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PNL-17
EBR-II INSTRUMENTED SUBASSEMBLY TEST
INTERIM REPORT
M. K. Millhollen and A. M. Sutey
June 1970

AEC RESEARCH & DEVELOPMENT REPORT

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EBR-II INSTRUMENTED SUBASSEMBLY TEST
INTERIM REPORT

By

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and

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June 1970

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ABSTRACT

PNL-17 is a 37-pin, instrumented subassembly being irradiated in EBR-II with thermocouples substituted for wire wrap on several of the pins. Hot junctions are so arranged that temperature readings are taken at both ~ 1.5 and ~ 6.0 in. above the bottom of the fuel column within selected coolant subchannels. The maximum calculated linear pin power generation is 9.20 kW ft; sodium coolant inlet temperature is 700 °F, and coolant flow through the subassembly is 53.3 gpm.

Subchannel coolant temperature readings at 20 MW and 50 MW reactor power levels early in the life of the subassembly have been corrected for thermocouple calibration and compared with values calculated by the COBRA II A Program. Correlation has been extremely good in most cases. The comparison of measured and calculated temperatures indicates that calculational methods being used to predict coolant channel performance of fuel test assemblies in EBR-II are satisfactory.

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PNL-17
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INTRODUCTION

A 37-pin, instrumented subassembly (XX02)* is being irradiated in a control rod position of EBR-II in support of the FFTF Driver Fuel Development Program. The fuel pins are non-encapsulated. Pin parameters are typical of proposed FFTF fuel pin designs. The pins are operating at a maximum linear heat rating of 9.20 kW/ft (50 MW reactor power). The fuel consists of pressed and sintered UO_2 - PuO_2 cylindrical pellets with a percent theoretical density of 93 ± 2 .

The principal purpose of this test is to determine the coolant flow-heat balance characteristics of a 37-pin subassembly in a manner to allow confirmation of calculational methods applied to other EBR-II irradiation test assemblies. A secondary purpose of the test is to determine the validity of the use of silicon carbide as a temperature monitor within fuel pins.

Previous irradiation tests have provided data only on bulk coolant inlet and outlet temperatures. Temperature changes within coolant subchannels have been calculated relative to the measured bulk temperatures. This test permits comparison of measured data with the subchannel calculations.

* XX02 is the EBR-11 designation for PNL-17.

DESCRIPTION OF EXPERIMENT

The irradiation test assembly consists of a 37-pin sub-assembly which is being irradiated in the Number 6 control rod position of EBR-II. Thirty-six of the pins are nonencapsulated fuel pins while the remaining pin is an empty tube which is used as an instrument lead conduit for the flowmeter sensor and the inlet thermocouple leads.

The fuel pins contain fuel in the form of sintered pellets of 75 wt% UO_2 -25 wt% PuO_2 . A nominal diametral gap of 0.006 in. exists between the fuel pellets and the cladding. The pins are clad in 20% CW 316 SS which is nominally 0.230 in. OD $\times$ 0.015 in. thick wall. Each pin is spirally wrapped with an 0.054 in. diameter spacer wire. Some wires are solid, 316 SS; some are 316 SS sheathed thermocouples; and some are 316 SS hypodermic needle tubing containing flux monitor wires.

The fuel pin cluster is contained within an instrumented subassembly test rig which was designed, fabricated, and assembled by Argonne National Laboratory. The fuel pins were assembled into the test rig at Argonne National Laboratory and all necessary instrument connections made. The arrangement of pins in the subassembly are as shown in Figure 1, and the arrangement of the thermocouples is presented in Figure 14, Appendix A. The entire rig, in excess of 36 ft long, was shipped to Idaho Falls by truck for installation in EBR-II. Figure 2 shows the instrumented test rig being moved to the preheater while Figure 3 shows the fueled end just before insertion into the preheater. After preheat, the test rig was installed in the control rod position.

The fuel pins are achieving a maximum heat generation rate of approximately 9.20 kW/ft at a reactor power level of 50 MW_t by using 65% enriched uranium in the mixed oxide fuel. Temperatures are measured and recorded in selected sodium coolant channels in planes normal to the axis of the subassembly at two

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FIGURE 1. Arrangement of Pins in Subassembly

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FIGURE 2. Instrumented Test Rig Being Moved to the Preheater
(Courtesy of Argonne National Laboratory)

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FIGURE 3. Fueled End Before Insertion into Preheater
(Courtesy of Argonne National Laboratory)

different vertical locations. Sodium inlet and outlet temperatures are also measured and recorded. Flow data are recorded to an accuracy of not less than $\pm 5\%$, using a calibrated magnetic flowmeter provided by ANL.

SUMMARY AND CONCLUSIONS

Temperatures recorded by thermocouples placed within the wire wraps on PNL-17 fuel pins have been analyzed for two periods during the first few hours of irradiation in EBR-II. A set of data taken at the 20 MW level on April 20, 1970, and a set of data taken at the 50 MW level on April 22 have been studied. These subchannel temperature data have been compared to calculations made with the COBRA II A Code.

Generally, calculated values nearly coincide with the experimental results. While this is not surprising at the level of ~ 1.5 in. above the fuel bottom, it is important that good correlation was found at the level of ~ 6 in. above the bottom of the fuel. This good correlation indicates that the COBRA code, as it is now used, is adequate in predicting fuel test assembly coolant channel temperatures in EBR-II.

Data taken across the bundle show coolant in central channels is, generally, at about the same temperature. Temperature tends to vary slightly from one side to the other because of the pin power variation that follows the same pattern. There is evidence that coolant in channels between the pins and the flow duct is substantially cooler than that of internal channels.

DISCUSSION OF RESULTS

EXPERIMENTAL COOLANT TEMPERATURES

Subchannel coolant temperatures of the PNL-17 fuel bundle measured via instrumented wire wraps are presented in Table 1 for EBR-II powers of 20 and 50 MW. Appropriate thermocouple calibration corrections have been applied to the data. During

the early phases of the experiment, thermocouples 10 and 12 became inoperative. In addition, thermocouples 1 and 7 provided obviously erroneous readings at 50 MW and were not included in subsequent data analysis.

TABLE 1. Experimental Subchannel Coolant Temperature Results

<u>Instrumented Pin Number</u>	<u>Axial^(a) Location</u>	<u>20 MW</u>	<u>50 MW</u>
1	1	705	731
2	2	734	782
5	2	735	790
6	1	709	722
7	2	735	735
10	2	708	Open
12	1	711	Open
13	2	731	793
Inlet		700	700
16	2	715	741
19	1	700	706
20	2	732	780
26	1	702	714
27	2	731	785
32	1	701	714
33	2	731	783
37	1	700	715
Outlet		766	853
Flow		53.3 gpm	53.3 gpm

a. 1 and 2 are approximately 1.5 and 6.0 in., respectively, downstream from the beginning of the start of the active fuel length.

Figures 4 through 7 present measured temperature distributions at bundle axial locations approximately 1.5 and 6.0 in. downstream from the beginning of the active fuel length, at power levels of 20 and 50 MW. As expected, thermocouples located 1.5 in. downstream of the start of the active section did not provide much heat transfer information since temperature disparities did not substantially develop over 1.5 in. The results at 1.5 in. showed no substantial temperature gradients across the wire wraps due to heat generation in the fuel pins. For a complete discussion of the temperature gradients which can exist across a wire wrap, refer to Appendix C.

The thermocouples located at ~6.0 in. downstream of the active section provided a radial temperature distribution across the bundle. As expected, the temperature variations in the center of the bundle are not great and the outer subchannels experience substantially lower temperature increases than internal subchannels. Similar results were obtained in the out-of-pile, 7-pin bundle investigations at BNW.⁽¹⁾ The experimental wire wrap temperatures are presented in Figure 12 (see page 18) in comparison with theoretical predictions. Additional discussion of these results will follow.

SUBCHANNEL CALCULATIONS

Subchannel calculations were performed using the COBRA II A Code⁽²⁾ which uses a rotating wire concept to model the effect of the wire wraps on the flow and enthalpy distribution in a fuel bundle. The COBRA II A Code is a specific utilization of the COBRA II Code⁽³⁾ applied to large, FFTF and LMFB type fuel bundles. The rotating wire concept of the COBRA II A Code accounts for the hydraulic-flow redistribution in the bundle caused by changes in wetted perimeter and flow area as wire wraps pass through the coolant subchannels. However, this concept does not model the forced diversion effect of the wire wraps as they pass between gaps separating adjacent fuel pins.

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FIGURE 4. Temperatures, Thermocouples and Wire Wrap Locations at 1.5 in. Downstream of the Beginning of the Active Fueled Section, 20 MW

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FIGURE 5. Temperatures, Thermocouples and Wire Wrap Locations at 6.0 in. Downstream of the Beginning of the Active Fueled Section, 20 MW

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FIGURE 6. Temperatures, Thermocouples and Wire Wrap Locations at 1.5 in. Downstream of the Beginning of the Active Fueled Section, 50 MW

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FIGURE 7. Temperatures, Thermocouples and Wire Wrap Locations at 6.0 in. Downstream of the Beginning of the Active Fueled Section, 50 MW

Calculations were performed for each half of the bundle using the local and axial power distributions of PNL-17 presented in Appendix B. Subchannel temperature distributions were calculated for the PNL-17 bundle and the conditions of power and flow provided by the EBR-II reactor. The following subcooled turbulent mixing correlation was used in the COBRA II A calculations.

$$\beta = 0.0124(D/S)R_e^{-0.1}$$

where β = mixing coefficient
 D = equivalent diameter
 S = rod spacing
 R_e = Reynolds Number.

The theoretical subchannel results are presented in Figures 8 through 11. These results display the same trends as the experimental results; namely, that coolant temperature variations in the interior of the bundle are not great and that the outer subchannels experience substantially lower coolant temperature increases than interior subchannels. These results also testify to the difficulty of experimentally resolving small temperature differences between subchannels.

A comparison of the experimental and theoretical results is presented in Figure 12 for axial positions of 1.5 and 6.0 in. from the start of the active section and for EBR-II power levels of 20 and 50 MW. Coolant temperatures are presented for each instrumented pin and its corresponding coolant subchannel. These results show the close correlation between the temperatures predicted by the theoretical model and the experimental results. It should be recognized that the experimental results were obtained over only one-half of a wire wrap pitch length and that additional experimentation is required to evaluate subchannel calculational models over several pitch

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FIGURE 8. Temperatures and Location of Thermocouples and Wire Wraps 1.5 in. Downstream of the Beginning of the Active Fueled Section, 20 MW

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FIGURE 9. Temperatures and Location of Thermocouples and Wire Wraps 6.0 in. Downstream of the Beginning of the Active Fueled Section, 20 MW

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FIGURE 13. Temperatures and Locations of Thermocouples and Wire Wraps 1.5 in. Downstream of the Beginning of the Active Fueled Section, 50 MW

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FIGURE 11. Temperatures and Locations of Thermocouples and Wire Wraps 6.0 in. Downstream of the Beginning of the Active Fueled Section, 50 MW

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FIGURE 12. Comparison of Experimental and Calculated Temperatures

lengths. However the present results indicate that calculational methods being used to predict EBR-II coolant channel performance are satisfactory. In Figure 12, the predicted coolant temperatures compare well with experimental results for both interior and exterior subchannels except for pin location No. 5. It is suspected that this poor agreement is due to the wire wrap slipping into an adjacent hot subchannel. As shown in Figure 11 for the 50 MW case, the adjacent subchannel has a temperature approximately that experimentally measured by instrumented pin No. 5. A similar argument applies to pin No. 5 for the 20 MW results.

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APPENDIX A

FABRICATION DETAILS

1914-1915

1914-1915

APPENDIX A

FABRICATION DETAILSFUEL PIN DATADescription of Fuel Pins

Fuel Composition	75 wt% UO_2 -25 wt% PuO_2
Uranium Enrichment	65 ± 1.0 wt% ^{235}U in U
Plutonium Enrichment	88 ± 0.5 wt% ^{239}Pu + ^{241}Pu in Pu
	0.5 wt% max ^{238}Pu
	11 ± 1 wt% ^{240}Pu in Pu
Fuel Pellet Diameter	0.194 ± 0.0015 in.
Fuel Column Length	13.5 ± 0.125 in.
Fuel Pellet Density	$93 \pm 2\%$ TD
Fuel Weight	67.4 ± 2 gms
Depleted UO_2 Pellet Diameter	0.194 ± 0.0015 in.
Depleted UO_2 Column Total Length	1.000 ± 0.063 in.
Cladding Material	316 SS (ASTM A-213 as modified)
Cladding Dimensions	0.230 in. ± 0.001 OD $\times 0.200$ in. ± 0.001 ID
End Cap Material	316 SS, ASTM A-276-55
Gas Plenum Volume	5.19 ± 0.1 cm ³
Plenum Gas	Helium + 1 cm ³ Xenon Tap
Gas Pressure at Room Temperature	1 atmosphere
Temperature Monitor	Silicon Carbide-Crusilite Beta
Temperature Monitor Dimensions	0.125 ± 0.002 OD $\times 0.50 \pm 0.016$

Fuel Pin Assembly and Quality Control

Pellets and internal pin hardware were loaded into each fuel pin from the top after the bottom end cap was welded in place, radiographed and helium leak tested. After the bottom end cap to cladding tube weld was established as acceptable,

the following loading sequence occurred: 1/2 in. of insulator pellets, 13 1/2 in. of fuel pellets, 1/2 in. of insulator pellets, the spacer tube with spacer cap, the spring and the top end cap. The top end cap was welded in place after a mixture of helium plus xenon was introduced into the pin interior. The gas mixture was at one atmosphere pressure. Pellets were checked statistically to assure compliance with specifications before loading.

Specifications were met for tube-to-end cap welds and each weld was carefully radiographed and helium leak tested to assure that it met specifications. OD's of welds were carefully measured to assure that weld diameter did not exceed the allowable dimension.

All fuel pins were wire wrapped with 0.054 in. diameter wire, hypodermic needle tubing or metal sheathed, ceramic insulated thermocouple. Where a solid wire was used, one end was welded to the top end cap and the wire then was wrapped on the fuel pin on a 12 in. pitch. The bottom end of the wire was pulled through the hole in the bottom end cap and TIG welded in place.

The hypodermic needle tubing was fastened to the fuel pin in much the same manner as described for the solid wire. The hypodermic tubing has a flux monitor wire inside in the length around the pin fuel column. Filler wire was pushed into the hypodermic tubing to position the flux monitor wire. The upper end of the tubes, with filler wire core were TIG welded to the top end caps. The filled hypodermic needle tubing then was wrapped on the pin on a 12 in. pitch, the bottom end which has a filler wire was pulled through the hole in the bottom end cap and TIG welded to the end cap.

The sheathed thermocouple wire was pushed through the hole in the top end cap until the proper length was through and was

then brazed to the top end cap at that point. After brazing, the thermocouple, with a length of solid wire below the hot junction, was wrapped on the pin on a 12 in. pitch. The solid end was pulled through the hole in the bottom end cap and TIG welded to it.

Prior to packaging for shipment, all pins were smear tested and found to be free from alpha and/or beta-gamma contamination.

The pins were shipped to Argonne National Laboratory where they were assembled into the instrumented subassembly test rig. This item was then shipped to EBR-II for irradiation.

..

NOTES

1. CLAD .230 ± .001 OD X .200 ± .001 ID, 316 SST.
- * 2. CALCULATED Q DIMENSIONS BETWEEN PINS.
3. WIRE .054 ± .0005 DIA, 316 SST; OR CHROMEL ALUMEL THERMOCOUPLE .054 ± .0005 DIA, 304 SST SHEATHED OR HYPODERMIC TUBING .054 ± .0005 DIA X .005 WALL, 316 SST OR 304 SST.
4. PINS MARKED #1 (8 REQ'D) WILL BE H BMOCP WIRE WRAPPED WITH HOT JUNCTION 4.57 ± .001 IN. B W Q OF BOTTOM WELD HOLE.
5. PINS MARKED #2 (8 REQ'D) WILL BE H BMOCP WIRE WRAPPED WITH HOT JUNCTION 9.0 ± .001 IN. A B W Q OF BOTTOM WELD HOLE.
6. PIN MARKED #3 (1 REQ'D) IS UN-FUELED INSTRUMENT CONDUIT.
7. PINS MARKED #4 (6 REQ'D) WILL BE HYPODERMIC NEEDLE TUBING WIRE WRAPPED. FLUX MONITOR WIRE WILL BE CONTAINED IN THE TUBING.
8. UNMARKED PINS WILL BE WIRE WRAPPED WITH SOLID WIRE (14 REQ'D).
9. ALL PINS THERMOCOUPLE WIRE WRAPPED WILL CONTAIN SILICON CARBIDE TEMPERATURE MONITORS (SEE DWG. SK-3-13481, ITEM 11).

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FIGURE 14 Proposed BNW Instrumented Subassembly for EBR-II Test (PNL-17)

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APPENDIX B
POWER DISTRIBUTION

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APPENDIX B
POWER DISTRIBUTION

TABLE B-1. Axial Power Distribution For PNL-17

<u>Active Distance, in.</u>	<u>X/L</u>	<u>Relative Power Normalized to Peak</u>	<u>Relative Power Sormalized to Average</u>
0	0	0.781	0.875
0.675	0.05	0.819	0.921
1.35	0.1	0.857	0.960
2.7	0.2	0.924	1.035
4.05	0.3	0.970	1.086
5.4	0.4	0.997	1.117
6.075	0.45	1.0	1.125
6.75	0.5	0.995	1.114
8.1	0.6	0.970	1.086
9.45	0.7	0.923	1.034
10.8	0.8	0.860	0.963
12.15	0.9	0.788	0.988
13.5	1.0	0.751	0.841

TABLE B-2. Local Radial Power Distribution Flux Ratio

<u>Pin No.</u>	<u>Peak/Average</u>
1	1.019
2	1.037
3	1.055
4	1.055
5	1.019
6	1.028
7	1.028
8	1.037
9	1.055
10	1.055
11	1.01
12	1.019
13	1.028
14	1.028
15	0
16	0.974
17	0.974
18	0.992
19	0.992
20	1.028
21	1.019
22	1.028
23	0.965
24	0.974
25	0.974
26	0.992
27	1.00
28	1.01
29	0.956
30	0.974
31	0.974
32	1.000
33	0.974
34	0.947
35	0.965
36	0.956
37	0.956

ϕ Average at 50 MW 447,000 Btu-hr-ft²
 20 MW 178,800 Btu/hr-ft²

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APPENDIX C

TEMPERATURE DISTRIBUTION IN WIRE WRAP

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APPENDIX C

TEMPERATURE DISTRIBUTION IN WIRE WRAP

Calculations were made of the temperature distribution of the instrumented wire wraps at the axial location of the thermocouple sensors. Since the wire wraps are in contact with the fuel pin there is a possibility that a temperature gradient exists across the wire wrap. A wire wrap was modeled, as shown in Figure 15, and the temperature distribution determined using the HEATING Code.⁽⁴⁾ A metal-metal contact width of 3 mil was assumed. An estimated temperature distribution at the boundary of the wire wrap was assumed. Results are presented in Figure 15. Calculations were performed to evaluate the effect of the contact coefficient between the thermocouple sheath and the Al_2O_3 filler. The average thermocouple bead temperature varied less than a degree even though the contact coefficient was varied from 40,000 to 10,000 Btu/hr-ft².

The maximum calculated difference between the thermocouple bead temperature and the subchannel bulk fluid temperature was approximately 7 °F for a flux of 532,000 Btu/hr-ft² which is near the average flux for 62.5 MW. The temperature gradient was proportionately less for smaller heat fluxes and for 50 MW is approximately 5 °F. Comparison of the experimental temperature measurements with theoretical temperature calculations shows no definite effect of a temperature difference as great as 5 °F. It is concluded that either the metal-metal contact or the estimated temperatures on the boundary of the wire wrap model were somewhat higher than the actual case. Consequently, the actual corrections due to the temperature gradient are somewhat less and are within the experimental error and scatter of the temperature data. Since the actual gradient across the wire wrap is not known and is in the order of only a few degrees, no correction was applied to the data.

However, the results of this analysis show that improved sub-channel temperature readings can be obtained if the thermocouple beads are in contact with the thermocouple sheath at locations far removed from the fuel pin.

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FIGURE 15. Calculated Temperature Distribution in Wire Wrap

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