AS-BUILT CONDITION AND OPERATING HISTORY OF THE U.S./JAERI HFIR MFE-RB-10J CAPSULE – K. E. Lenox and J. P. Robertson (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this report is to provide information on the current status of the HFIR MFE-RB-10J experiment.

SUMMARY

The HFIR-MFE-RB-10J experiment is being conducted under the auspices of the U.S. Department of Energy (DOE)/Japan Atomic Energy Research Institute (JAERI) Collaborative Testing Program. The final specimen loading lists, operating constraints, and operating history of the experiment are discussed. The experiment has undergone approximately ten (10) days of irradiation, but has been removed from HFIR due to the development of a leak in the primary containment vessel. The associated europium liner has also been removed. Efforts are underway to apply for approval to continue the irradiation of the RB-10J experiment as soon as possible.

PROGRESS AND STATUS

Description of the RB-10J Capsule

The RB-10J capsule contains three temperature zones designed to operate at 250°C, 420°C, and 480°C. Two of the zones (420°C and 480°C) contain vanadium specimens in lithium-filled containers, or subcapsules, while the third zone (250°C) consists of steel specimens placed into cutouts in an aluminum block. The lithium-filled subcapsules are nested inside of a stainless steel primary containment vessel, which is nested inside of a stainless steel secondary containment vessel. The stainless steel specimens in the aluminum block are outside of the primary containment vessel, but inside the secondary containment vessel. The secondary containment vessel is in contact with the reactor coolant water. (See Figs. 1-2)

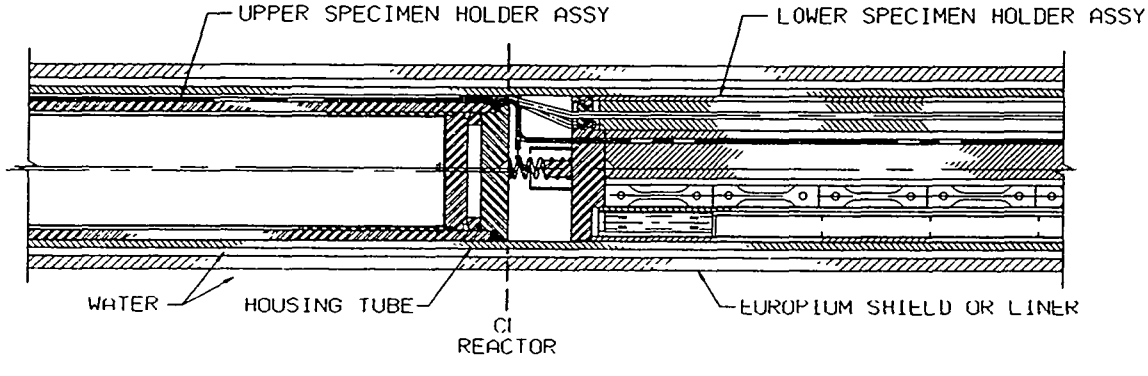

Fig. 1. The interface between the upper and lower halves of the RB-10J specimen region. The positions of the housing tube and the europium shield are also shown.

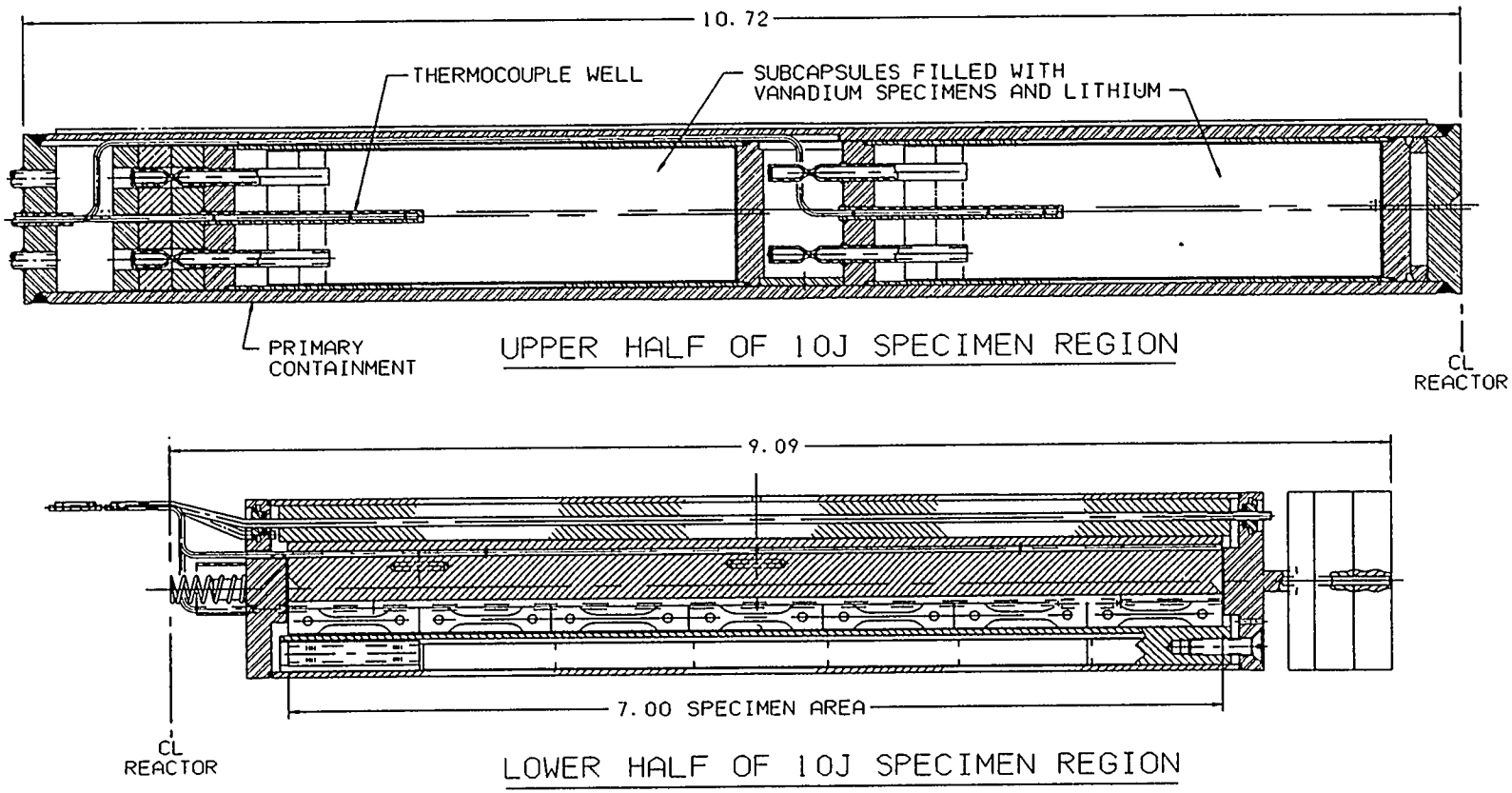

Fig. 2. Upper and lower halves of the RB-10J specimen region. The upper half contains the primary containment vessel and two lithium filled subcapsules. The lower half contains steel specimens in a cylindrical aluminum block.

Temperature control is maintained by varying the conductivity in a gas-filled gap inside of the secondary containment vessel. The conductivity is changed by varying the composition of gas in the gap. The gas composition can range from pure helium to pure neon or any mixture of the two. Additional neon can be added to the region around the lithium-filled subcapsules in order to boost the temperature of the vanadium specimens, without increasing the temperature of the steel specimens. There are thermocouples in each temperature zone, and the data from the thermocouples are used to control the gas mixture in the gap.

Additional descriptions of the capsule have been reported previously. [1,2]

Specimen Loading Lists

Table 1 contains information on the specimens loaded into the RB-10J capsule. The table is sorted into each of eight (8) specimen types: Charpy or bend bars (CVN), tensile specimens (SS-3), TEM disks, notched thin strip specimens (TS), notched strip specimens (NS), J-type tensile specimen (SS-3J), and disk compact tension (DCT) specimens, and pressurized creep tube specimens (PT). Under each specimen type, a listing of individual specimens is given, grouped by their location and accumulated DPA values. The operating temperatures are also shown.

Operating Constraints

Several operating constraints, above and beyond that of typical MFE type capsules, were placed upon the RB-10J capsule due to the presence of lithium. The constraints are intended to make the possibility of interaction between molten lithium and the reactor coolant water an incredible event. The constraints also influenced the design and physical makeup of the capsule.

The constraints include the requirement of two independent containment vessels, each with its own monitoring system to verify the integrity of the containment, along with extensive requirements on the type and amount of additional analyses and testing that had to be performed on capsule components. A probabilistic risk assessment was performed to evaluate the potential for a catastrophic failure of both containment vessels. Furnace experiments were performed using lithium to evaluate the potential for lithium to attack the capsule materials for the given conditions. A finite element stress analysis was performed on the lithium-filled subcapsules to evaluate the behavior of the subcapsules during the melting and solidification of lithium during the irradiation. In addition, internal and external pressure tests of the containment vessels and lithium-filled subcapsules were performed prior to irradiation to confirm the integrity of the as-built capsule.

Operating History

The irradiation of the RB-10J experiment began on Oct. 13, 1998. The 250°C region was brought up to the desired operating temperature within thirty (30) minutes after the reactor reached full power (84 MW). Due to unexpectedly high temperature readings in one of the three thermocouples in the 420°C region, the temperatures in the lithium filled regions were left at 30°C below the desired values until Oct. 16, 1998. At that time, because all other temperature indications showed that the lithium-filled regions were in fact below the desired operating temperature, the temperatures were brought up to the desired values. The temperature readings from the deviant thermocouple in the 420°C region stabilized after five days, most likely due to the release of a helium bubble trapped in the molten lithium. The average temperature readings in the three zones for the period from Oct. 16, 1998 to Oct. 23, 1998 were 265°C, 410°C and 475°C.

Table 1. Axial Location, Accumulated DPA, and Operating Temperatures of specimens in RB-10J.

Type:	CVN								
DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code	DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.12	-18.6	291±7	SA-316F	8HA9	0.20	-5.9	291±7	SA-316F	8HB4
				8HC1					8HD1
				8HD2				SA-JPCA	8NA4
0.13	-16.1	291±7	SA-316F	8HB2	0.21	-3.4	291±7	SA-316F	8HC8
				8HC5				SA-JPCA	8NA0
			SA-JPCA	8NA3					8NA2
0.15	-13.5	291±7	SA-316F	8HB0	0.27	5.8	479±7	V-4Cr-4Ti	RC42
				8HC6					RC43
			SA-JPCA	8NA1					RC44
0.17	-11.0	291±7	SA-316F	8HB3					RC45
				8HD0					RC89
				8HD4					RC90
	18.2	415±10	V-4Cr-4Ti	RC11					RC98
				RC12					RC99
				RC13	0.28	3.2	479±7	V-4Cr-4Ti	RC31
				RC14					RC32
				RC82					RC33
				RC83					RC34
				RC91					RC35
				RC92					RC36
0.18	-8.4	291±7	SA-316F	8HB1					RC37
				8HC2					RC38
				8HD3					RC39
0.19	15.6	415±10	V-4Cr-4Ti	RC15					RC40
				RC16					RC41
				RC17					RC87
				RC18					RC88
				RC19					RC96
				RC20					RC97
				RC21	Grand Total of 67				
				RC22					
				RC23					
				RC24					
				RC25					
				RC84					
				RC85					
				RC93					
				RC94					

DPA calculation basis: 865 MWD of operation; The peak DPA/MWD value is 0.000255 for SS and 0.000324 for V.
DPA varies with axial location with the equation: cos(0.00858(z-12.7)) + 0.0000171(z-12.7)^2, z in mm (see Ref. 3).
All DPA values have been rounded off to 2 decimal places.

z (cm) is the axial distance of the midpoint of the specimen from the HFIR centerline. All distances have been rounded off.

Operating temperatures are based on the thermocouple data, corrected for the specimen type and location. The given ranges represent the variation in thermocouple data.

Table 1. Axial Location, Accumulated DPA, and Operating Temperatures of specimens in RB-10J. (cont.)

Type: NS

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.12	-18.8	285±10	SA-316F	1HA6
				4HA1
	-18.6	269±10	SA-316F	1HA2
				2HA2
				3HA0
				4HA2
			SA-JPCA	1NA0
				3NA0
0.13	-16.2	285±10	SA-316F	5HA6
			SA-JPCA	1NA3
	-16.1	269±10	SA-316F	5HA3*
				7HA2
			SA-JPCA	1PA0
				2PA0
				3PA1
				7NA0
0.15	-13.7	285±10	SA-316F	3HA6
				7HA5
	-13.5	269±10	SA-316F	1HA3
				2HA3
				3HA3
				4HA3
			SA-JPCA	1NA1
				3NA1
0.16	-11.1	285±10	SA-JPCA	3NA3
				7NA3
0.17	-11.0	269±10	SA-316F	5HA3*
				7HA3
			SA-JPCA	1PA1
				2PA1
				3PA0
	-11.0	269±10	SA-JPCA	7NA1
0.18	-8.6	285±10	SA-316F	1HA7
				3HA7
	-8.4	269±10	SA-316F	1HA4
				2HA4
				3HA1
				4HA4
			SA-JPCA	1NA2
				3NA2
0.20	-6.1	285±10	SA-316F	4HA6
				5HA5
	-5.9	269±10	F82H IEA heat	NS03
				NS04
				NT07
				NT10
			SA-316F	5HA4
				7HA4
				7HA7
			SA-JPCA	7NA2
0.21	-3.5	285±10	SA-316F	7HA6
	-3.4	269±10	F82H IEA heat	NS01
				NS02
				NT04
				NT06
			SA-316F	1HA5
				3HA5
				4HA7
				5HA7
Grand Total of 59				

*One of these two entries may be in error. One may actually be 5HA2.

Type: SS-3J

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.17	17.7	415±10	V-4Cr-4Ti-0.5SiAlY	LB01
				LB02
				LB03
0.27	5.3	479±7	V-4Cr-4Ti-0.5SiAlY	LB04
				LB05
				LB06
Grand Total of 6				

Type: DCT

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.21	14.1	415±10	V-4Cr-4Ti	RC01
0.28	1.7	479±7	V-4Cr-4Ti	RC03
Grand Total of 2				

DPA calculation basis: 865 MWD of operation; The peak DPA/MWD value is 0.000255 for SS and 0.000324 for V.
DPA varies with axial location with the equation: cos(0.00858(z-12.7)) + 0.0000171(z-12.7)^2, z in mm (see Ref. 3).
All DPA values have been rounded off to 2 decimal places.

z (cm) is the axial distance of the midpoint of the specimen from the HFIR centerline. All distances have been rounded off.

Operating temperatures are based on the thermocouple data, corrected for the specimen type and location. The given ranges represent the variation in thermocouple data.

Table 1. Axial Location, Accumulated DPA, and Operating Temperatures of specimens in RB-10J. (cont.)

Type:	SS-3								
DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code	DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.12	-18.8	289±7	F82H IEA heat	A905	0.17	18.2	415±10	V-4Cr-4Ti	RC06
				A913					RC07
				A926					RC08
				A934					RC09
			JPCA	CPA0					RC10
			SA-316F	CHB4					RC21
				CHC5					RC23
				CHC6					RC30
			SA-JPCA	CNA0					RC31
				CNA7					RC32
0.13	-16.2	289±7	F82H IEA heat	A906					RC33
				A916					RC34
				A922					RC35
				A936					RC36
			JPCA	CPA1					RC37
			SA-316F	CHB5					RC38
				CHC7					RC39
				CHC8					RC94
			SA-JPCA	CNA1					RC95
				CNA8					RC97
0.15	-13.7	289±7	F82H IEA heat	A907				V-4Cr-4Ti-RF	RV05
				A918					RV06
				A927					RV07
				A937	0.18	-8.6	289±7	F82H IEA heat	A909
			JPCA	CPA2					A915
			SA-316F	CHB6					A930
				CHC9					A939
				CHD0				SA-316F	CHB8
			SA-JPCA	CNA2					CHC2
				CNA9					CHD3
0.16	-11.1	289±7	F82H IEA heat	A908					CHD4
				A919				SA-JPCA	CNA4
				A929					CNB1
				A938	0.19	15.6	415±10	V-4Cr-4Ti	RC24
			SA-316F	CHB7					RC25
				CHC1					RC40
				CHD1					RC41
				CHD2					RC42
			SA-JPCA	CNA3					RC43
				CNB0					RC44
0.17	18.2	415±10	V-4Cr-4Ti	RC03					RC45
				RC04					RC46
				RC05					RC47

DPA calculation basis: 865 MWD of operation; The peak DPA/MWD value is 0.000255 for SS and 0.000324 for V.
DPA varies with axial location with the equation: cos(0.00858(z-12.7)) + 0.0000171(z-12.7)^2, z in mm (see Ref. 3).
All DPA values have been rounded off to 2 decimal places.

z (cm) is the axial distance of the midpoint of the specimen from the HFIR centerline. All distances have been rounded off.

Operating temperatures are based on the thermocouple data, corrected for the specimen type and location. The given ranges represent the variation in thermocouple data.

Table 1. Axial Location, Accumulated DPA, and Operating Temperatures of specimens in RB-10J. (cont.)

Type: SS-3 (cont.)

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.19	15.6	415±10	V-4Cr-4Ti	RC48
				RC49
			V-4Cr-4Ti-0.5SiAlY	LB01
				LB02
				LB05
				LB06
				LB07
			V-4Cr-4Ti-RF	RV01
				RV02
				RV08
				RV09
				RV10
0.20	-6.1	289±7	F82H IEA heat	A910
				A923
				A932
				A942
			SA-316F	CHB9
				CHC3
				CHD5
				CHD6
			SA-JPCA	CNA5
				CNB2
0.21	-3.5	289±7	F82H IEA heat	A911
				A925
				A933
				A944
			SA-316F	CHC0
				CHC4
				CHD7
			SA-JPCA	CHD8
				CHD9
				CNA6
				CNB3
0.27	5.8	479±7	V-4Cr-4Ti	RC01
				RC02
				RC100
				RC101
				RC13
				RC14
				RC15
				RC16
				RC17
				RC18
0.27	5.8	479±7	V-4Cr-4Ti	RC26
				RC27
				RC66
				RC67
				RC68
				RC69
				RC70
				RC71
				RC72
				RC73
				RC74
				RC75
				RC98
			V-4Cr-4Ti-RF	RV20
				RV21
				RV22
0.28	3.2	479±7	V-4Cr-4Ti	RC28
				RC29
				RC56
				RC57
				RC58
				RC59
				RC60
				RC61
				RC62
				RC63
				RC64
				RC65
			V-4Cr-4Ti-0.5SiAlY	LB03
				LB04
				LB09
				LB10
				LB11
			V-4Cr-4Ti-RF	RV03
				RV04
				RV17
				RV18
				RV19
Grand Total of 167				

DPA calculation basis: 865 MWD of operation; The peak DPA/MWD value is 0.000255 for SS and 0.000324 for V.
DPA varies with axial location with the equation: cos(0.00858(z-12.7)) + 0.0000171(z-12.7)^2, z in mm (see Ref. 3).
All DPA values have been rounded off to 2 decimal places.

z (cm) is the axial distance of the midpoint of the specimen from the HFIR centerline. All distances have been rounded off.

Operating temperatures are based on the thermocouple data, corrected for the specimen type and location. The given ranges represent the variation in thermocouple data.

Table 1. Axial Location, Accumulated DPA, and Operating Temperatures of specimens in RB-10J. (cont.)

Type:	TEM			
DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.21	-4.3	291±7	SA-JPCA	SN13
	-4.2	291±7	SA-316F	SH10
				SH14
			F82H IEA STD	A914
				A903
	-4.1	291±7	F82H IEA STD	A922
			SA-316F	SH18
				SH25
				SH17
	-4.0	291±7	SA-316F	SH29
			F82H IEA STD	A912
				A904
				A905
	-3.9	291±7	F82H IEA STD	A915
				A917
			SA-316F	SH27
	-3.8	291±7	F82H IEA STD	A913
				A920
				A921
			SA-316F	SH21
	-3.7	291±7	SA-JPCA	SN09
			SA-316F	SH11
				SH15
			F82H IEA STD	A918
	-3.6	291±7	F82H IEA STD	A901
				A908
				A909
				A919

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.21	-3.5	291±7	F82H IEA STD	A907
				A916
			SA-316F	SH12
				SH26
	-3.4	291±7	F82H IEA STD	A910
			SA-JPCA	SN03
				SN05
				SN07
	-3.3	291±7	SA-JPCA	SN01
				SN06
				SN11
			F82H IEA STD	A902
	-3.2	291±7	SA-316F	SH13
			SA-316F	SH19
			F82H IEA STD	A906
				A911
	-3.1	291±7	SA-316F	SH16
				SH28
			SA-JPCA	SN10
	-3.0	291±7	SA-316F	SH20
				SH23
			SA-JPCA	SN08
				SN02
	-2.9	291±7	SA-316F	SH24
				SH22
			SA-JPCA	SN04
				SN14
	-2.8	291±7	SA-JPCA	SN00
				SN12

Type:	TS			
DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.12	-18.6	275±9	SA-316F	3HB5
0.13	-16.1	275±9	SA-316F	7HB1
0.15	-13.5	275±9	SA-316F	3HB3
0.17	-11.0	275±9	SA-316F	7HB4
0.18	-8.4	275±9	SA-316F	3HB2
0.20	-5.9	275±9	SA-316F	7HB5
Grand Total of 6				

DPA calculation basis: 865 MWD of operation; The peak DPA/MWD value is 0.000255 for SS and 0.000324 for V.
DPA varies with axial location with the equation: cos(0.00858(z-12.7)) + 0.0000171(z-12.7)^2, z in mm (see Ref. 3).
All DPA values have been rounded off to 2 decimal places.

z (cm) is the axial distance of the midpoint of the specimen from the HFIR centerline. All distances have been rounded off.

Operating temperatures are based on the thermocouple data, corrected for the specimen type and location. The given ranges represent the variation in thermocouple data.

Table 1. Axial Location, Accumulated DPA, and Operating Temperatures of specimens in RB-10J. (cont.)

Type: TEM (cont.)

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.21	14.1	415±10	V-4Cr-4Ti	RC01
				RC02
				RC03
				RC04
				RC05
				RC06
				RC47
				RC48
				RC49
				RC50
				RC51
			V-4Cr-4Ti-RF	RB31*
				RV32
				RV33
				RV34
				RV42
				RB43*
				RV44
				RV45
			V-4Cr-4Ti-SiAlY	LB01
				LB02
				LB05
				LB06
				LB07
				LB08

*May actually be RV31 and RV43

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.28	1.7	479±7	V-4Cr-4Ti	RC07
				RC08
				RC09
				RC10
				RC11
				RC12
				RC52
				RC53
				RC54
				RC55
				RC56
			V-4Cr-4Ti-RF	RV35
				RV36
				RV37
				RV38
				RV46
				RV47
				RV48
				RV49
			V-4Cr-4Ti-SiAlY	LB03
				LB04
				LB09
				LB10
				LB11
				LB12

Grand Total of 107

Type. PT

DPA	z (cm)	Operating Temp. (C)	Alloy	ID Code
0.17	18.2	415±10	V-4Cr-4Ti	20
				21
				22
				23
				F
				G
0.27	5.8	479±7	V-4Cr-4Ti	24
				25
				26
				27
				Q
				R

Grand Total of 12

DPA calculation basis: 865 MWD of operation; The peak DPA/MWD value is 0.000255 for SS and 0.000324 for V.
DPA varies with axial location with the equation: cos(0.00858(z-12.7)) + 0.0000171(z-12.7)^2, z in mm (see Ref. 3).
All DPA values have been rounded off to 2 decimal places.

z (cm) is the axial distance of the midpoint of the specimen from the HFIR centerline. All distances have been rounded off.

Operating temperatures are based on the thermocouple data, corrected for the specimen type and location. The given ranges represent the variation in thermocouple data.

Approximately five days into the irradiation, on Oct. 18, 1998, pressure readings on the primary containment system started a slow persistent decline. The primary containment system is a static system, and therefore, a loss of pressure indicated a breach of the primary containment system. An in-reactor pressure test was performed on Oct. 23, 1998, and the test confirmed that the leak was in the in-vessel portion of the experiment, not in the associated piping and valves.

Based on the operating constraints for the experiment, HFIR was shut down on Oct. 23, 1998 and the experiment was removed. HFIR was restarted on Oct. 26, 1998 to complete the rest of the irradiation cycle. The europium liner associated with the experiment was removed after the completion of the cycle.

Current Status

The RB-10J experiment and the europium liner are currently stored in the HFIR pool. All of the instrumentation is still hooked up to the experiment and is fully operational. A variety of pressurization experiments have been performed on the capsule to determine the size of the leak, and the data have been provided to an independent researcher who is currently working on a report on the leak and its behavior. An independent review committee has evaluated the operational data, in conjunction with the design of the experiment, and has provided valuable input into possible approaches to operating the experiment with the existing leak. Several members of the staff involved in the design, construction, and operation of the experiment are currently working on these conceptual approaches from the review committee in an effort to develop a feasible plan to apply for approval to resume the irradiation of the experiment. The RB-10J capsule must be approved by the HFIR Reactor Experiment Review Committee prior to re-insertion in the reactor.

REFERENCES

1. J. P. Robertson, K. E. Lenox, M. L. Grossbeck, A. F. Rowcliffe, S. Jitsukawa and K. Shiba, "Description and Status of the U.S./JAERI HFIR-MFE-RB-10J Irradiation Capsule," *Fusion Materials Semiannual Progress Report for the Period Ending December 31, 1997*, DOE/ER-0313/23, pp. 347-351.

2. J. P. Robertson, M. Howell, and K. E. Lenox, "Status of Lithium-Filled Specimen Subcapsules for the HFIR-MFE-RB-10J Experiment," *Fusion Materials Semiannual Progress Report for the Period Ending June 30, 1998*, DOE/ER-0313/24, pp. 257-259.

3. R. L. Senn and W. R. Mixon, "Experimental Measurement of Gamma Heat in the High Flux Isotope Reactor," *Nuclear Technology*, Vol. 12, pp. 235-240, October 1971.