HEAVY WATER ORGANIC COOLED REACTOR

FABRICATION OF SAP-CLAD URANIUM CARBIDE FUEL ASSEMBLIES FOR THE HWO CR IRRADIATION TESTING PROGRAM

By
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ABSTRACT

The SAP*-clad uranium carbide (UC) fuel system has been under investigation for use in the Heavy Water Organic Cooled Reactor system (HWOCR).

The materials (SAP and UC), critical processes (eutectic bonding of fuel rod end closures), general design criteria, and current status are described for six fuel element assemblies fabricated for the irradiation test program.

*SAP (sintered aluminum powder) is an aluminum base alloy which is dispersion-strengthened with Al_2O_3 .

5 4 3 2 1

6 5 4 3 2 1

7 6 5 4 3 2 1

I. INTRODUCTION

The SAP-clad uranium carbide fuel system has been under investigation as part of the HWOCR Program. A series of SAP UC fuel element assemblies have been fabricated for irradiation testing. Two organic cooled reactor sites owned and operated by the Atomic Energy of Canada Limited (AECL) have been used for irradiation testing: the U-3 loop at the NRU reactor, located at Chalk River Nuclear Laboratory (CRNL), Ontario, Canada, and core positions in the WR1 reactor, located at Whiteshell Nuclear Reactor Establishment, Manitoba, Canada.

As of July 1967, the first irradiation test (NRU-305) had been discharged from the U-3 loop after attaining its design burnup of 10,000 Mwd/MTU and the post-irradiation examination was nearing completion. The second test (NRU-Alt. I) had attained an estimated peak burnup of $\sim 13,000$ Mwd/MTU and was continuing irradiation. Two irradiation tests (WR1-951 and -952) were in-pile at the WR1 reactor and had accumulated estimated peak burnups of $\sim 10,000$ and $\sim 1,000$ Mwd/MTU, respectively. Additional experiments (NRU-305 Alt. II and WR1-954) have been fabricated and are awaiting insertion at the respective test facilities.

Data pertinent to each of these six irradiation tests are presented in Table 1.

TABLE 1
DESIGN CRITERIA AND STATUS OF HWOCR
SAP UC IRRADIATIONS

	NRU-305	NRU-305 Alt. I	NRU-305 Alt. II	WR1-951	WR1-952	WR1-954
Design Peak Burnup (Mwd/MTU)	10,000	10,000 min	15,000 min	15 to 20,000	15,000 min	15 to 20,000
Peak Linear Heat Release Rate (kw/ft)	21	21	27	16	16	25
Peak fuel centerline temperature (°F)	2,100	2,100	2,400	2,000	2,200	2,100
Peak Cladding Temperature (°F)	850	850	850	800	800	850
Reactor Insertion Date	7/65	5/66	-	5/66	5/67	-
Peak Burnup Attained to 7/67	10,000*	13,000	-	10,000	1,000	-
Status	Hot Cell Examination in progress	In test	Ready for test	In test	In test	Ready for test
UC Fuel Weight (kg)	31.3	31.3	62.6	52	52	20
UC Fuel Enrichment (wt% U-235)	1.5	1.5	1.5	3.0	3.0	4.9
Cladding Alloy	XAP 001	XAP 001 XAP 005	XAP 001	XAP 005	XAP 005	XAP 005
Fuel Rod Length (in.)	16-1/4	16-1/4	16-1/4	43-1/2	43-1/2	43-3/4
Fuel Rods/Bundle	18	18	18	19	19	7(+ 12 unfueled)
Fuel Bundles/Irradiation Test Instrumentation	3 [†]	3 [†]	6	2	2	2
Cladding thermocouples	7	19	18	27	27	20
Coolant thermocouples	5	5	6	2	2	13
In-fuel thermocouples				4	4	2
Flux monitors				2	2	3
Pressure sensor						1

*Discharged 4/66 upon failure of Zr- UO_2 rods

†Plus two Zr- UO_2 fuel bundles

II. MATERIALS AND PROCESSES

A. SAP

In-pile testing of SAP-clad fuel elements for the HWOCR program has been limited to SAP alloys XAP 001 and XAP 005. These SAP alloys are dispersion-strengthened with 5 to 7 wt % Al_2O_3 and were produced by Aluminum Company of America (ALCOA). The properties of the two SAP alloys are essentially the same, with the main difference being refinements in production of billet stock, which greatly reduced the amount of particulate inclusions and degree of oxide segregation in XAP 005. Cross sections typical of SAP cladding tubes extruded from XAP 001 (ALCOA 1962 production) and of XAP 005 (ALCOA 1964 production) are shown in Figures 1 and 2. Typical properties of several lots of extruded SAP cladding tubes are presented in Tables 2 and 4. Typical cladding geometries used in the HWOCR irradiation experiments are illustrated in Figure 3. The SAP Handbook* will provide a comprehensive reference on SAP properties.

B. URANIUM CARBIDE

Hyperstoichiometric UC, which contains some second phase UC_2 , has been found to be compatible with SAP up to $950^\circ\text{F}^\dagger$ which is well above the maximum anticipated fuel-clad interface temperature for the HWOCR.

The arc-melted and cast UC fuel slugs used in the irradiation testing program have been highly characterized with regard to fabrication procedures and techniques, physical characteristics, and structural differences. Of the 250 kg of UC fuel slugs in the HWOCR irradiation experiments, the chemical composition, density, and microstructure have been individually characterized for 45 kg (~350 fuel slugs).

Typical UC fuel slugs are shown in Figure 4. Typical UC fuel slug specification requirements (WR1-951 and 952) are presented, and compared with analytical data, in Table 5.

*"SAP Handbook," AI-CE-Memo-24 (to be published)

†P. E. Elkins and W. R. Kerr, "Compatibility of Uranium Carbide with Dispersion Strengthened Aluminum," AI-64-103 and Addendum (May 15 and November 20, 1964)

a. Segregation Pattern
Following Surface
of Tube

6427-2-1

b. Segregation Pattern
Not Following Surface
of Tube

6424-4-1

Figure 1. Cross Sections of Typical XAP 001 Cladding Tubes
(Sheet 1 of 2)

c. Scattering of Small Inclusions

6417-1-1

d. Rather Large Inclusions

6426-7-2

Figure 1. Cross Sections of Typical XAP 001 Cladding Tubes
(Sheet 2 of 2)

6347-5-1

Figure 2. Typical Cross Section of Inclusion-Free and Segregation-Free XAP-005 Cladding Tube

TABLE 2
CHEMICAL ANALYSIS OF SAP FUEL CLADDING TUBES USED
IN HWO CR IRRADIATION EXPERIMENTS

	XAP 001		XAP 005			Current Specification Requirements
	NRU-305 NRU-305 Alt. I	NRU-305 NRU-305 Alt. I NRU-305 Alt. II	NRU-305 Alt. I	WR1-951 WR1-952	WR1-954	
Al ₂ O ₃ (wt %)	6.31	6.86	6.36	5.96	6.00	5.0 to 8.0
Boron (ppm)	<3	<3	<10	<10	<10	20 maximum
Cadmium (ppm)	<10	<10	<10	<10	<10	30 maximum
Calcium (ppm)	50	50	50	<100	<100	-
Carbon (wt %)	0.68	0.59	0.54	0.67	0.61	0.95 maximum
Chromium (ppm)	1	10	5			
Copper (ppm)	10	10	10	<20	<20	
Gallium (ppm)	50	50	50	200	<100	
Iron (ppm)	500	1000	500	<500	<500	2000 maximum
Lead (ppm)	10	<10	10	<40	<40	
Magnesium (ppm)	20	30	10			
Molybdenum (ppm)	<10	<10	<10	<10	<10	
Nickel (ppm)	10	10	10			
Silicon (ppm)	>1000	>1000	900	<300	<300	2000 maximum
Sodium (ppm)				<500	<100	
Tin (ppm)	10	10	10	<50	<50	300 maximum
Titanium (ppm)	20	<10	20			
Vanadium (ppm)	25	50	10			
Zinc (ppm)	<100	<100	<100	<40	<40	500 maximum
Zirconium (ppm)	500	10	<10	<50	<50	
Nitrogen (ppm)	110	110	242	191	223	800 maximum
Hydrogen (ppm)	17	30	28	37	22	25 maximum

TABLE 3
MECHANICAL PROPERTIES OF SAP FUEL CLADDING
TUBES USED IN HWO CR IRRADIATION EXPERIMENTS

SAP Alloy	Irradiation Experiments	Number Tests	Test Temperature (°F)	0.2% Yield Strength (psi)	Ultimate Strength (psi)	Elongation (%)
XAP 001	NRU-305, NRU-305 Alt I	2	RT	31,650	40,150	6.5
XAP 001	NRU-305, NRU-305 Alt I, NRU-305 Alt II	3	RT	29,733	41,033	11.0
XAP 005	NRU-305 Alt I	2	RT	29,250	36,600	9.0
XAP 005	WR1-951, 952	10	RT	26,240	37,150	11.3
XAP 005	WR1-954	9	RT	28,720	35,170	9.1
Current Specification Requirements			RT	19,000	32,000	10.0
XAP 001	NRU-305, NRU-305 Alt I	2	600	15,750	17,800	10.0
XAP 005	NRU-305 Alt I	2	600	14,600	16,150	8.0
XAP 001	NRU-305, NRU-305 Alt I	2	700	13,100	14,500	5.0
XAP 005	NRU-305 Alt I	2	700	12,900	13,750	4.5
XAP 001	NRU-305, NRU-305 Alt I	2	850	10,700	11,500	2.0
XAP 001	NRU-305 Alt I	2	850	9,800	10,700	2.0
XAP 001	NRU-305, NRU-305 Alt I, NRU-305 Alt II	3	900	10,100	10,900	2.0
XAP 005	WR1-951, 952	10	900	9,180	8,570	2.8
XAP 005	WR1-954	10	900	9,980	9,270	3.0
Current Specification Requirements			900	5,000	6,000	2.0

TABLE 4
BURST TEST RESULTS OF SAP FUEL
CLADDING TUBES USED IN U-305
IRRADIATION EXPERIMENTS

SAP Alloy	Irradiation Experiment	Test Temperature (°F)	Number Tests	Burst Stress (psi)
XAP 001	U-305, U-305 Alt I	RT	2	38,450
XAP 001	U-305, U-305 Alt I, U-305 Alt II	RT	2	39,450
XAP 005	U-305 Alt I	RT	2	37,250
XAP 001	U-305, U-305 Alt I, U-305 Alt II	600	2	18,250
XAP 001	U-305, U-305 Alt I	650	2	16,650
XAP 005	U-305 Alt I	650	2	14,650
XAP 001	U-305, U-305 Alt I, U-305 Alt II	700	2	15,800
XAP 001	U-305, U-305 Alt I	750	2	13,150
XAP 005	U-305 Alt I	750	2	11,950
XAP 001	U-305, U-305 Alt I, U-305 Alt II	800	2	14,350
XAP 001	U-305, U-305 Alt I	850	2	9,650
XAP 005	U-305 Alt I	850	2	9,200
XAP 001	U-305, U-305 Alt I, U-305 Alt II	900	2	9,260
XAP 001	U-305, U-305 Alt I	950	2	8,450
XAP 005	U-305 Alt I	950	2	7,400
XAP 001	U-305, U-305 Alt I, U-305 Alt II	1000	2	6,450

8-29-67 UNC

7680-5601

Figure 3. Cladding Geometries Used in HWO CR Irradiation Tests

7568-4045

Figure 4. Typical UC Fuel Slugs

TABLE 5
COMPARISON OF URANIUM CARBIDE SPECIFICATION WITH
ANALYSIS OF FUEL USED IN THE WR1-951
IRRADIATION TEST

Impurity Element	Specification Requirement (ppm - weight) (max.)	Analysis* (10 casting heats - 500 kg total) (ppm)	
Aluminum	100	<10	
Barium	10	<10	
Beryllium	1	<1	
Bismuth	2	<2	
Boron	3	<0.5	
Calcium	100	<20	
Cadmium	1	<0.5	
Chromium	50	<5	
Cobalt	10	<2	
Copper	100	10	
Iron	300	20	
Lithium	8	<2	
Magnesium	50	<5	
Manganese	25	<5	
Nickel	200	<10	
Nitrogen	300	<40	
Oxygen	300	<100	
Lead	10	<2	
Silicon	200	<10	
Sodium	75	<50	
Tin	10	<2	
Titanium	75	<20	
Vanadium	15	<2	
Zinc	60	<10	
Molybdenum + Niobium	500	<200	
Total	<2500	<539	
Alloying Constituents		<u>min.</u>	<u>max.</u>
Carbon (wt %) [†]	5.1 ± 0.25	4.97	5.16
Uranium-235 (wt %)	3.00 ± 0.05	2.96	3.01
Density (% of Theor.) [§]	98.5 (min.)	99.0	99.8

*Maximum, regardless of heat

[†]Five random samples from each heat (total of 50)

[§]Seventy characterized fuel slugs

C. EUTECTIC BONDING

Eutectic bonding was developed at AI as an end closures technique for fabricating SAP-clad UO_2 fuel elements for the Organic Moderated Reactor Experiment (OMRE).^{*} Four irradiation experiments were tested in the OMRE for periods up to two years. Two of these contained 25 fuel rods; two contained 24 fuel rods. No failures in the eutectic bonded fuel rod end closures occurred.

A total of 660 fuel rod end closures have been fabricated for HWOCR irradiation experiments. The average time "in-pile" of these end closures was one year, as of July 1967, with no failures occurring.

In addition to the in-pile operating experience accumulated on eutectic bonded fuel rod closures, more than 1,000 end closures have been fabricated and used to evaluate the mechanical properties of SAP cladding tubes. Typical mechanical property tests are short-term elevated temperature burst tests (Figure 5) and long-term (500 to 5,000 hr), elevated temperature (750 to 900°F), biaxial stress rupture tests (Figure 6). No failure has occurred in a eutectic bonded end closure during these tests.

A cross section of an eutectic bonded closure is shown in Figure 7. A silver-plated, 1100 Aluminum Alloy end plug is bonded to a SAP tube end by application of temperature and pressure. Bonding occurs when the molten silver-aluminum eutectic, formed at the silver-1100 Aluminum Alloy end plug interface, wets and diffuses into the SAP tube wall. Bonds were made in an inert atmosphere chamber such as illustrated in Figure 8a. The internal bonding arrangement is shown in Figure 8b. Induction heating was used while pressure was applied by a collar acting on a segmented collet (Figure 8c.)

Acceptance of eutectic bonded closures for use in irradiation experiments is based on helium leak inspection and destructive examination of sample end closures. All of the SAP clad fuel rods fabricated by AI have contained either helium or a helium-argon gas mixture for heat transfer purposes. Helium leak inspection has been accomplished by enclosing completed fuel rod assemblies in a secondary container which is subsequently evacuated and monitored for helium

^{*}J. L. Ballif, III, W. H. Friske and R. B. Gordon, "Fabrication and Testing of Prototype APM-Clad UO_2 Fuel Elements," New Nuclear Materials Including Non-Metallic Fuels, Vol II, IAEA, Vienna (1963)

7680-40213

Figure 5. SAP Burst Test Specimens

7680-1850

Figure 6. SAP Stress-Rupture Specimens

7973-1-1

a. Cross Section

7876-9 4

b. Ag - Al Eutectic Formation on End Plug Face

7876 8-2

c. SAP - 1100 Al Bond Interface

Figure 7. Eutectic Bonded End Closure

a. Exterior

7660-1801

b. Interior

7600-51160

c. Bonding Collet Details

7680-40220

Figure 8. Inert Atmosphere Bonding Chamber

leakage on a helium leak detector with a sensitivity of $\geq 2 \times 10^{-10}$ std cc/sec. Destructive examination of sample end closures has been found to be the most effective technique for assuring helium leak-tight, eutectic bonded closures. Typical test specimens are shown in Figure 9. The destructive examination

Figure 9. Chisel Test Specimens

7680-40214

consists of longitudinal sectioning through the cladding wall and attempting to separate the cladding tube-end plug interface with a sharp chisel. Test specimens are examined before and after each batch of fuel rod assemblies is bonded (a batch usually consists of ~ 15 to 40 SAP fuel tubes). Test specimens are rated as: "A" (good bond), "B" (fair bond), and "C" (poor bond). Bonding of fuel rod assemblies is begun only if the initial test specimen is rated as an "A" bond. A batch of fuel rods is considered acceptable if the final test specimen is rated as being an "A" or "B" bond. If the final test specimen is rated as a "C" bond, the end closure on the fuel rod assembly bonded just prior to the test specimen is destructively examined (even if helium-tight) and rated. Examination of fuel rod closures is continued until an "A" or "B" bond is located. Of ~ 50 fuel rod batches (~ 900 end closures), fabricated for HWOCR irradiation experiments, two batches were partially destructively examined, resulting in disassembly of four fuel rod assemblies for refabrication. The reliability of the "chisel test" is attested to by the fact that a yield $>98\%$ was realized in fuel rod fabrication.

III. EXP-NRU-305 IRRADIATION TEST SERIES

A. EXP-NRU-305

The NRU-305 irradiation experiment, shown in Figure 10, consisted of three SAP clad UC, and two Zircaloy 2 clad- UO_2 fuel bundles. Each SAP-UC fuel bundle contains eighteen fuel rods, 16-1/4 in. long, in a circular array (Figure 11) positioned by Type 304 stainless steel end spacers. The rods of the outer row are fastened to the top and bottom end spacers by flat-head machine screws. The rods of the inner row are fastened only to the upper end spacers, and are free to float in the lower spacer to allow for the difference in thermal expansion between the inner and outer rows.

To monitor cladding surface and coolant temperatures, the SAP clad UC fuel assemblies are instrumented with stainless-steel-sheathed, magnesium-oxide-insulated, Chromel-Alumel thermocouples. The thermocouples are embedded in the cladding fins (Figure 12), or attached to the end spacers, (Figure 13).

The three SAP UC and two Zr- UO_2 fuel bundles are held together by a 3/8-in. diameter Type 347 stainless steel support rod which occupies the center position in the fuel bundles. The end plates are keyed together to prevent rotational movement of the fuel bundles. An Inconel spring assembly at the bottom of the central support rod allows for axial thermal expansion. The fuel bundles are suspended from a Type 304 stainless steel hanger tube which is welded to the fuel channel closure seal. Thermocouples are routed from the fuel bundles, through the hanger tube, and through a compacted graphite powder seal in the fuel channel closure (Figure 14).

Irradiation of the NRU-305 was initiated in July 1965 and continued until April 1966, when activity in the loop coolant indicated that a fuel rod failure had occurred. Post-irradiation examination of the NRU-305 revealed the SAP UC fuel rods are intact and that several of the Zr- UO_2 fuel rods had ruptured.*

*G. E. Culley and E. D. Falk, "HWO CR Fuels Irradiation Test EXP-NRU-305," AI-CE-43 (to be published)

Figure 10. EXP-NRU-305 Irradiation Experiment
(Photo Supplied through Courtesy of AECL)

a. Upper End View

7660-51158

b. Lower End View

7660-51162

Figure 11. U-305 Configuration Fuel Rod Cluster

Figure 12. Installation of TC in SAP Tube Fin

7680 51177

Figure 13. Attachment of TC's to
Bundle End Spacers

7660-51154

COMPRESSION NUT

SEAL GLANDS

CHANNEL CLOSURE

7660-51150

Figure 14. Fuel Channel Closure with Graphite Instrumentation Seal

B. EXP-NRU-305 ALT. I

The NRU-305 Alt. I is identical in design to the NRU-305 and was installed in the U-3 loop in May 1966, upon discharge of the NRU-305.

In June 1966, the compacted graphite seal, through which the thermocouples are routed, failed and an estimated 500 gallons of organic coolant were discharged from the U-3 loop. The graphite seal was recompacted at that time and the irradiation was continued. The graphite seal began to leak (~ 750 cc/day) in September 1966, and by November 1966, began to leak sufficiently ($\sim 1,200$ cc/day) to cause concern over the possibility of another failure.

Problems with a leaking graphite seal on the WR1-951 experiment (see IV-A) had been encountered in April 1966, and were resolved by replacing the compacted graphite seal with a brazed seal assembly.

The NRU-305 Alt. I was removed from the U-3 loop in November 1966 and transferred to the NRU fuel storage block for replacement of the leaking graphite seal with a brazed seal assembly similar in design to the seal developed for use in the WR1 reactor. The braze seal assembly is shown in Figure 15.

The NRU-305 was reinserted in the U-3 loop in November 1966 and, as of July 1967, had obtained an estimated peak UC burnup of 13,000 Mwd/MTU.

a. Braze Seal Components

7680-40105

b. Instrumentation Leads Brazed to Seal (Photo Supplied through Courtesy of AECL)

Figure 15. Fuel Channel Closure with Typical Brazed Instrumentation Seal

C. EXP-NRU-305 ALT. II

The NRU-305 Alt. II, shown in Figure 16, consists of six SAP-clad UC fuel bundles. Completed in July 1965, the NRU-305 Alt. II is to be irradiated in the U-3 loop upon termination of the NRU-305 Alt. I test.

Figure 16. EXP-NRU-305 Alt. II Fuel Element Assembly

7680-51100

The graphite instrumentation seal, originally installed on the NRU-305 Alt. II, was replaced with a brazed seal in July 1966.

IV. EXP-WR1-951 IRRADIATION TEST SERIES

A. EXP-WR1-951

The EXP-WR1-951 irradiation experiment, shown in Figure 17, consists of two SAP-clad UC fuel bundles. Each bundle contains 19 fuel rods, 43-1/2 in. long, in a hexagonal array. The Type 304 stainless steel end spacers, which maintain the fuel rod array, are brazed honeycomb spacers, as illustrated in Figure 18. The two bundles, mounted end-to-end are secured in place by three 1/8-in. diameter Type 347 stainless steel rods which form a birdcage assembly. An Inconel compression spring, at the top of the fuel string, assures alignment of the fuel bundles while allowing for differential expansion. Rotational misalignment of the fuel bundles is prevented by the compression spring and by keying of the birdcage wires to the guide block located on the periphery of the brazed end spacers.

Instrumentation of the WR1-951, as in the U-305 experiments, consists of thermocouples to monitor cladding surface and coolant temperatures. In addition, the experiment contains in-fuel thermocouples and thermal neutron flux detectors.

Fuel centerline temperatures are monitored in four fuel rods by means of W-5Re vs W-26Re thermocouples.* Penetration of the 1100 Aluminum Alloy end caps are made by Type 304 stainless steel tubes to which the in-fuel thermocouples are welded at the thermocouple transition sleeves. The 1100 Aluminum Alloy to Type 304 stainless steel end cap penetration was developed for the WR1 irradiation experiments,[†] and incorporates a tungsten diffusion barrier to prevent formation of brittle intermetallics. Bonding of the tungsten-coated stainless steel to the 1100 Aluminum is accomplished by hot isostatic gas pressure bonding. Bonding components and a completed end cap assembly are shown in Figure 19. Fuel rod components are shown in Figure 20.

*The in-fuel portion of the thermocouple is sheathed with molybdenum and the remainder by Type 304 stainless steel. A brazed Type 304 stainless steel sleeve joins the two sheaths.

[†]W. R. Jackson, "Development of a SS-Al Transition Joint for High Temperature Service," AI-CE-72 (to be published)

a. Overall View (Photo Supplied through Courtesy of AECL)

b. Fuel Bundles

Figure 17. EXP-WR1-951 Element Assembly

1-14-66 UNC

7680 51119

a. Spacer Assembly

5 16-66 UNC

7680 51173

b. "Birdcage" Wires Installed on Guide Blocks

Figure 18. Brazed Spacer Assembly, WR1-951 Design

a. Bonding Components

7680-5192

b. Machined End Caps

7680-40166

Figure 19. Fabrication of End Caps for In-Fuel Instrumentation

b. Completed Fuel Rod Assembly

7680-51120

Figure 20. Instrumented WR1-9 Fuel Rod Assembly

7680-51298

a. Fuel Element Assembly

7680-51301

b. Closeup of Upper Fuel Bundle Assembly Showing Pressure Sensor Attached to Fuel Rod

Figure 22. EXP-WR1-954 Irradiation Experiment

V. SUMMARY

A total of 313 SAP clad-UC fuel rods have been fabricated for 6 fuel element assemblies.

Irradiation of one fuel element assembly (NRU-305), containing 54 SAP UC fuel rods, was terminated after 9 months in-pile when failures occurred in some zirconium-clad UO_2 fuel rods that were part of the fuel element string. The SAP-clad UC fuel rods did, however, reach their minimum design peak burnup of 10,000 Mwd/Mtu before the test was terminated. No failures occurred in the SAP UC fuel rods.

Two fuel element assemblies, the NRU-305 Alt. I and the WR1-951, containing 92 SAP UC fuel rods, had completed 14 months of irradiation and attained calculated peak burnups of 13,000 and 10,000 Mwd/Mtu, respectively, as of July 1967.

One fuel element assembly, the WR1-952 containing 38 SAP UC fuel rods, had completed two months of irradiation testing and attained a calculated peak burnup of 1,000 Mwd/MTU, as of July 1967.

Two additional fuel element assemblies, the NRU-305 Alternate II and the WR1-954 containing 122 SAP UC fuel rods, have been fabricated and are ready for irradiation testing.

No failures have yet occurred in any of the SAP UC fuel rods fabricated to date.