	TD76	F7B0		
			F2A8	FSA1			L1V1	L2V5	FV3	F5A7	F7A6		
			A2AF	F397			L2V3	L2V4	FV2	F6A4	F6A2		
			TD95	TD96			L2V1	L2V2	FV1	F7A1	TD72		
									E--2				
									E--1				
									B--3				
									B--2				
									B--1				
									A--5				
									A--3				
									A--2				
									A--1				
									A--4				
Row	8		9		10		11		12	13			
	SS-J		SS-J		SS-3		SS-J		BB7	SS-J			
	GB38	GB39	AL19	AA47	FK08	FK09	TA03	TD16	H--5	TD55	TD40		
	GA39	GA30	AF87	AL17	FK06	FK07	TD36	TD25	H--4	TD85	TD84		
	LHV1	LHV4	AF85	AF82	FK04	FK05	F8AG	TA00	H--3	TD52	TD65		
	LHV5	YD08	AF84	AF86	FK02	FK03	TD10	TD93	H--2	TD83	TD45		
	GD30	YD09	AF91	AF92	FK00	FK01	TD13	F8A7	H--1	TD54	TD63		
	AA41	YD04	AF90	AA44	TH04	TH05	TA04	TD30	F--3	TD41	TD43		
	AA39	YD10	AA45	AF79	TH02	TH03	TD94	TD23	F--3	TD56	TD82		
	AA37	YD06	AL16	AF81	TJ01	TJ02	F8AR	TD33	F--2	TD70	TD81		
	AA36	YD05	AL20	AA49	N203	N204	TA05	TD32	G--5	TD80	TD53		
	AA40	YD03	AF80	AF77	N201	N202	TA01	TD11	G--4	TD35	TD61		
	AA38	YD07	AA43	AA48			TD21	TA06	G--3	TD82	TD51		
	GD38	YD01	AF83	AA42			TD15	TA02	G--2	TD86	TD71		
	GB37	YD02	AL18	AA46			F8AH	TD26	G--1	TD50	TD64		
	LHV2	LHV3	AF89	AF88			TD12	TD24	J--5	TD46	TD44		
	GA38	GA37	AF78	AL15			TD22	TD14	J--4	TD42	TD86		
	GD37	GD39	AL14	AL13			TD26	TD31	J--3	TD60	TD34		
									J--2				
									J--1				
									F--4				
									E--3				
									F--5				
									I--5				
									I--4				
									I--3				
									I--2				
									I--1				

they are loaded in the capsules. As with the previous tables, specimens loaded side by side appear in adjacent columns under the same row number. Table 7 shows the loading for the outer holder of 11J. In cases where more than one type of specimen is loaded into one slot, all types are listed at the column head. The loadings for the inner and outer central holders for 12J appear in Tables 8 and 9, respectively.

As can be seen in Tables 7 and 9, the TEM specimens are in the outer holders of each capsule, all in one hole in each capsule. The TEM specimens are loaded in tubes with welded end caps and placed into the holes provided. The tubes are of various lengths up to 25 mm in length. Most of the tubes are aluminum with slots for ease of disassembly, but some are zirconium and are completely sealed for protection of vanadium alloys. The loading of the tubes is shown in Tables 10 and 11 for 11J and 12J, respectively. The Zr tubes are indicated below the tube designation. Tubes 1-1 and 2-1 contain radioactive specimens from a previous irradiation in the FFTF. The specimens are listed in the order loaded so that the bottom specimen is listed first. Multiple columns are used simply to accommodate the large number of specimens; all are loaded one on top of the other.

Thermal Neutron Shield

Development of the thermal neutron shield presented the most difficult challenge of the irradiation experiment. The first task was to select the absorber material for the shield. Most available thermal absorbers can be excluded. Hafnium has been used as a thermal neutron shield in flux tailoring experiments in the HFIR,[1] but in the space available, only a factor of ten attenuation can be achieved. Gadolinium and cadmium have such high cross sections that they burn too fast to achieve the required exposure. Boron can be made to last for the duration of the experiment, in this case about one year, especially since it may be enriched in the ^{10}B isotope. However, since the absorption reactions are (n, α), helium will collect in the shield container and produce a gas pressure of about 70 MPa, 10,000 psi, in the duration of the irradiation. This would necessitate using precious space for thick container walls. Europium can be used because the two isotopes initially present transmute into five additional isotopes of Eu and five isotopes of Gd, many of which have cross sections greater than 1000 barns. Thus each initial atom of Eu can ultimately absorb several neutrons.

Having chosen Eu for the absorber, many restrictions involving practicality and reactor safety must be considered. Europium is a very reactive metal necessitating glove box handling. Because of the reactivity and the fact that the atomic density of monoclinic Eu_2O_3 is 30% higher than Eu metal, europium oxide was selected as the absorber material. Europium oxide reacts with water to form a hydroxide which causes disintegration of the physical structure and swelling of about a factor of two. In the case of a leak in the can containing the shield, Eu_2O_3 could escape, and the can could swell and prevent removal from the reactor.

For the first line of defense, a shield can was designed such that two independent welds would have to fail in order to produce a leak. The design of the welds is illustrated in Fig. 3. In the event of a leak, a packed powder of Eu_2O_3 (which could easily be packed to 50% of theoretical density) would allow percolation of water and swelling in a matter of a few days at 70°C. To provide a second line of defense, the Eu_2O_3 was sintered to 92% of theoretical density to reduce percolation of water. In addition, the Eu_2O_3 was coated with aluminum to provide a water resistant coating.

A shield 413 mm in length was required to cover the specimen region of the capsule, but in order to reduce the shield to manageable sections, rings 25 to 50 mm in length were fabricated. The thickness of the rings was 1.85 mm and the outside diameter was 48.3 mm. A step 0.76 mm in length and of half the wall thickness was machined on each end in order to avoid neutron streaming through the cracks between the rings when stacked together. Several completed rings are shown in Fig. 4.

Table 7. Specimen Loading for the Central Outer Holder for HFIR-MFE-RB-11J

Center Section											
Outer Holder											
Row	1	2	3					4	5	6	
Specimen Type	CVN	CVN	BB1, BB2, BB3, BB4					CVN	CVN	1.5 CVN	
	A001	N201	Y605	Y606				QC61	TWO5	L1V1	L1V2
	A002	N202	DYO7	DY26	DY31	DY32	DY13	FK02	TWO4	L1V3	L1V4
	A003	N203	DY08	DY25	DY29	DY50	DY14	FK03	TWO3	L1V5	L1V6
	A004	N204	DY02	DY91				FK04	TWO2	L2V1	L2V2
	A005	FA42	DY09	DY21	DY22	DY15		A021	TWO1	L2V3	L2V4
	A006	FA49	DT01	DT04				A023	TJ15	L2V5	L2V6
	FA38	FA50	Y601	Y607				A024	TJ14	LFV1	LFV2
	FA39	FA51	DY38	DY40				A025	TJ13	LFV3	LFV4
	FA40	FA54	DY01	DY05				A026	TJ12	LFV6	LFV7
	FA41	FA55	DY37	DY39				QC62	TJ11	LFV8	LFV9
			Y602	Y604						LBV1	LBV2
			DT03	DT06						LBV3	LBV4
			DY10	DY23	DY24	DY16				LBV5	LBV6
			DT05	DY12							
			DY11	DY27	DY33	DY34	DY17				
			DY03	DY18	DY19						
			Y603	Y608							
Row	7	8	9		10	11	A	B	C		
	CVN	CVN	1.5 CVN		BB8	BB8	Pressurized Tubes	Pressurized Tubes	TEM Holders		
	FK34	QC64	LHV1	LHV2	917 T4	919 M2	LFVG	L8VF	1–2		
	FK33	N205	LHV3	LHV4	1–6 SIC	13–18 SIC	LFVF	LBVD	1–1		
	FK32	FK01	LHV5	LHV6	T13	942 T4	LFVD	LBVB	1–8		
	FK31	FK00	LHV7	LHV8	917 M4	19–24 SIC	LFVB	LBVA	1–9		
	FK30	145Z1	LHV5	LHV9	843 M2	942 M4	LFVA	L2VF	1–10		
	130Z1	144Z1	GF31	GF32	T11	917 T3	L2VA	L2VD	1–11		
	129Z1	143Z1	GF33	GF34	843 T4	919 M1	LHVG	L2VB	1–12		
	127Z1	142Z1	GF35	GF36	T7	943 M3	LHVF	L1VF	1–6		
	126Z1	138Z1	LDV1	GF37	7–12 SIC	25–30 SIC	LHVD	L1VD	1–5		
	125Z1	QC63	LDV2	LDV3	843 M1	919 T2	LHVB	L1VB	1–4		
			LDV4	LDV5			LHVA	L1VA			
			LDV6	LDV7							
			LDV8	LDV9							

Table 8. Specimen Loading for the Central Inner Holder for the HFIR-MFE-RB-12J

Center Section									
Inner Holder									
Row	1		2		3		4		5
	SS-J		SS-J		SS-J		SS-J		1.5 CVN
	TH61	TH56	F7F0	F6A8	AA87	AFJ7	AFL7	AFL2	LFW6
	TH46	TH74	F8AL	F7A5	AF72	AA90	AFL1	AFK5	LFW5
	TH73	TH71	F6AL	F5A4	AA97	AFJ8	AFL3	AFL8	LFW4
	TH58	TH63	F5AG	F4AF	AFK9	AA95	AFK3	AFL9	LFW3
	TH51	TH55	TB06	TB05	AA99	AA92	LDW2	AFL6	LFW2
	TH77	TH75	F4AM	F6A9	AF70	AFK1	LFW1	L2W2	LFW1
	TH66	TH72	TB00	TB03	AA94	AA98	LBW2	LHW2	LHW6
	TH80	TH64	TB07	TB04	AF75	AA96	L1W2	L2W1	L1W6
	TH53	TH62	F7AF	F8AM	AFJ0	AA89	LHW1	LFW3	L1W5
	TH47	TH54	F6A5	F7AA	AF71	AF67	L1W1	LBW1	L1W4
	TH48	TH76	F7G0	F6AD	AF76	AF73	LFW2	LDW1	L1W3
	TH60	TH57	F8AB	F8AD	AA91	AA88	AFK7	AFK8	L1W2
	TH50	TH70	F8A4	F7A2	AF74	AFJ9	AFM2	AFM1	L1W1
	TH81	TH65	TB01	TB02	AF69	AA93	AFL4	AFK6	
	TH67	TH52	F6AK	F8A9	AF68	AA86	AFL5	AFK4	
	TH45	TH78	AV99	AV98	AFK0	AFK2	AFL0	TH38	
Row	6	7		8	9		10	11	
	BB5, BB7	SS-3		BB7	SS-3		BB7	SS-3	
	FY6	N206	N207	G-+5	71	71	H-+3	TH06	TH07
	FY5	FA14	FA15	C-+3	70	70	A-+5	TW07	TW08
	FY4	A056	A055	I-+3	UC16	UC17	E-+4	TJ05	TJ06
	FX7	A038	A039	I-+4	ZC16	ZC17	D-+2	FK18	FK19
	FX6	A036	FA13	H-+5	ST10	ST11	M-+2	FK16	FK17
	FX5	A034	A035	D-+4	ST08	ST09	B--4	FK14	FK15
	FX4	A031	A033	H-+4	XC17	XC16	C-+2	FK12	FK13
	FX3	A029	A030	G-+2	TJ07	TJ08	A-+2	FK10	FK11
	FX2	FA16	FA17	F-+1	Z144	Z145	J-+1	TW05	TW06
	FX1	N208	N209	F-+5	Z146	Z147	D-+5	TH08	TH09
	G-+1			A-+3			B-+4		
	F-+1			H-+2			J-+2		
	E-+1			C-+4			E--4		
	D-+1			F-+2			B-+3		
	C-+1			C-+5			K-+1		
	B-+1			H-+1			E--5		
	A-+1			D-+3			B--5		
	FZ7			E-+5			I-+2		
	FZ6			J-+5			G-+3		
	FZ5			J-+4			M-+1		
	FZ4			G-+4			K-+2		
	FZ3			J-+3			K-+2		
	FZ2			E-+3			K-+3		
	FZ1			A-+4			E-+2		
	FVA			I-+1			B-+2		
	FVD			F-+4			B-+5		

Table 8. Specimen Loading for the Central Inner Holder for the HFIR-MFE-RB-12J (cont'd)

Center Section										
Inner Holder										
Row	12	13	14		15		16		C	D
	BB1	1.5 CVN	SS-J		SS-J		SS-J		SIC Tubes	SIC Tubes
	Blank	LBW6	TH92	TH88	TH31	TH23	AV92	AV95	J2	J20
	Blank	LBW5	TH84	TH93	TH17	TH35	AVB5	AVB6	J4	J12
	Y624	LBW4	TH98	TH87	TH33	TH41	AV00	AVB1	J6	J14
	Y623	LBW3	TH82	TH96	TH30	TH14	AVB3	AVB9	J8	J16
	Y622	LBW2	TH97	TH91	TH26	TH27	F2A6	F5A4	J10	J18
	Y621	LBW1	TH86	TH95	TH24	TH44	F2A5	F2AM		
	Y620	LHW5	TH90	TH94	TH25	TH20	F5AD	F2AR		
	Y619	L2W6	TH85	TH83	TH36	TH32	F4A5	F4A6		
	Y618	L2W5	YD13	YD12	TH21	TH18	F349	F4A2		
	Y617	L2W4	YD16	YD17	TH11	TH28	F2AK	F4A7		
	Y615	L2W3	YD14	YD18	TH42	TB08	F346	F2A3		
	Y614	L2W2	YD19	YD11	TH13	TH43	F5A2	F5A8		
	Y613	L2W1	YD20	YD15	TH10	TH34	AVB4	AVB7		
	Y612		F343	F344	TH40	TH12	AV96	AVB8		
	Y611		AVC1	AV55	TH15	TH22	AVB2	AV94		
	Y610		AVB0	AV56	TH37	TH16	AV97	AV93		
	Y609									

Table 9. Specimen Loading for the Central Outer Holder for the HFIR-MFE-RB-12J

Center Section										
Outer Holder										
Row	1	2	3	4	5	6	7	8	9	10	
	CVN	B6	1.5 CVN, CVN	CVN	BB8	CVN	BB6	CVN	CVN	BB1	
	QC65	P6	149Z1	QC66	942MI	QC67	S8	QC68	QC69	DY06	DY49
	151Z1	D5	148Z1	FA47	T3	FK09	N3	FK39	N211	DY44	DY45
	A027	H3	147Z1	FA46	942T2	FK06	D7	FK38	N210	DY80	DY83
	A007	G4	135Z1	FA45	942M2	FK05	S7	FK37	N209	DY52	DY54
	A012	P5	134Z1	FA43	942T1	FA48	S3	FK36	N208	DT07	DT11
	A011	G3	133Z1	FA44	917M1	FA64	N2	FK35	TW10	DY02	DY04
	A010	H2	132Z1	A031	917M2	FA62	H5	FK13	TW09	DT14	DT16
	A009	G1	131Z1	A030	917T2	FA61	D6	FK11	TW08	DY93	DY96
	A008	H1	LHW4	A029	917T1	FA59	N1	N207	TWO7	DT10	DT12
		P2	LHW3	A028	T5	FA58	S1	N206	TW06	DY94	DY95
										DY81	DY82
										DY46	DY47
										DT08	DT09
										DT53	DY55
										DT13	DT15
										DY43	DY48
										Y616	Y616
Row	A	B	C	D							
	Pressurized Tubes	Pressurized Tubes	Pressurized Tubes	TEM Holders							
	3	L2WA	5	2–12							
	11	L2WB	9	2–11							
	12	L2WD	1	2–10							
	LFWA	X6X6	LIWA	2–9							
	LFWB	X7X7	LIWB	2–8							
	LFWD	X8X8	LBWA	2–1							
	LFWF	X9X9	LBWD	2–2							
	LHWB	1010	LHWA	2–4							
	LIWD	1111	LHWD	2–5							
	LBWD	1414	LHWF	2–6							
	LHWG	1515	LFWG								

Table 10. Loading of TEM Specimens in HFIR-MFE-RB-11J

Holder	1–1	1–2		1–4			1–5		
					(Zr)				
Bottom	YS52	G604	KKG1	TE10	TE70	TED0	F2AG	F4D5	F65L
	YS55	G603	KKG2	TE11	TE71	TED1	F2AF	F4D8	F65A
	YS73	G602	KKG3	TE12	TE72	TED2	TEJ0	TEK3	F65F
	YY52	G610	KKB2	TE13	TE73	TED3	F2AM	F4DR	F65H
	YY55	G609	KKH1	TE14	TE74	TED4	F2AS	F4DG	F659
	YY72	G612	KKH2	TE20	TE80	TEE0	TEJ1	TEK4	F657
	YZ55	G611	YD59	TE21	TE81	TEE1	F2A8	F4DD	TEM0
	YZ73	G601	YB38	TE22	TE82	TEE2	F2AK	D4DF	TEM1
	N234	KKA1	KKI1	TE23	TE83	TEE3	TEJ2	TEL0	TEM2
	N235	KKA2	KKI2	TE24	TE84	TEE4	F2AA	F56F	TEM3
	N236	KKA3	KKI3	TE30	TE90	TEG0	F2AH	F56S	F755
		KKB3	KKJ1	TE31	TE91	TEG1	TEJ3	TEL1	F75V
		KKC1	KKJ2	TE32	TE92	TEG2	F374	F565	F75D
		KKC2	KKJ3	TE33	TE93	TEG3	F37X	F56A	F75G
		KKC3	JAR1	TE34	TE94	TEG4	TEJ4	TEL2	F75H
		KKD1	TW36	TE40	TE00	TEH0	F378	F56G	F75S
		KKD2		TE41	TE01	TEH1	F37K	F56D	F75L
		KKD3		TE42	TE02	TEH2	TEK0	TEL3	F754
		KKE2		TE43	TE03	TEH3	F37M	F65R	F868
		KKF1		TE44	TE04	TEH4	F37F	F655	F86T
		KKF2		TE50	TEA0		TEK1	TEL4	F86V
		KKF3		TE51	TEA1		F4D9		F86H
				TE52	TEA2		F4DB		F866
				TE53	TEA3		TEK2		F86L
				TE54	TEA4				
				TE60	TEB1				
				TE61	TEB2				
				TE62	TEB3				
				TE63	TEB4				
				TE64					

Table 10. Loading of TEM Specimens in HFIR-MFE-RB-11J (cont'd)

Holder	1–6				1–8			1–9		
			(Zr)							
Bottom	AV01	AV16	ND16	46	LFV1	GA3B	FML1	YB19	YB58	YB91
	AV02	AV17	ND10	XD25	LFV2	GA3D	FML2	YB20	YB59	YB93
	AV03	AV18	ND18	XD50	LFV3	GA3F	FML3	YB21	YB60	YB93
	AV04	AV19	ND05	XD45	LFV4	GB3A	FR01	YB22	YB61	YB94
	AV05	AV20	ND19	ZD26	LFV5	GB3B	FR02	YB23	YB62	YB95
	AV06	AV21	ND25	ZD50	LFV6	GB3D	FR03	YB24	YB63	A028
	AV07	AV22	XD32	ZD30	LFV7	GB3F	FR04	YB25	YB64	A029
	AV08	AV23	XD48	UD38	LFV8	GG3D	YB01	YB26	YB65	
	AV09	AV24	XD47	UD45	LFV9	GD3A	YB02	YB27	YB66	
	AV10	AV25	XD34	UD25	LFVA	GD3B	YB03	YB28	YB67	
	AV11	AV26	ZD42	ND08	LFVB	GF3A	YB04	YB29	YB68	
	AV12	AV27	ZD36	ND20	LFVD	GF3B	YB05	YB30	YB69	
	AV13	AV28	ZD27	ND27	LFVF	GF3D	YB06	YB31	YB70	
	AV14	AV29	ZD34	ND09	LFVG	GF3F	YB07	YB32	YB71	
	AV15	AV30	UD33	ND02	LFVH	G03A	YB08	YB33	YB72	
		AV31	UD30	UD48	LBV1	G03B	YB09	YB34	YB73	
		AV32	UD46	ZD31	LBV2	G030	YB10	YB35	YB74	
		AV33	UD26	ZD38	LBV3	G03F	YB11	YB36	YB75	
		AV34	71	XD29	LBV4	G13A	YB12	YB37	YB76	
		AV35	71	XD43	LBV5	G13B	YB13	YB39	YB77	
		AV36	71	ND29	LBV6	G13D	YB14	YB40	YB78	
			70	ND28	L1V1	G13F	YB15	YB41	YB79	
			70	UD21	L1V2	FMA1	YB16	YB42	YB80	
			72		L1V3	FMA2	YB17	YB43	YB81	
			72		L1V4	FMA3	AB18	YB44	YB82	
					L1V5	FMD1	A025	YB45	YB83	
					L1V6	FMD2	A026	YB46	YB84	
					L2V1	FMD3		YB47	YB85	
					L2V2	FMF1		YB48	YB86	
					L2V3	FMF2		YB49	YB87	
					L2V4	FMF3		YB50	YB88	
					L2V5	FMH1		YB51	YB89	
					L2V6	FMH2		YB52	YB90	
					LHV1	FMH3		YB53		
					LHV2	FMK1		YB54		
					LHV3	FMK2		YB55		
					LHV4	FMK3		YB56		
					LHV7			YB57		
					LHV8					
					LHV9					
					LHVA					

Table 10. Loading of TEM Specimens in HFIR-MFE-RB-11J (cont'd)

Holder	1–10				1–11		1–12		
Bottom	YB97	XR1T	AF13	AF46	AA07	LDV1	A001	TWO1	SiC
	YB98	XR1X	AF14	AF47	AA08	LDV2	A002	TW02	SiC
	YB99	XR1Y	AF15	AF48	AA09	LDV3	A003	TW03	SiC
	YD50	XR21	AF16	AF49	AA10	LDV4	A004	TW04	SiC
	YD51	XR22	AF17	AF50	AA11	LDV5	A005	TW05	N425
	YD52	XR23	AF18	AH51	AA12	LDV6	A006	TW06	N227
	YD53	XR24	AF19	A030	AL01		A007	TW07	N228
	YD54	XR25	AF20	A031	AL02		A008	TW08	
	YD55	AA01	AF21	A032	AL03		A009	TW09	
	YD56	AA02	AF22	TW25	AL04		A010	TW10	
	YD57	AA03	AF23	CAPA?	AL05		FA14	XI62	
	YD58	AA04	AF24	N232	AL06		FA19	XI67	
	YD60	AA05	AF25		AL07		FA20	XI70	
	YD61	AA06	AF26		AL08		FA10	XI59	
	XR11	AF01	AF27		AL09		FA31	XH63	
	XR12	AF02	AF38		AL10		FA15	HX68	
	XR13	AF03	AF29		AL11		FA12	XH69	
	XR14	AF04	AF30		AL12		N201	XH66	
	XR15	AF05	AF31		AC01		N202		
	XR16	AF06	AF32		AC02		N203		
	XR17	AF07	AF33		AC03		N204		
	XR18	AF08	AF34		AC04		N205		
	XR19	AF09	AF35		AC05		N206		
	XR1A	AF10	AF36		AC06		N207		
	XR1B	AF11	AF37		B000		N208		
	XR1D	AF12	AF38		B001		N209		
	XR1F		AF39		B100		N210		
	XR1G		AF40		B101				
	XR1H		AF41		B200				
	XR1K		AF42		B201				
	XR1L		AF43		B300				
	XR1M		AF44		B301				
	XR1R		AF45						
	XR1S								

Table 11. Loading of TEM Specimens in HFIR-MFE-RB-12J

Holder	2–1	2–2		2–4			2–5			
					(Zr)				(Zr)	
Bottom	YS53	G605	KKE-1	TE15	TE75	TED5	F2AB	FD4A	F65K	AV56
	YS54	G606	KKE-2	TE16	TE76	TED6	F2AB	F4DS	F65D	AV57
	YS56	G607	KKF-1	TE17	TE77	TED7	TEJ5	TEK7	F65G	AV58
	YS57	G608	KKF-2	TE18	TE78	TED8	F2AL	F4DW	F653	AV59
	YY53	G613	KKF-3	TE19	TE79	TED9	F2A4	FRDZ	F65S	AV60
	YY54	G614	KKG-1	TE25	TE85	TEE5	TEJ6	TEK8	F656	AV61
	YY56	G615	KKG-2	TE26	TE86	TEE6	F2AT	F4F1	TEM5	AV62
	YY57	G616	KKG-3	TE27	TE87	TEE7	F2A7	F4F3	TEM6	AV63
	YY74	YC42	KKH-1	TE28	TE88	TEE8	TEJ7	TEK9	TEM7	AV64
	YY75	AFB9	KKH-2	TE29	TE89	TEE9	F2AD	F4F4	TEM8	AV65
	YZ53	KKA-1	KKH-3	TE35	TE95	TEG5	F2AV	F4F5	TEM9	
	YZ54	KKA-2	KKI-1	TE36	TE96	TEG6	TEJ8	TEL5	F75A	
	YZ56	KKA-3	KKI-2	TE37	TE97	TEG7	F379	F563	F758	
	YZ57	KKB-1	KKI-3	TE38	TE98	TEG8	F37A	F565	F756	
	YZ74	KKB-2	KKJ-1	TE39	TE99	TEG9	TEJ9	TEL6	F75K	
	YZ75	KKC-1	KKJ-2	TE45	TE05	TEM5	F37G	F56B	F753	
	YS74	KKC-2		TE46	TE06	TEM6	F37H	F56H	F75R	
	YS75	KKC-3		TE47	TE07	TEM7	TEK5	TEL7	F757	
		KKD-1		TE48	TE08	TEM8	F37W	F56M	F863	
		KKD-2		TE49	TE09	TEH9	F37Y	F56T	F867	
		KKD-3		TE55	TEA5		TEK6	TEL8	F86A	
				TE56	TEA6			F65T	F86G	
				TE57	TEA7			F654	F86M	
				TE58	TEA8			TEL9	F86R	
				TE59	TEA9					
				TE65	TEB5					
				TE66	TEB6					
				TE67	TEB7					
				TE68	TEB8					
				TE69	TEB9					

Table 11. Loading of TEM Specimens in HFIR-MFE-RB-12J (cont'd)

Holder	2-6			2-8				2-9			
		(Zr)									
Bottom	AV66	ND15	71	LFW1	LHW1	G05A	FMB1	FR05	YC12	YC26	LDW1
	AV67	ND14	71	LFW2	LHW2	G05B	FMB2	FR06	YC48	YC62	LDW2
	AV68	ND30	46	LFW3	LHW3	G05D	FMB3	FR07	YC13	YC27	LDW3
	AV69	ND24	46	LFW4	LHW4	G15A	FMG1	F409	YC49	YC63	LDW4
	AV70	ND03	72	LFW5	LHW5	G15B	FMG2	FR0A	YC14	YC28	LDW5
	AV71	ND12	72	LFW6	LHW6	G15B	FMG3	FR0D	YC50	YC64	LDW6
	AV72	XD22	71	LFW7	LHW7	G15D	FMAA	FR0F	YC15	YC29	TW45
	AV73	XD26	71	LFW8	LHW8	G15F	FMAB	YC01	YC51	YC39	TW47
	AV74	XD41	71	LFW9	LHW9	FMA4	FMBA	YC02	YC16	YC30	TW48
	AV75	XD49	46	LFWA	LHWA	FMA6	FMBB	YC03	YC52	YC37	
	AV76	ZD37	46	LFWB	GA5A	FMA7	FMDA	YC59	YC17	XR33	
	AV77	ZD25		LFWD	GA5B	FMD4	FMDB	YC04	YC53	YC88	
	AV78	ZD21		LFWF	GA5D	FMD5	FMFA	YC06	YC18	XR34	
	AV79	ZD40		LFWG	GA5F	FMDG	FMFB	YC07	YC54	YC41	
	AV80	UD43		LFWH	GB5A	FMF4	FMGA	YC43	YC19	XR35	
	AV81	UD20		LBW1	GB5B	FMF5	FMGB	YC08	YC55	YC54	
	AV82	UD40		LBW2	GB5D	FMF6	FMHA	YC44	YC20	XR36	
	AV83	UD32		LBW3	GB5F	FMH4	FMHB	YC09	YC56	XR37	
	AV84	71		LBW4	GG5A	FMH5	FMKA	YC45	YC21	XR38	
	AV85	71		LBW5	GG5D	FMH6	FMKB	YC10	YC57	XR39	
	AV86	71		LBW6	GD5A	FMK4	FMLA	YC46	YC22	XR3A	
	AV87	70		L1W1	GD5B	FMK5	FMLB	YC11	YC58	B002	
	AV88	70		L1W2	GD5F	FMK6		YC47	YC23	B003	
	AV89	70		L1W3	GF5A	FML4			YC24	B102	
	AV90	72		L1W4	GF5B	FML5			YC60	B103	
	AV91	72		L1W5	GF5D	FML6			YC25	B202	
		72		L1W6	GF5F				YC61	B203	
		70		L2W1						B302	
		72		L2W2						B303	
				L2W3							
				L2W4							
				L2W5							
				L2W6							

Table 11. Loading of TEM Specimens in HFIR-MFE-RB-12 (cont'd)

Holder	2–10				2–11			2–12	
Bottom	YC31	AFA8	AFD1		AFF1	AFG3	AA55	A011	TW11
	YC65	YC78	YC92		YD76	XR26	XR2R	A012	TW12
	YC32	AFA9	AFD2		AFF2	AFG4	AA56	A013	TW13
	YC66	YC79	YC93		YD77	XR27	XR2S	A014	TW14
	YC33	AFA0	AFD3		AFF3	AFG5	AA57	A015	TW15
	YC67	YC80	YC94		YD78	XR28	XR2T	A016	TW16
	YC68	AFB1	AFD4		AFF4	AFG6	AA58	A017	TW18
	YC35	YC81	YC95		YD79	AFG7	XR2X	A018	TW19
	YC69	AFB2	AFD5		AFF5	XR2A	XR2Y	A019	TW20
	YC36	YC82	YC96		YD80	AFG8	AA60	A020	XI66
	YC70	AFB3	AFD6		AFF6	AFG9	XR31	FA17	XI57
	AFA1	YC83	Y097		YD81	XR2D	AA61	FA16	XI65
	YC71	AFB4	AFD7		AFF7	AFG0	XR32	FA13	XI63
	AFA2	YC84	YC98		YD82	XR2G	AA62	FA18	XH60
	YC72	AFB5	AFD8		AFF8	AA51	XR2F	FA22	XH65
	AFA3	YC85	YC99		YD83	XR2H	AC19	FA11	XH56
	YC73	AFB6	AFD9		AFF9	AA52	AC20	FA09	XH58
	AFA4	YC86	AFD0		YD84	XR2K	AC21	N211	
	YC74	AFB7	TW34		AFF0	AA53	AC22	N212	
	AFA5	YC87	TW35		YD85	XR2L	AC23	N213	
	YC75	AFB8	TW37		AFG1	AA54	AC24	N214	
	AFA6	YC88	TW30		YD86		XR2M	N215	
	YC76	YC89	TW44	N231	AFG2		AA59	N216	
	AFA7	AFB0	TW40	N237	YD87			N217	
	YC77	YC90	A037	N243				N218	
			A038	N229				N219	
			A043	N230				N220	
			A027						
			A044						

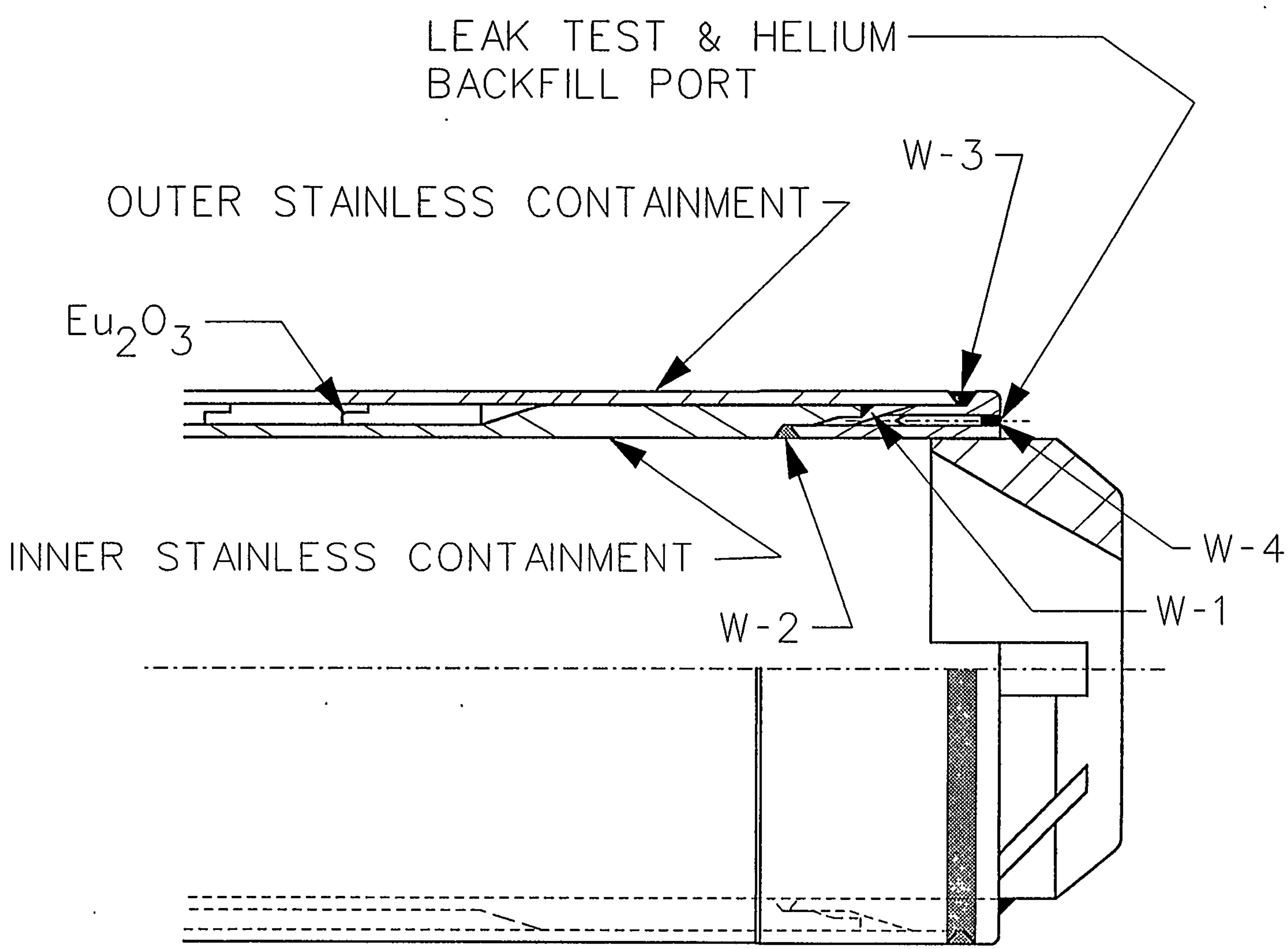


Fig. 3. Bottom section of the shield can showing the details of the seal welds. Weld W-1 and one of W-2, W-3, or W-4 must fail in order to produce a leak. W-4 is the seal for the helium back-fill port to provide a means of leak checking the welds.

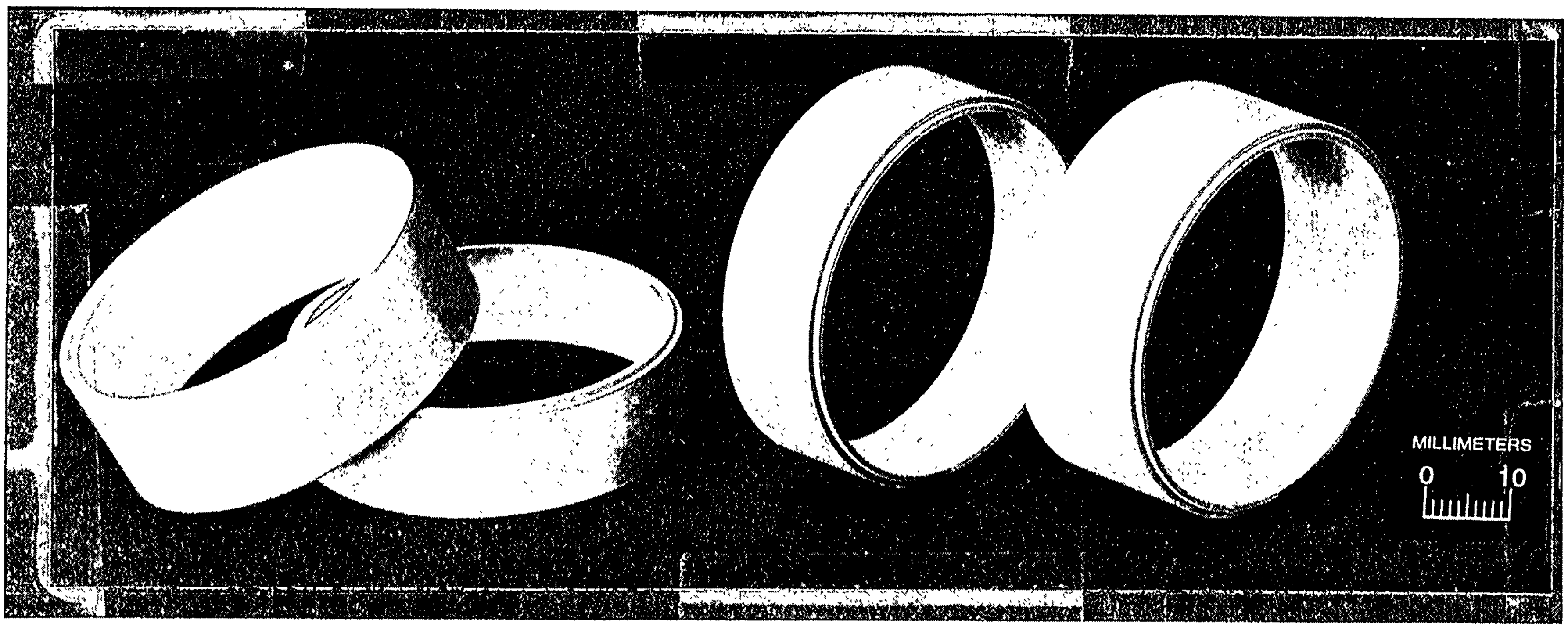


Fig. 4. Rings of europium oxide prior to coating with aluminum and assembling into a shield.

The rings were fabricated by cold pressing and sintering. Cubic Eu_2O_3 powder was isopressed and calcined at 1800°C to transform it to the more dense monoclinic phase. Following crushing, grinding, and milling operations, a binder was introduced to facilitate die pressing. The powder was then pressed in a steel die at 310 MPa, resulting in a compact of 65% of theoretical density. The binder was then burned out at 1300°C in an air atmosphere. The rings were then sintered at 1730°C for one hour in an argon-4%H atmosphere. The final shape was machined to a tolerance of 0.03 mm.* Coating with aluminum was done by plasma sputtering to produce a coating 2-4 μm in thickness. Since the coating produced by this technique was porous, it was sintered in a vacuum at 576°C, 0.9 of the melting point of aluminum, for 4 hours.

The rings were then fitted together on the inner wall of the shield can to form the cylindrical shield pictured in Fig. 5. The ends of the capsules were shielded with sections of a HFIR control plate containing Eu_2O_3 in an Al matrix. Space was not a constraint so that two such 25 mm plates were used and were placed in the specimen chamber which had a monitored containment. In the case of a leak, a high moisture level in the purge gas could be detected within a few minutes.

Thermal Performance

The temperature distribution in the capsules was examined carefully during the first cycle of operation. The temperature distributions are shown in Figs. 6 and 7 for 11J and 12J, respectively. The temperatures plotted are thermocouple temperatures. Specimen temperatures are higher according to heat conduction from the particular specimen and to local nuclear heating, which depends upon axial position and shielding. Calculated corrections to thermocouple temperatures are given in Figs. 6 and 7. It is apparent that the end regions are cooler than expected in both capsules. In 11J, the ends were about 50°C lower than the design temperature, and in 12J the end regions were about 150°C below the design temperature.

It is believed that the low temperatures are the result of two causes: end losses and centering pad losses. A few specimens in the outer middle region are also affected by centering pad losses. Centering pads are used to maintain the position of the specimen holder in the capsule and to maintain the gap needed for the flow of the control gas. However, the centering pads also provide a pathway for heat loss. The localized temperature depression is approximately 20°C (3%) in 11J and 50°C (6%) in 12J. The centering pads affect only those specimens that are near centering pad locations, along with all the upper and lower regions.

The majority of the specimens in both capsules is operating within the desired temperature bands: ±20 C for both the 300 and 500°C capsules. The average of the central thermocouples was chosen for the control temperature in both capsules. The end regions are considered to be at 250 and 350°C for 11J and 12J, respectively. As with any irradiation experiment that does not contain liquid metal, variations between specimens are expected.

Conclusions

Two unique first of a kind irradiation experiments have begun irradiation in the HFIR. The newly developed europium oxide thermal shields permit fast reactor irradiations in the HFIR including, if desired, irradiation at temperatures as low as 60°C. The experiments contain a very large number of specimens of alloys and ceramics of many specimen configurations.

The temperatures at the ends of the capsules were slightly lower than the design temperatures, but this is not unexpected in an experiment of such a new design. The low temperatures are attributed to undesirable heat conduction through centering pads. The design will be modified in future irradiation experiments to alleviate this condition. The experiment will serve as a prototype for other collaborative HFIR experiments between Japan and the U.S.

*Machining was performed by Chand Associated, Inc., Worcester, MA.

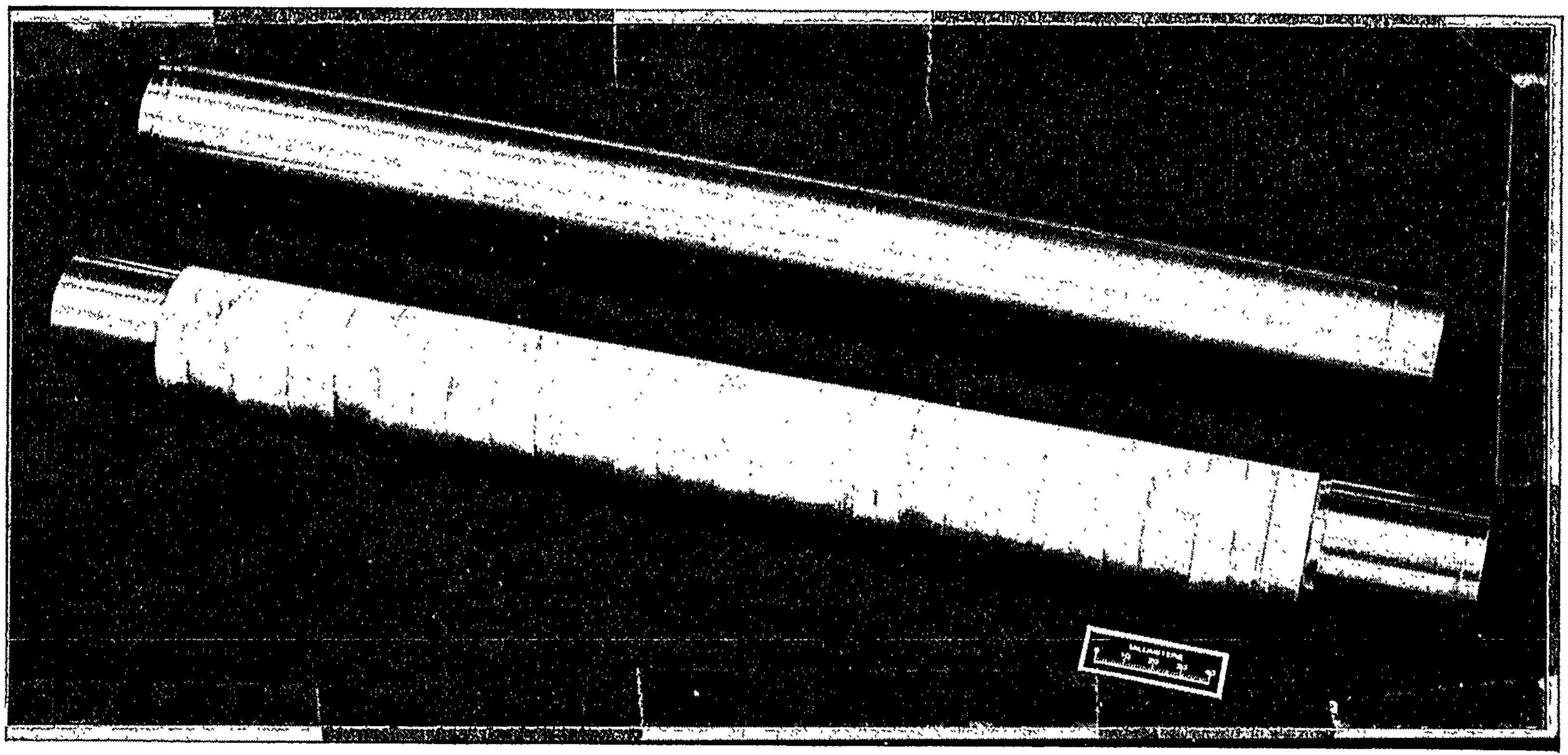
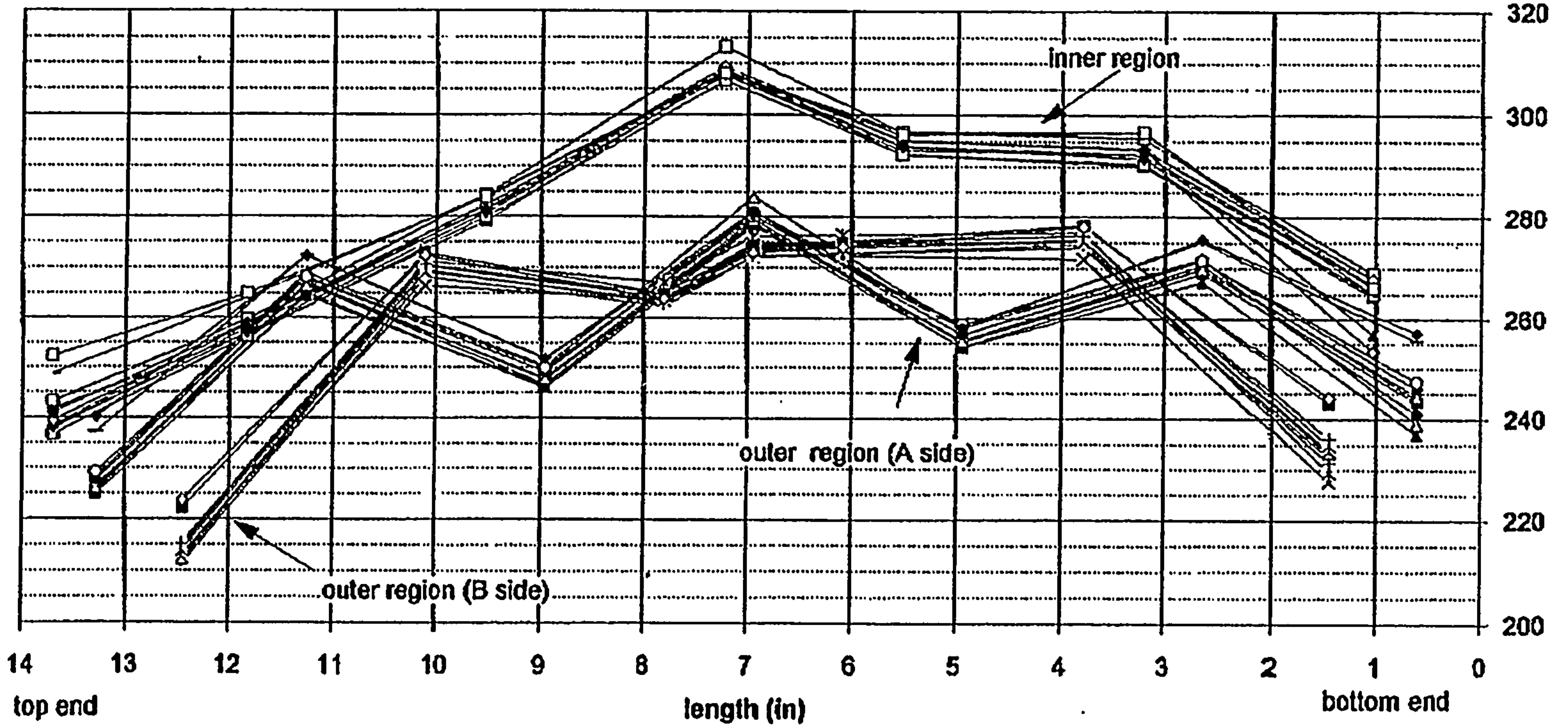


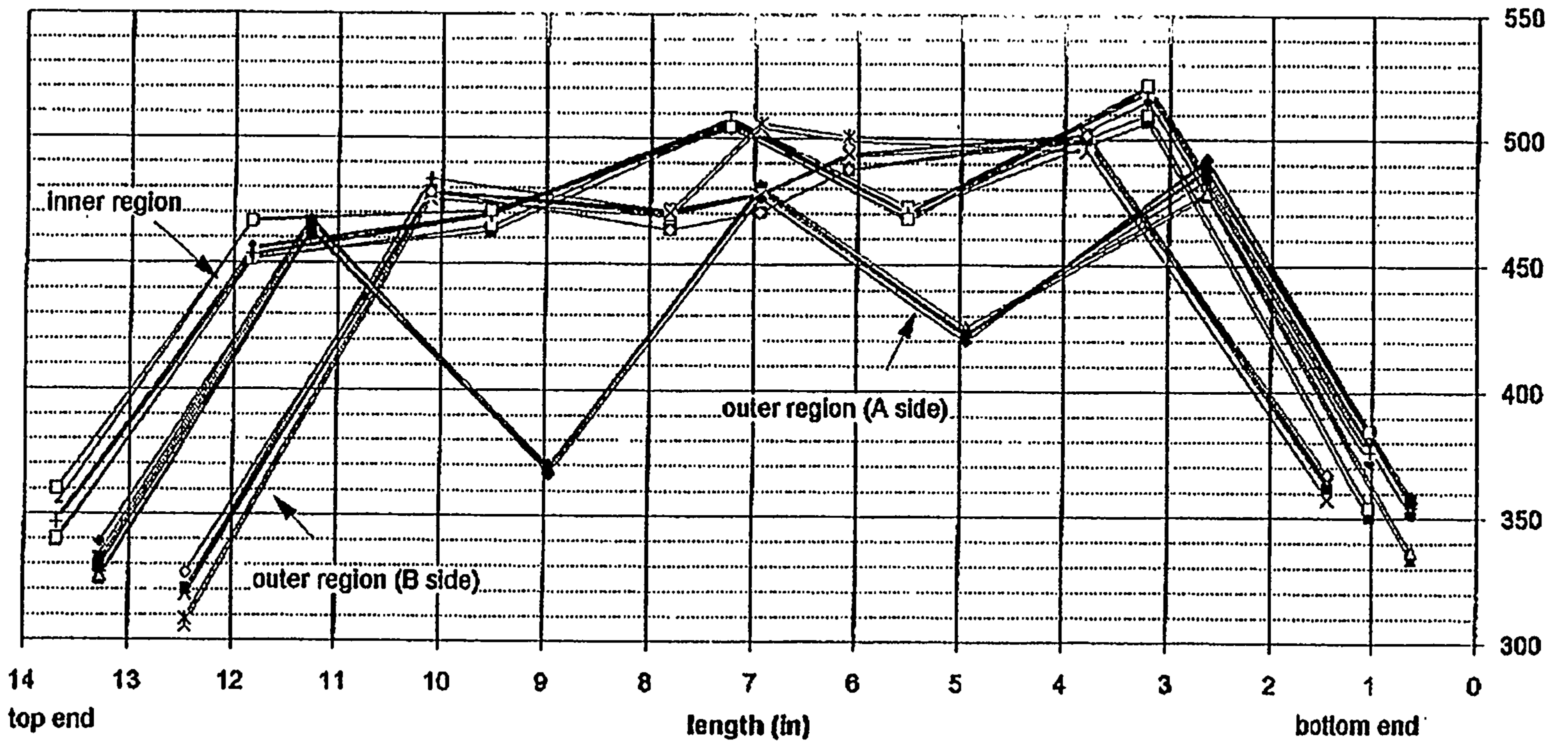
Fig. 5. Europium oxide rings in place on the inner wall of the shield can. The outer wall is at the top in the figure and will be fitted over the europium rings and welded in place.



Desired Control Temperature (°C)	
Ends	295
Inner	294
Outer	275

Specimen Temperature Corrections	
Ends	+5 to 10°C
Inner	+7 to 14°C
Outer	+11 to 29°C

Fig. 6. Temperature data for the first cycle of operation of HFIR-RB-11J.



Desired Control Temperature (°C)	
Ends	500
Inner	491
Outer	471

Specimen Temperature Corrections	
Ends	+5 to 10°C
Inner	+7 to 14°C
Outer	+11 to 29°C

Fig. 7. Temperature data for the first cycle of operation of HFIR-RB-12J.

REFERENCES

1. A. W. Longest, J. E. Corum, D. W. Heatherly, and K. R. Thoms, "Design of Spectrally Tailored Fusion Reactor Materials Experiments in the HFIR RB* Capsule Irradiation Facility, *J. Nucl. Mater. 155-157* (1988), 1346.