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Dispersion Element Irradiation
Experiments
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A SUMMARY OF UO_2 - STAINLESS STEEL DISPERSION ELEMENT IRRADIATION EXPERIMENTS

A search of the literature to obtain information concerning enriched UO_2 -stainless steel dispersion type fuel elements has disclosed five programs which have pertinent information. The primary aim of the search was to discover maximum burnups and temperatures for safe use of this type of element. Tests were labeled a failure if swelling, cracking or fission products release resulted from the irradiation. Moderate swelling or blisters without the other indications was called a slight failure since further irradiation or higher temperature would undoubtedly cause complete failure.

Pratt and Whitney conducted an irradiation program at MTR (1953-1956) using 30 wt. % UO_2 in stainless steel matrix clad with Type 347 stainless steel. All of these plates were produced by BMI and were nominally $9/16'' \times 3/16'' \times .020''$. * The bulk of this program (96 samples) was conducted in capsules using water pressurized with approximately 4000 psi helium as the heat transfer media. Four samples had cores of UO_2 dispersed in Fe only. The remainder had elemental powder matrices of 18% Cr, 9% Ni, and 73% Fe. About half of the samples had UO_2 particles that were less than 3μ ; the remainder had 15-44 μ particle size. Most had .013'' thick cores; however, the first 24 had .008'' cores. These samples were subjected to burnups from .29 to 2.6% of total core atoms (4.4 to 39.7% burnup U235) at temperatures from 350 to 1080° F. Sixteen similar samples used sodium

* See reference for PWAC irradiations in appendix.

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pressurized with 65 psig helium as the heat transfer media. Eight of these samples irradiated at 1765° F to a burnup of 1% of the total core atoms failed. Two at 1400° F and .75% burnup failed while the other six at these conditions appeared all right. The two which failed were the plates with small UO_2 particles. Thus, it would appear this is a border line condition. It was noted that the larger particle size exhibited less tendency toward core cracking.

A second program was conducted by NDA (1954-1956) and a final report issued.* Of the eight irradiated capsules containing twelve plates and four pins, two plates and one pin exhibited irradiation damage, one melted from improper cooling, and one leaked at a brazed joint. The plates were produced by GEANP and were nominally 1.5" x .25" x .040" with the core being .030" thick. The pins were produced by Sylvania and were 2.75" long of .080" diameter with a core diameter of .070". All plates were 30 wt. % UO_2 in Type 310 stainless steel clad with Type 310 stainless steel; all pins were 30 wt. % UO_2 in prealloyed Type 316 stainless steel clad with Type 316 stainless steel. Sodium pressurized with helium (1/3 atm.) was used as heat transfer media.

A third program was that of GEANP (1953-1955).** Four single plate samples 1 3/4" x 3/4" x .012" were irradiated. The cores were 30 wt. % UO_2 in Type 310 stainless steel clad with .004" Type 310 stainless steel. Three gave satisfactory results; however, the one with the

* See reference for NDA irradiations in appendix.

** See reference for GEANP irradiations in appendix.

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least burnup and the lowest temperature failed. This program also included three multistage elements in which no failure occurred.

The four program - - - conducted by KAPL (1953-1956) - - - involved the examination of both plate (ribbon) and pin type fuel samples from 5-30 wt. % UO_2 in several stainless steel composition matrices. * Most of the pins were clad with .010" of Type 347 or 304 stainless steel; plates were Type 347 and 310 stainless steel clad .004" or .010" thick. Both prealloyed and elemental powder matrix material was used.

The fifth program was that associated with the APPR and was conducted by ORNL. ** All tests were made using Type 304 stainless steel as matrix and cladding. ORNL 17, Phase II was the irradiation of one 18 plate assembly having 24 $7/8"$ x $2.66"$ x $.030"$ plates with matrices of the following compositions: 18.75, 22.18, and 26.89 wt. % UO_2 (six plates of each). Cladding was .008", .010", and .012" respectively. ORNL 21, Phase I was made using smaller plates ($2.65"$ x $.69"$ x $.020"$) - - - 22 were made with 25.8 wt. % UO_2 and 4 were of 17.9 wt. % UO_2 . Cladding was either .005" or .007" thick. ORNL 21, Phase III involved 12 plates ($4.5"$ x $.815"$ x $.030"$) having cores of 17.92 wt. % UO_2 . Cladding was .005" thick. The oxides were prepared by four different methods and the plates were rolled by three techniques. These specimens contained .19 to .39 wt. % natural B_4C burnable poison. There were no failures in these tests.

* See reference for KAPL irradiation in appendix.

** See reference for ORNL irradiation in appendix.

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A plot of the tests has indicated a curve may be drawn to separate failure from non-failure conditions relative to burnup and testing temperature. Two failures appear on the non-failure side of the separating line. However, since there are almost eight times as many non-failure tests at higher temperatures and/or higher burn-up it would indicate that other factors or inaccurate test control caused these failures.

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APPENDIX

REFERENCES

PWAC Irradiations

BMI-X-101	Radiation Specimens of a Fuel Element for Super Critical Water Reactor.
BMI-X-102	Radiation Specimens of a Fuel Element for the Super Critical Water Reactor -experiment PW-1-4 and PW-1-5.
BMI-X-108	Radiation Specimens of a Fuel Element for the Super Critical Water Reactor -experiment PW-1-6, PW-1-7, and PW-1-8.
BMI-X-116	Radiation Specimens of a Fuel Element for the Super Critical Water Reactor-experiment PW-1-9, PW-1-10, and PW-1-11.
BMI-X-125	Radiation Specimens of a Fuel Element for the Super Critical Water Reactor-experiment PW-1-12 and PW-1-13.
PWAC 544	Nuclear Engineering Program-Engineering Progress Report No. 14 for October 1 to December 31, 1954.
PWAC 551	Nuclear Engineering Program-Engineering Progress Report No. 15 for January 1 to March 31, 1955.

NDA Irradiations

NDA 37	Fuel Element Irradiation Program Final Report, March, 1957.
ANL 5734	Examination of Irradiated Stainless Steel-UO ₂ Fuel Specimens for Nuclear Development Associates, Inc., July, 1957.

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GEANP Irradiations

APEX 234

GE-ANP-3 Experiments at MTR, June, 1955.

KAPL Irradiations

WASH 741

Performance of Fuel Elements at Elevated Temperatures, September, 1957.

KAPL 1688

A Summary of Irradiation Studies of UO_2 -Stainless Steel Dispersion Elements.

ORNL Irradiations

CF 57-5-50

Summary of APB-ORNL Materials Meeting, May, 1957.

To be published data on ORNL-21, Phase II by
L. D. Schaffer, ORNL

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FUEL SAMPLE DATA

SAMPLE NO.	LOADING wt%UO ₂ *	MATRIX	CLADDING	BURNUP	C-calc.	ESTIMATED	THERMAL	TIME HRS.	RESULTS
				%U-235	M-meas.	SURFACE	FLUX		
						TEMP, °F	neutrons cm ² sec x 10 ⁻¹³		
P and W Samples									
1-2	30	18, 9, 73E**	.006"-347SS	5.2 C	.34 C	350	5.5	500	6 plates; no failures
1-4	30	18, 9, 73E	.006"-347SS	13.3 C	.87 C	700	13.7	600	8 plates; no failures
1-5	30	18, 9, 73E	.006"-347SS	5.31 M	.35 M	550	9.1	610	8 plates; no failures
1-6	30	18, 9, 73E	.004"-347SS	4.4 M	.29 M	650	9.1	425	8 plates; no failures
1-7	30	18, 9, 73E	.004"-347SS	5.38 M	.35 M	650	11	412	8 plates; no failures
1-8	30	18, 9, 73E	.004"-347SS	12.1 M	.79 M	700	7	1038	8 plates; no failures
1-9	30	18, 9, 73E	.004"-347SS	12.4 C	.81 C	850	12	633	8 plates; no failures
1-10	30	18, 9, 73E	.004"-347SS	39.7 M	2.6 M	650	7	2550	8 plates; no failures
1-11	30	18, 9, 73E	.004"-347SS	23.45 M	1.54 M	800	12		8 plates; no failures
1-12	30	18, 9, 73E	.004"-347SS	33.3 M	2.17 M	766	7	4015	8 plates; no failures
1-13	30	18, 9, 73E	.004"-347SS	28.6 M	1.86 M	1080	12	2415	8 plates; no failures
SP-2	30	18, 9, 73E	.004"-347SS	12.9 M	.84 M	1400	7	1889	8 plates; 6 no failure
SP-3	225	18, 9, 73E	.004"-347SS	17.4 M	1.14 M	1765	6.5	880	2 cracked 8 plates; all swelled and cracked
NDA Samples									
1-2	30	310SS	.005"-310SS	4.6 M	.30 M	1260	6	370	2 plates; no failures
1-3	30	310SS	.005"-310SS	4.8 M	.31 M	1420	5.7	420	2 plates; no failures
1-4	30	310SS	.005"-310SS	2.7 C	.18 C	1200	3.5	370	2 plates; no failures
1-5	30	310SS	.005"-310SS	2.8 C	.18 C	1280	3.5	380	2 plates; no failures
1-6	30	310SS	.005"-310SS	3.0 M	.20 M	1470	4.0	360	2 plates; no failures
1-9	30	310SS	.005"-310SS	1.8 M	.12 M	1560	3.3	370	2 plates; no failures
1-1	30	316SS	.005"-310SS	4.2 C	.27 C	840	5.2	380	2 pins; no failure
1-7	30	316SS	.005"-310SS	3.0 C	.20 C	1160	3.8	270	2 pins; 1 warped and surface eruptions

* Approximately 93% enriched for all specimens

** Elemental powder

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Fuel Sample Data (continued)

SAMPLE NO.	LOADING wt%UO ₂ *	MATRIX	CLADDING	BURNUP	C-calc.	ESTIMATED	THERMAL	TIME HRS.	RESULTS
				%U-235	M-meas. %tot. atoms	SURFACE TEMP, °F	FLUX neutrons cm ² -sec x 10 ⁻¹³		
GEANP Samples									
3B	30	310 SS	.004"-310SS	.65 C	.04C	1650		100	1 plate; no failure
3C	30	310 SS	.004"-310SS	.85 C	.06C	1780		100	1 plate; no failure
3D	30	310 SS	.004"-310SS	1.57 C	.10C	1650		250	1 plate; no failure
3E	30	310 SS	.004"-310SS	.51 C	.03C	1600		120	1 plate; ruptured
1B	30	310 SS	.004"-310SS	1.09 M	.09M	1550		288	2 stage; no failure
1C	30	310 SS	.004"-310SS	.58 C	.04C	1650		68	2 stage; no failure
1D	30	310 SS	.004"-310SS	.93 C	.06C	1650		100	4 stage; no failure
KAPL Samples									
1-8 LTS 23	30	18, 9, 73E	.008"-347SS	2.3 C	.15 C	325			Good stability
1-8 LTS 24	30	18, 9, 73E	.008"-347SS	5.2 C	.34 C	325			Good stability
14-5	10	18, 9, 73E	.006"-347SS	3.3 C	.07 C	325	9.5	1918	Good stability
	23			50	2.45	554			Swelled slightly
14-6	10	18, 9, 73E	.006"-347SS	20 C	.40 C	662	12	1130	Good stability
14-6	30	18, 9, 73E	.006"-347SS	19 C	1.24 C	662			Good stability
1-13 B-1	10	23, 17, 60	.004"-310SS	33-35C	.68 C	662			Good stability
1-13 B-1	20	23, 17, 60	.004"-310SS	33-35C	1.43 C	662			Good stability
1-13 B-1	30	23, 17, 60	.004"-310SS	33-35C	2.21 C	662			Good stability
	23			3	.15	770			Good stability
1-22 C-1	30	18, 12, 70	.007"-347SS	28	1.82	797			Good stability
1-22 C-1	30	18, 12, 70	.010"-347SS	24	1.56	797			Slight swelling
1-22 C-2	30	18, 12, 70	.010"-347SS	28	1.82	797			Swelled, released fission gas
1-22 C-2	30	18, 12, 70	.007"-347SS	34	2.21	797			Slight swelling
1-22 C-3	30	18, 12, 70	.007"-347SS	40	2.60	797			Swelled, released fission gas

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Fuel Sample Data (continued)

SAMPLE NO.	LOADING wt%UO ₂ *	MATRIX	CLADDING	BURNUP	C-calc.	ESTIMATED	THERMAL	TIME HRS.	RESULTS
				%U-235	M-meas.	SURFACE	FLUX		
						TEMP, °F	neutrons cm ² -sec x 10 ⁻¹³		
KAPL Samples									
1-22 C-3	30	18,12,70	.010"-347SS	35	2.28	797			Swelled, released fission gases
	24.5			2	.10	886			Good stability
	23			21	1.03	824			Swelled, released fission gases
18-43	24	2-347SS	2-.010" 347SS	8.2 M	.42 M	842			Good stability
		1-18,12,70	1-.010" 304SS						
1L-30	24	2-347SS	2-.010" 347SS	3 M	.15 M	842			Good stability
(LTSB 20)		1-18,12,70	1-.010" 304SS						
18-30	23	347SS	.010"-347SS	6.7 M	.33 M	860		790	Good stability
18-35	23	347SS	.010"-347SS	28 C	1.37 C	860			Good stability
	24.5			12	.62	905			Good stability
	28.5			12	.74	905			Good stability
	25			5-11	.27-.58	932			Good stability
18-13	30	347SS	.010"-347SS	8.9 M	.58 M	932		1000	Good stability
18-14	30	347SS	.010"-347SS	3.7 M	.24 M	932		620	Good stability
18-44	24	2-347SS	2-.010"-347SS	16 M	.82 M	932			Slight gas release, no swelling
		1-18,12,70	1-.010"-304SS						
1L-46L	25	18,8,74E	.010"-304SS	12-25	.64-1.3	977		4530	Swelled, retained fission gas
	30			12-25	.78-1.63	977			Swelled, retained fission gas
1-14 B-3	5	23,17,60	.004"-310SS	32-55 C	.31-.54 C	977			Good stability
1-14 B-3	10	23,17,60	.004"-310SS	32-55 C	.64-1.10 C	977			Good stability
1-14 B-3	30	23,17,60	.004"-310SS	32-55 C	2.08-3.58 C	977			Good stability

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Fuel Sample Data (continued)

SAMPLE NO.	LOADING wt%UO ₂ *	MATRIX	CLADDING	BURNUP	C-calc. M-meas.	ESTIMATED SURFACE TEMP, °F	THERMAL FLUX	TIME HRS.	RESULTS
				%U-235	%tot.atoms		neutrons cm ² -sec x 10 ⁻¹³		
1-18 B-9	30	18,12,70		8.7 C	.57C	977			Good stability
1-18 B-9	30	18,12,70		7.2 C	.47C	977			Good stability
1-18 B-10	30	18,12,70		17 C	1.11C	977			Good stability
1-18 B-10	30	18,12,70		14. C	.91C	977			Good stability
18-22	23		.010"-347SS	4.6 M	.23M	995		1162	Good stability
	24.5	347 SS		18	.94	1058			Grew slight,
	28.5			18	1.12	1058			retained fission gas
1L-40 C-21	25	18,12 E	.010"-304SS	12	.64	1112			Good stability
1L-40 C-22	25	18,12 E	.010"-304SS	25	1.23	1112		4320	Slight swelling,
1L-40 C-23	25	18,12 E	.010"-304SS	21	1.11	1112		4320	no cracks
1L-40 C-24	25	18,12 E	.010"-304SS	8	.42	1112		4320	Swelled, cracked,
18-28	23	347 SS	.010"-347SS	18	.88	1112			released fission gas
18-29	23	347 SS	.010"-347SS	12.6	.62	1112			Swelled, cracked
18-27	23	347 SS	.010"-347SS	21	1.03	1202			released fission gas
14-9	5	23,17,60	.004"-310SS	19-20	.20	1292		814	Good stability
14-9	10	23,17,60	.004"-310SS	19-20	.40	1292		814	Good stability
14-9	20	23,17,60	.004"-310SS	19-20	.84	1292		814	Good stability
14-9	30	23,17,60	.004"-310SS	17	1.11	1292		814	Good stability
18-L-72-L	25	18,12,70	.010"-304SS	48 C	1.33 C	1472			Good stability
									Swelled, cracked
									and released fission
									gas

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Fuel Sample Data (continued)

SAMPLE NO.	LOADING wt%UO ₂ *	MATRIX	CLADDING	BURNUP %U-235	C-calc. M-meas. %tot. atoms	ESTIMATED SURFACE TEMP, °F	THERMAL FLUX neutrons cm ² -sec x 10 ⁻¹³	TIME HRS.	RESULTS
KAPL Samples									
14-12	5	23, 17, 60	.004"-310SS	19-20	.20	1832		1630	Good stability
14-12	10	23, 17, 60	.004"-310SS	19-20	.40	1832		1630	Surface bubbles, fission gases retained.
14-12	20	23, 17, 60	.004"-310SS	19-20	.84	1832		1630	Surface bubbles, fission gases retained
14-12	30	23, 17, 60	.004"-310SS	19-20	1.30	1832		1630	Surface bubbles, fission gases retained
18-71L	25	18, 12, 70	.010"-304SS	33 C	1.75 C	2192			Swelled, cracked and released fission gas
ORNL-21-Phase I									
18 plates	25.8	304 SS	.005"	35±15C	1.8±8C	186	5		No failure
4 plates	25.8	304 SS	.or 304LSS	20±10C	1.0±.5C	186	11		No failure
4 plates	17.9	304 SS	.007"	20±10C	.75±38C	186	11		No failure
ORNL-17-Phase II									
1-18	18.75	304 SS	.008"-304LSS	16 M	.7 M	212	6.6	400	No failure
plate	22.18	304 SS	.010"-304LSS	18 M	.9 M	212	6.6	400	No failure
assembly (6 of each)	26.89	304 SS	.012"-304LSS	12 M	.8 M	212	6.6	400	No failure
ORNL-21-Phase III									
A0	17.92	304 SS	.005"-304LSS	52.5 M	1.93 M	190	6		No failure
A10	17.92	304 SS	.005"-304LSS	40 M	1.48 M	190	6		No failure
A30	17.92	304 SS	.005"-304LSS	45.4 M	1.68 M	190	6		No failure

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Fuel Sample Data (continued)

SAMPLE NO.	LOADING wt%UO ₂ *	MATRIX	CLADDING	BURNUP	C-calc.	ESTIMATED	THERMAL	TIME HRS.	RESULTS
				%U-235	M-meas. %tot. atoms	SURFACE TEMP, °F	FLUX neutrons cm ² -sec x 10 ⁻¹³		
ORNL-21-PHASE III (continued)									
B0	17.92	304 SS	.005"-304LSS	10.5 M	.39 M	190	6		No failure
B10	17.92	304 SS	.005"-304LSS	40 M	1.48 M	190	6		No failure
B30	17.92	304 SS	.005"-304LSS	53.5 M	1.98 M	190	6		No failure
C0	17.92	304 SS	.005"-304LSS	51.2 M	1.89 M	190	6		No failure
C10	17.92	304 SS	.005"-304LSS	13.1 M	.48 M	190	6		No failure
C30	17.92	304 SS	.005"-304LSS	56.9 M	2.10 M	190	6		No failure
D0	17.92	304 SS	.005"-304LSS	53.1 M	1.96 M	190	6		No failure
D10	17.92	304 SS	.005"-304LSS	48.1 M	1.78 M	190	6		No failure
D30	17.92	304 SS	.005"-304LSS	29.2 M	1.08 M	190	6		No failure

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Burnups vs Surface Temperature for Fully Enriched UO_2 - Stainless Steel Dispersion Fuel Samples