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RERTR PROGRAM PROGRESS IN QUALIFYING REDUCED-ENRICHMENT FUELS*

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RERTR Program Progress in Qualifying Reduced-Enrichment Fuels

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I. INTRODUCTION

In order to provide the technical means for reducing the enrichment of uranium used to fuel research and test reactors, the U.S. Reduced Enrichment Research and Test Reactor (RERTR) Program has been engaged in the development and testing of higher-uranium-density fuels than had been used previously. This fuel development effort included work to increase the density of fuels which were being used at the time the Program began and work on a fuel with the potential for much higher density. The ultimate goal of the fuel development and testing phase of the Program is to "qualify" the fuel for use. A fuel is considered qualified when a sufficient data base for the fuel exists that it can be approved by regulating bodies for use in reactors. To convert a core to the use of reduced-enrichment fuel it is necessary to show that the core will behave properly during normal and off-normal operating conditions and to show that the fuel will behave properly to a reasonable margin beyond the conditions expected during normal operation. It is this latter area that this paper will address. The main characteristics to be considered in evaluating the performance of a fuel are its swelling, its blister-threshold temperature, and its metallurgical appearance. Data for the qualification of the reduced-enrichment fuels being developed by the RERTR Program are obtained from examination of miniature fuel plates (miniplates) which successfully pass the irradiation screening tests and from examinations of full-sized fuel elements. This paper will summarize the miniplate data reported in other papers presented during this meeting (Refs. 1-4) and will give the status of full-sized element irradiations. Finally, the current status of qualification of the various fuel types will be discussed and some projections of the future will be given.

II. MINIPLATE IRRADIATIONS AND POSTIRRADIATION EXAMINATIONS

Beginning in July 1980, irradiations of miniplates of three dispersion fuel types began in the Oak Ridge Research Reactor (ORR). The development of the UAl_x-Al and U_3O_8-Al fuels began from the uranium densities which were being used in reactors at the time the Program began with the goal of increasing those densities as much as possible. At that time, 1978, UAl_x-Al fuel was being used at a maximum density of 1.7 Mg/m^3 and U_3O_8-Al fuel was being used at a miximum density of 1.3 Mg/m^3. The development work on the UAl_x-Al and U_3O_8-Al fuels was carried out by EG&G Idaho, Inc. and by Oak Ridge National Laboratory (ORNL), respectively. Argonne National Laboratory (ANL) pursued the development of a fuel containing uranium-silicide dispersed in an aluminum matrix. Because of the high density and high uranium content of the uranium-silicide compounds, these fuels had the potential for uranium densities of up to 7.0 Mg/m^3 in the fuel meat. Subsequent to the start of fuel development activities in the United States, NUKEM in Germany and the Comision Nacional de Energia Atomica (CNEA) of Argentina began fuel development efforts and produced miniplates for irradiation in the ORR. Both NUKEM and the CNEA have paid a pro-rata share of the irradiation charges. The RERTR Program provided the irradiation modules and other incidental services. It should be mentioned that the NUKEM work is associated with the German Anreicherungsreduzierung in Forschungsreaktoren (AF) Program.

The status as of November 1, 1982, of the various miniplate modules is summarized in Table I. The miniplate experiment is currently out-of-pile awaiting removal of Modules 1 and 9, which have, in fact, exceeded their goal burnups. As soon as two modules of dummy plates are available, the experiment will be reinserted in the reactor for further irradiation of Modules 6 and 13. As can be seen in Table I, a number of the modules, each of which contained 12 miniplates, have been unloaded for postirradiation examination of the miniplates. Some results of these examinations will be summarized below by fuel type. Results of blister tests will be discussed in a separate section.

II. A. UAl_x-Al and UAl_2-Al Fuels

Table II gives a summary of the specifications, fission densities achieved, and measured thickness changes of uranium-aluminide miniplates irradiated under the RERTR Program. The fission densities listed in Table II and following tables are based on estimates of the average burnup of each module without any correction for intra-module flux profiles. More accurate burnup determinations must await the results of absolute burnup measurements on selected miniplates. It should be noted that the 22 UAl_x-Al miniplates irradiated covered both low-enriched uranium (LEU) and medium-enriched uranium (MEU) and covered the range of fuel meat and cladding thicknesses expected to be needed for most applications. The CNEA miniplates containing UAl_2-Al fuel meat will continue under irradiation unless problems develop in the plates of Module 6. No abnormalities were noted with any of the uranium-aluminide miniplates during irradiation.

Four of the 40.24%-enriched EG&G miniplate were removed from Module 1 during July 1981, after approximately 63% depletion of the ^{235}U, for use in fission-product-release threshold-temperature tests.[1] The thickness changes noted were measured prior to performing these tests. More recently, measurements on the EG&G LEU miniplates have been completed. As the postirradiation examinations progress, the volume change of the fuel meat will be measured to more accurately determine the swelling. It should be noted that the volume change is always less than the thickness change since the micrometer only measures the high points on the surface. Therefore, it would appear that UAl_x-Al fuel up to a uranium density of 2.3 Mg/m^3 and 1.2×10^{27} fissions/m^3 behaves very well. It is expected that the examination of the higher-burnup plates will also give acceptable swelling results. It should be pointed out that high-enriched uranium (HEU) UAl_x-Al fuel of 1.7-Mg/m^3 uranium density has been successfully irradiated to a burnup of 2.7×10^{27} fissions/m^3. Therefore, no problems are anticipated with any of the UAl_x-Al miniplates.

Due to its higher density and uranium content, attention has been focused more recently on UAl_2-Al fuel. In addition to the five CNEA miniplates under irradiation in the ORR, nine UAl_2-Al miniplates are curently being irradiated in the Advanced Test Reactor (ATR) as part of a joint U.S. Department of Energy/ University of Missouri program.[2] At least one of the highly-loaded miniplates has already surpassed the 2.1×10^{27} fissions/m^3 point with lower-than-expected swelling. The goal burnup for this plate is 3.3×10^{27} fissions/m^3.

II. B. U_3O_8-Al Fuel

Table III gives a summary of the specifications, estimated fission densities achieved, and volume changes for the U_3O_8-Al miniplates irradiated under the RERTR Program.[3] As for the uranium-aluminide plates, both LEU and MEU fuel and a range of fuel meat and cladding thicknesses were covered. One fully-enriched plate of low uranium density was included for comparison with previously-irradiated plates. As noted in Ref. 3, three of the ORNL 44.97%-enriched miniplates "pillowed" in core. A "pillow" denotes a blister-like phenomenon which covers a large part of the plate surface and is visible on both sides of the plate. When viewed from an edge the plate appears puffed-up like a pillow. The large degree of swelling exhibited by the two similar plates which did not pillow suggests that these plates were approaching the pillowing threshold. Pending determination of the actual burnup, it appears that the threshold for pillowing of U_3O_8-Al miniplates of uranium density above 2.4 Mg/m^3 is in the range of 1.9 to 2.0 × 10^{27} $fissions/m^3$. It should be noted that there was no evidence of fission-product release from any of the plates which pillowed in core. Two of the plates might even have operated for some time in the pillowed condition. For plates with fission densities below the pillowing threshold, the swelling measured for the ORNL plates is acceptable.

II. C. U_3Si-Al, U_3SiAl-Al, and U_3Si_2 Fuels

Table IV gives a summary of the specifications, estimated fission densities achieved, and volume changes for the uranium-silicide miniplates irradiated under the RERTR Program.[4] Because of the high-uranium-loading potential of the silicide fuels, all of the fuel was LEU and only fuel meat thicknesses of the order of 0.51 mm thick were tested. One 4.62-Mg/m^3 miniplate pillowed during irradiation. Study of the channel-gap-spacing records suggested that the pillowing occurred gradually as the burnup increased from 1.9 to 2.0 × 10^{27} fissions/m^3. No fission product release into the ORR primary water was detected. Other miniplates which achieved approximately the same burnup did not pillow but showed evidence, from thickness measurements, of substantial swelling. Swelling of the order of 9-11% of the fuel meat volume were measured for the U_3Si and U_3SiAl fuels which had achieved fission densities of 1.7 to 1.8 × 10^{27} $fissions/m^3$. This amount of swelling is comparable to that measured for the U_3O_8-Al fuel at comparable fission density, and it is felt that such swelling can be adequately accommodated in the design of fuel elements. Although a model of the swelling mechanism is emerging, more work is needed before one can say with certainty that a pillowing threshold exists in the 1.8 to 2.0 × 10^{27} $fissions/m^3$ range.

II. D. Blister-Threshold Temperatures

Table V gives the results of blister-threshold-temperature tests on a number of irradiated miniplates. The data for the UAl_x-Al fuel was obtained during fission-product-release tests and was determined quite precisely. The 561°C blister-threshold temperature is the most probable value, based upon the results of the four measurements. No blisters were detected following the 550°C heating, so 550°C is a lower limit.

The U_3O_8-Al miniplates had a consistently high blister-threshold temperature, with the exception of one plate which had suffered long term over heating in a hot cell following irradiation. This plate blistered after the 500°C test. However, due to its previous history, the data should not be weighted heavily. The trend of the data indicates a slight decrease in the blister-threshold temperature as the uranium density increases. It should be noted that one plate showed a slight blister near one end following the 375°C anneal. However, since this blister did not change until after the 550°C anneal and did not show up in other plates, it is concluded that the lower-temperature phenomenon is related to some fabrication defect in the particular plate.

The blister-threshold temperatures for the uranium-silicide fuels are somewhat lower than for the aluminide and oxide, but are still sufficiently high. The degree of burnup appears to affect the manner in which the plates first blister. The lower-burnup plates pillowed at the indicated temperature, but had no visible conventional blisters. The higher-burnup U_3Si-Al and U_3SiAl-Al plates first blistered conventionally around the periphery of the fuel meat and then pillowed as the temperature was raised to 515°C. The U_3Si_2-Al plate only pillowed, but at a somewhat higher temperature than the other species.

III. FULL-SIZED ELEMENT IRRADIATIONS

Table VI summarizes the characteristics of the full-sized plate-type fuel elements which have been, or are being, procured for testing under the RERTR Program. Fabrication has been completed on all but four of the elements. The elements being tested cover a range of uranium densities up to 6.0 Mg/m^3. A detailed description of the fuel elements and of the projected irradiation-testing program have been presented previously.[5] The present status of the fuel elements being irradiated in the ORR is given in Table VII. The irradiation of most of the 45%-enriched, 1.7-Mg/m^3 elements has been completed. Element CLE453, which is still under irradiation, was fabricated from plates which had a somewhat smaller minimum cladding thickness than was specified. Although no postirradiation examinations have been performed to date, results of channel-gap-spacing measurements indicate[6] that the elements performed well. Postirradiation examinations of these elements will begin within the next few months.

A special explanation is in order concerning the long delay in beginning the irradiation of the LEU U_3O_8-Al and UAl_x-Al elements in the ORR. This delay had nothing to do with the fuel itself but resulted from the neutronic behavior of the elements in the ORR core. The elements were designed to test fuel plates containing the thickest fuel meats which might ever be used. The very high metal-to-water ratio of these elements resulted in a very hard neutron spectrum which rapidly softened near the axial reflectors. This spectrum softening resulted in a power spike at the bottom of the element (no control rods in the bottom part of the core) which gave too large a heat flux, according to the required conservative calculations. Considerable time has been consumed in studying this phenomenon and in determining a core position where the irradiations can occur. The work on these elements was deferred for several months to concentrate on starting the irradiation of the uranium-silicide elements. It is anticipated that irradiation of these thick-plate elements will begin shortly.

The two uranium-silicide elements fabricated by NUKEM have been under irradiation since late May and have performed flawlessly to date. No changes have been detected in the channel gaps.[6] These particular fuel elements were fabricated using U_3Si_2 fuel powders at a volume loading (~43%) greater than for any of the U_3Si_2 miniplates. Therefore, these elements will be limited to 50% average depletion of the ^{235}U until more data is available to support further irradiation.

The status of the full-sized fuel elements (plates) being irradiated in the HFR-Petten and SILOE is given in Table VIII. The elements being irradiated in the HFR-Petten are similar to the thick-plate elements for the ORR discussed previously, but with slightly thinner fuel meat. These elements have performed well to date.[7] Postirradiation examination of the lower-burnup elements will begin within the next few months. The one 45%-enriched full-sized element irradiated in SILOE reached its scheduled burnup with no sign of problems and is now at CEN-Saclay awaiting postirradiation examination.[8] The U_3Si-Al fuel plates being irradiated in SILOE will reach their scheduled burnup in March 1983 if all goes well.

In addition to the plate-type fuels, the RERTR Program has been irradiating U-ZrH_x (TRIGA) fuel rods in the ORR.[9] The irradiations of the 20-wt% (1.3-Mg U/m^3) and 30-wt% (2.2-Mg U/m^3) fuels have been completed. It is estimated that approximately one more year will be required to reach the goal burnup of 50% in the 45-wt% (3.7-Mg U/m^3) rods. All rods appear to be behaving normally.

IV. QUALIFICATION STATUS OF, AND PROGNOSIS FOR, REDUCED-ENRICHMENT FUELS

IV. A. UAl_x-Al and UAl_2-Al Fuels

Based upon the results of the irradiation of the 45%-enriched full-sized elements and the history of performance of fully-enriched UAl_x-Al fuels, the 1.7-Mg/m^3 UAl_x-Al fuel can be considered qualified at this time. Confirmatory results will be obtained from postirradiation examination of the 45%-enriched elements. However, in view of the very high burnup achieved in one element from each fabricator with no external sign of problems, it is the position of the RERTR Program that one should be able to obtain regulatory approval to use these fuels with either MEU or LEU at any time. In fact, the Ford Nuclear Reactor (FNR) at the University of Michigan is now licensed for this type of fuel.

Irradiations of UAl_x-Al fuel with uranium densities up to 2.3 Mg/m^3 and both MEU and LEU have been completed and preliminary measurements of swelling (based on thickness changes) indicate acceptable behavior. In addition, the MEU miniplates have been blister tested with good results. Two full-sized fuel elements have been irradiated to high burnup in the HFR-Petten with no sign of trouble. It will be necessary to complete postirradiation examinations of the miniplates and full-sized elements before these fuels can be considered qualified because no data base exists at these densities. It is anticipated that this work will require approximately one year to complete. Full results from the irradiation of the 2.1- and 2.3-Mg/m^3 UAl_x-Al elements in the ORR will be available in approximately two years. However, sufficient data should exist by the end of 1983 to qualify these fuels, with the ORR tests providing further confirmation.

The irradiation of a few LEU UAl_2-Al miniplates fabricated by the CNEA is proceeding successfully thus far. It appears, from tests on high-enriched miniplates, that the UAl_2-Al fuel might be used successfully with MEU if the need were to arise. The RERTR Program will monitor the results of the ATR irradiations. The possibility exists of irradiating some MEU UAl_2-Al plates and elements in order to qualify this fuel. A decision on this is expected in six to nine months.

IV. B. U_3O_8-Al Fuel

Based upon the results of the irradiation of the 45%-enriched, full-sized elements, there appears to be no problem with the 1.7-Mg/m^3 U_3O_8-Al fuel. However, since the data base for this fuel at this loading is substantially smaller than for UAl_x-Al fuels, some results from the postirradiation examination of these elements are required to provide all the data needed for qualification to very high burnup levels. This data will be available within one year. However, for the lower burnup levels experienced in some reactors, such as the FNR, this fuel can be considered qualified now. In fact, the FNR is now licensed to use the LEU U_3O_8-Al fuel, subject only to the development of fabrication specifications.

The higher-density U_3O_8-Al fuels, up to 3.1 to 3.2 Mg U/m^3, appear to be usable to the fission density limit of 1.7×10^{27} fissions/m^3 established for the MEU miniplates. Since the maximum fission density achievable upon 100% burnup of the ^{235}U contained in 3.2-Mg/m^3, LEU U_3O_8-Al fuel cannot exceed 1.7×10^{27} fissions/m^3, there is every confidence that the 3.2-Mg/m^3 fuel can be qualified for LEU. In order to confirm this opinion and to provide data needed for qualification, the irradiation of two 3.2-Mg/m^3 U_3O_8-Al fuel elements will begin shortly in the ORR. The RERTR Program is considering procuring additional elements of this type for testing. Sufficient data for qualification of the fuel should be available in approximately two years.

Some concern is still being expressed by some potential users about the possibility of an exothermic reaction releasing a significant amount of energy during an accident. Although studies conducted at ORNL appear to have shown that no significant energy release occurs in unirradiated fuel plates,[10] questions have arisen regarding irradiated fuel. If such tests appear warranted, they can be completed within the two year time frame given for qualification of the fuel.

IV. C. Uranium-Silicide Fuels

More study is necessary before being able to assess the potential of the uranium-silicide fuels. Some of the highest-density miniplates remain under irradiation. During the next six months it is expected that a better understanding of the swelling and pillowing mechanism will be developed which can be used to assess the burnup potential of the various fuel types. Additional data will be available during the next year from the irradiation of full-sized elements and plates in the ORR and SILOE. In view of the uncertainties which exist now with respect to the fuel, one can only say at this time that if the silicide fuel is determined to be useful, its qualification can be expected to occur four to six years from now.

IV. D. U-ZrH_x Fuel

Following the non-destructive examination of the 20- and 30-wt% U-ZrH_x rods whose irradiation has been completed, sufficient data will exist to qualify these fuels for use in steady-state applications. This data should be available shortly. As indicated previously, another year of irradiation of the 45-wt% rods is required. Qualification could come soon after the end of the irradiations.

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Table I. ORR Miniplate Irradiation Summary - November 1, 1982

Position	Module No.	Module Contents		Total Exposure* Full-Power Days	Average Flux 10^{14} n/cm^2-s	Calculated Burnup at%
1	14	-	Al	54	0.7	-
2	13	ANL	U_3Si	148	1.0	38
3	6	CNEA CNEA CNEA	UAl_2 U_3O_8 U_3Si	188	1.3	53
4	9	CNEA CNEA	UAl_x U_3O_8	352	1.4	87
5	1	EG&G ORNL	UAl_x U_3O_8	470	1.1	84
P.I.E., ORNL P.I.E., ANL (8/31/81)**	2	ORNL ANL	U_3O_8 U_3Si	305	-	77
P.I.E., ANL (10/5/80)**	3	ANL	U_3Si	75	-	34
Poolside Cooling P.I.E., ORNL (5/27/82)**	4	EG&G ORNL ANL	UAl_x U_3O_8 U_3Si	420	-	88
P.I.E., ORNL (7/10/81)**	5	ORNL	U_3O_8	268	-	75
P.I.E., ANL (11/15/81)**	7	ANL	U_3Si	300	-	83
P.I.E., GE/VNC (3/25/82)**	8	NUKEM NUKEM	UAl_x U_3O_8	262	-	77
Poolside Cooling (7/24/82)**	10	ANL	U_3Si	262	-	65

*This represents the total ORR exposure which may include residence at several axial positions during the course of the irradiation.

**This is the date of last irradiation.

Table II. Summary of Specifications, Fission Densities, and Thickness Changes of Uranium-Aluminide Miniplates (November 1, 1982)

Fabricator	No. of Plates	Enrichment, %	Uranium Density, Mg/m^3	Fuel Meat Thickness, mm	Cladding Thickness, mm	Fission Density, 10^{27} fiss/m^3	Thickness Chang $\%\Delta t/t_m$
EG&G	4	40.24	2.20-2.31	0.54-0.88	0.33-0.38	1.2-1.7	2.2[c]
EG&G	4	40.24	1.88-1.95	0.56-0.85	0.30-0.37	1.1-1.4	1.2-4.5[d]
EG&G	1	19.92	2.28	0.67	0.31	0.9	1.9
EG&G	3	19.92	1.88-1.99	0.70-0.96	0.29-0.32	0.8	4.7-6.5
NUKEM	2	39.85	2.13-2.20	0.51	0.38	1.4-1.5	-
NUKEM	2	27.14	2.14-2.15	0.76	0.38	1.0	-
CNEA	1	45.08	1.47	0.65	0.31	1.3	-
CNEA	5[a]	19.82	2.99-3.09	0.53-0.75	0.32-0.39	0.7[b]	-
CNEA	2	20.18	2.48-2.52	0.78	0.37-0.38	1.0	-
CNEA	3	20.18	2.28-2.32	0.65-0.77	0.31-0.37	0.9	-

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[a] UAl_2-Al, others are UAl_x-Al.

[b] Irradiation not completed.

[c] Only the lowest-burnup plate measured.

[d] Only two lowest-burnup plates measured.

Table III. Summary of Specifications, Fission Densities, and Volumes Changes of U_3O_8-Al Miniplates (November 1, 1982)

Fabricator	No. of Plates	Enrichment, %	Uranium Density, Mg/m^3	Fuel Meat Thickness, mm	Cladding Thickness, mm	Fission Density, 10^{27} $fiss/m^3$	Thickness Change, $\%\Delta V/V_m$
ORNL	1	93.21	0.71	0.48	0.51	1.1	3.0
ORNL	3	44.95	3.10	0.51-0.52	0.38-0.39	1.9-2.4	11.2[c]
ORNL	2	44.95	2.46-2.77	0.49-0.50	0.39-0.40	1.9-2.1	9.7[d]
ORNL	9	19.47	3.09-3.13	0.52-0.88	0.33-0.45	0.9-1.2	(-3.8)-3.6
ORNL	11	19.47	2.76-2.79	0.50-0.86	0.33-0.45	0.8-1.1	(-1.3)-3.0
ORNL	5	19.47	2.44-2.48	0.50-0.85	0.26-0.45	0.7-0.8	0.0-1.1
NUKEM	2	39.7	2.40	0.51	0.37	1.6	-
NUKEM	2	27.3	3.12-3.13	0.52	0.39	1.5	-
NUKEM	2	27.3	2.30	0.77	0.36-0.38	1.1	-
NUKEM	2	20.37	3.07	0.77	0.37	1.1	-
CNEA	3	19.67	3.49-3.58	0.64-0.77	0.32-0.38	0.8[a]	-
CNEA	2	19.67	3.12	0.60-0.74	0.34-0.39	0.7-1.2[b]	-
CNEA	1	19.67	2.91	0.52	0.38	1.2	-
CNEA	2	19.67	2.46-2.47	0.74-0.90	0.31-0.40	1.0	-

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[a] Irradiation not completed.

[b] Irradiation not completed for low-burnup plate.

[c] Two plates at 2.4 × 10^{27} $fiss/m^3$ "pillowed" in core.

[d] One plate at 2.1 × 10^{27} $fiss/m^3$ "pillowed" in core.

Table IV. Summary of Specifications, Fission Densities, and Volumes Changes of Uranium-Silicide Miniplates (November 1, 1982)

Fabricator	No. of Plates	Enrichment, %	Uranium Density, Mg/m^3	Fuel Meat Thickness, mm	Cladding Thickness, mm	Fission Density, 10^{27} $fiss/m^3$	Thickness Change, $\%\Delta V/V_m$
ANL	6	19.51	6.89-6.99	0.54-0.56	0.49-0.50	1.2[c]	-
ANL	5	19.89	6.23-6.44	0.54-0.56	0.36-0.50	1.1-1.9[d]	-
ANL	4	19.51	6.12-6.18	0.52-0.54	0.38-0.39	1.0[c]	-
ANL	7	19.88-19.89	5.61-5.90	0.50-0.56	0.36-0.52	1.0-2.1	-
ANL	4[a]	19.89	5.65-5.72	0.56-0.59	0.35-0.49	1.7	-
ANL	6[a]	19.88	4.77-4.81	0.46-0.49	0.39-0.53	1.9-2.0	8.9-19[e]
ANL	5[a]	19.88	4.79-4.83	0.46-0.50	0.41-0.53	0.7	~0
ANL	7	19.88	4.51-4.66	0.49-0.52	0.38-0.53	1.7-2.0	9.6-20.0[f]
ANL	7	19.88	4.65-4.68	0.49-0.50	0.39-0.52	0.7	~0
ANL	4[b]	19.87	3.72-3.76	0.44-0.50	0.40-0.52	1.5	3.7-4.8
CNEA	1[a]	19.82	6.10	0.57	0.35	1.3[c]	-
CNEA	2[a]	19.82	5.18-5.20	0.70	0.41	1.1[c]	-

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[a] U_3Si-Al } others are U_3SiAl-Al.

[b] U_3Si_2-Al }

[c] Irradiation not completed.

[d] Irradiation not completed for the one plate at low burnup.

[e] Estimated on basis of thickness change for higher-burnup plates.

[f] Highest-burnup plate pillowed in core.

Table V. Summary of Miniplate Blister-Threshold Temperature Data

Fuel Type	No. of Plates Tested	Uranium Density, Mg/m^3	Fission Density, 10^{27} fiss./m^3	Blister-Threshold Temperature, °C	
				Lower Limit	Most Probable
UAl_x-Al	4	1.94-2.31	1.1-1.3	550	561
U_3O_8-Al	4	3.09-3.12	0.9-1.2	525	550[a,b]
U_3O_8-Al	2	2.76-2.78	0.8-1.1	525	550[c]
U_3O_8-Al	1	2.47	0.7	550	>550
U_3Si-Al	2	4.80-4.81	1.9-2.0	475	500
U_3Si-Al	2	4.79-4.81	0.7	500	510
U_3SiAl-Al	1	4.51	1.8	475	500
U_3SiAl-Al	2	4.68	0.7	500	515
U_3Si_2-Al	1	3.75	1.5	515	530

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[a] One plate showed slight blister at 350°C which remained stable until 550°C test.

[b] One plate which had experienced long-term elevated temperature in the hot cell blistered at 500°C.

[c] One plate had not blistered at 550°C.

Table VI. Plate-Type Fuel Elements for Irradiation Testing under the U.S. RERTR Program

Fuel[a] Type	U Dens., Mg/m^3	Enrich., %	No. of Plates	Fuel Meat Thk., mm	Fabricator	No. of Elem.	Compl. Fab.	Reactor	Begin Irrad.
U_3O_8-Al	1.7	45.0	19	0.51	TI	4	9/80	ORR	5/81
UAl_x-Al	1.7	44.9	19	0.51	CERCA	3	4/81	ORR	7/81
UAl_x-Al	1.7	44.9	19	0.51	NUKEM	2	4/81	ORR	7/81
UAl_x-Al	2.2	44.8	23	0.51	CERCA	1	12/80	SILOE	2/81
UAl_x-Al	2.1	19.8	13	1.50	CERCA	1	9/81	ORR	~2/83
UAl_x-Al	2.3	19.8	13	1.50	CERCA	1	9/81	ORR	11/82
U_3O_8-Al	2.3	19.6	13	1.50	NUKEM	2	4/81	ORR	11/82
UAl_x-Al	2.1	19.8	16	1.32	CERCA	2	12/81	HFR-Petten	1/82
U_3O_8-Al	2.1	19.6	16	1.32	NUKEM	2	5/81	HFR-Petten	10/81
U_3O_8-Al	3.2	19.7	18	0.76	CERCA	2	8/82	ORR	~12/82
U_3SiAl-Al	4.8	19.5	19	0.51	B&W	2	~1/83	ORR	~2/83
U_3Si_2-Al	4.8	19.7	19	0.51	NUKEM	2	1/82	ORR	5/82
U_3Si_2-Al	4.8	19.8	19	0.51	CERCA	2	12/82	ORR	~2/83
U_3Si-Al	5.5	19.8	2[b]	0.51	CERCA	b	5/82	SILOE	6/82
U_3Si-Al	6.0	19.8	2[b]	0.51	CERCA	b	5/82	SILOE	6/82

[a] Cladding Materials: TI and B&W, 6061 Al; CERCA, Ag 2 N.E. or AG 3 N.E. Al; NUKEM, AlMg1

[b] Four full-sized plates are mounted in a special irradiation element.

Table VII. Irradiation Status of Full-Sized Fuel Elements Being Tested in the ORR (Start of Cycle 163-A, October 30, 1982)

Element No.*	Fuel Type	Enrichment, %	Present Location	Initial U Dens., Mg/m^3	Initial ^{235}U, g	^{235}U Depletion, %	Remarks
T291X	U_3O_8	45.0	POOL	1.7	280	56	Irrad. Completed 10/13/81
T292X	U_3O_8	45.0	POOL	1.7	280	72	Irrad. Completed 4/16/82
T293X	U_3O_8	45.0	POOL	1.7	280	55	Irrad. Completed 10/11/82
T294X	U_3O_8	45.0	POOL	1.7	280	58	Irrad. Completed 6/22/82
NLE451	UAl_x	44.9	POOL	1.7	284	73	Irrad. Completed 10/11/82
NLE452	UAl_x	44.9	POOL	1.7	284	59	Irrad. Completed 6/22/82
CLE451	UAl_x	44.9	C-7	1.7	282	72	
CLE452	UAl_x	44.9	POOL	1.7	282	56	Irrad. Completed 4/16/82
CLE453	UAl_x	44.9	C-5	1.7	284	44	
NLE201	U_3O_8	19.6	POOL	2.3	340	0	Permission to irradiate not yet received, but expected shortly.
NLE202	U_3O_8	19.6	POOL	2.3	340	0	
CLE201	UAl_x	19.8	VAULT	2.1	312	0	
CLE202	UAl_x	19.8	VAULT	2.3	336	0	
NSI201	U_3Si_2	19.7	D-8	4.8	340	36	
NSI202	U_3Si_2	19.7	D-2	4.8	340	36	

*First letter in element no. designates fabricator: CERCA (C), NUKEM (N), or Texas Instruments (T).

Table VIII. Status of Full-Sized Fuel Elements Being Tested in the HFR-Petten and SILOE (November 1, 1982)

Reactor	Element No.	Fuel Type	Enrichment, %	Present Location	Initial ^{235}U, g	^{235}U Depletion, %	Remarks
HFR	LC-01-CD	UAl_x	19.8	A8	330	59	
HFR	LC-02	UAl_x	19.8	Pool	329	47	Irradiation Completed 6/7/82
HFR	LN-01-CD	U_3O_8	19.6	A2	328	74	
HFR	LN-02	U_3O_8	19.6	Pool	328	47	Irradiation Completed 6/7/82
SILOE	SAHU001	UAl_x	44.8	a	420	50	Irradiation Completed 11/81
SILOE	b	U_3Si	19.8	Core	c	20	

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[a] At CEN-Saclay awaiting PIE.

[b] Four plates in special irradiation element.

[c] Plate loadings are 5.5 and 6.0 Mg/m^3.