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FABRICATION OF ORNL FUEL IRRADIATED IN THE PEACH BOTTOM REACTOR AND POSTIRRADIATION EXAMINATION OF RECYCLE TEST ELEMENTS 7 AND 4

E. L. Long, Jr. R. B. Fitts F. J. Homan

OAK RIDGE NATIONAL LABORATORY

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SEPTEMBER 1974

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CONTENTS

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ABSTRACT

Seven full-sized Peach Bottom Reactor. fuel elements were fabricated in a cooperative effort by Oak Ridge National Laboratory (ORNL) and Gulf General Atomic (GGA) as part of the National HTGR Fuel Recycle Development Program. These elements contain bonded fuel rods and loose beds of particles made from several combinations of fertile and fissile particles of interest for present and future use in the High-Temperature Gas-Cooled Reactor (HTGR). The portion of the fuel prepared for these elements by ORNL is described in detail in this report, and it is in conjunction with the GGA report (GA-10109) a complete fabrication description of the test. In addition, this report describes the results obtained to date from postirradiation examination of the first two elements removed from the Peach Bottom Reactor, RTE-7 and -4. The fuel examined had relatively low exposure, up to about 1.5 $\times 10^{21}$ neutrons/cm* fast (>0.18 MeV) fluence, compared with the peak anticipated HTGR fluence of 8.0 $\times 10^{21}$, but it has performed well at this exposure. Dimensional data indicate greater irradiation shrinkage than expected from accelerated test data to higher exposures. This suggests that either the method of extrapolation of the higher exposure data back to low exposure is faulty, or the behavior of the coated particles in the neutron spectrum characteristic of the acclerated tests does not adequately represent the behavior in an HTGR spectrum.

INTRODUCTION

This report describes work done by Oak Ridge National Laboratory (ORNL) and Gulf General Atomic (GGA) as part of the National HTGR Recycle Development Program.[1,2] Fuel was fabricated for the Recycle Test Elements (RTE's) by both ORNL and GGA. Since GGA has published its fabrication data,[3] this report, taken with GGA's, is a complete collection of fabrication data for the RTE's. Much of the information contained in this report has been previously published in progress reports.[4–8]

The irradiation testing portion of the National HTGR Recycle Development Program Plan is divided into four subtasks. They are (1) capsule irradiation tests, (2) Peach Bottom irradiation tests, (3) large-scale recycle element irradiation tests, and (4) refabricated fuel irradiation tests. This report covers work on the second subtask. The irradiation testing portion of the National Program has three main objectives: (1) to provide kilogram quantities of irradiated HTGR fuel for head-end reprocessing studies, (2) to provide irradiated fuel blocks for testing engineering-scale reprocessing equipment, and (3) to provide irradiation proof tests of recycle fuel particles and rods prepared in prototype equipment using the processes to be used in the Thorium-Uranium Recycle Facility (TURF).

To achieve these objectives seven RTE's were fabricated and inserted into the Peach Bottom Reactor. Eight elements were originally planned, but one (RTE-3) was not built. Two of the elements have been withdrawn and examined. This report covers the postirradiation examination and analysis of those two elements, in addition to describing the fabrication of the ORNL fuel for the RTE series.

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1. Oak Ridge National Laboratory and Gulf General Atomic, *National HTGR Fuel Recycle Development Program Plan,* ORNL-4702 (August 1971).
2. Oak Ridge National Laboratory, Gulf General Atomic, and Idaho Chemical Processing Plant, *National HTGR Fuel Recycle Development Program Plan,* ORNL-4702, Rev. 1, in publication.
3. R. P. Morissette and K. P. Steward, *Recycle Test Element Program Design, Fabrication, and Assembly,* GA-10109 (September 1971).
4. J. M. Robbins and J. H. Coobs, *GCR Program Semiannu. Progr. Rep. Mar. 31, 1970,* ORNL-4589, pp. 10-15.
5. R. S. Lowrie and V. C. A. Vaughen, *GCR-TU Programs Semiannu. Progr. Rep. Sept. 30, 1970,* ORNL-4637, pp. 97-99; J. D. Sease, F. J. Furman, P. A. Haas, C. B. Pollock, and J. M. Robbins, ibid., pp. 104–9.
6. R. B. Fitts, *GCR-TU Programs Annu. Progr. Rep. Sept. 30, 1971,* ORNL-4760, pp. 65-67.
7. R. B. Fitts, *Metals and Ceramics Div. Annu. Progr. Rep. June 30, 1972,* ORNL-4820, pp. 138-39.
8. *ORNL Gas-Cooled Reactor Programs Annu. Progr. Rep. Oct. 1, 1971–Dec. 31, 1972,* ORNL-4911 (in press).

The fuels being irradiated in the RTE's include all those thought to be of prime interest at the time the tests were being planned. The test conditions cover a range of temperatures from 500 to 1300°C, burnups to 20% FIMA in the mixed thorium-uranium particles, and fast neutron (>0.18 MeV) exposures of up to 4.2×10^{21} neutrons/cm^2. Both sol-gel oxide fuels (fabricated at ORNL) and carbide fuels (fabricated at GGA) were included. Many changes have occurred in the HTGR recycle program since the RTE tests were planned and the fuel was fabricated. Some of the information previously published[4–8] has been superseded.

DESCRIPTION OF THE RECYCLE TEST ELEMENTS

The RTE's were designed to replace standard Peach Bottom Reactor core 2 fuel elements. A detailed description is contained in the GGA report on design, fabrication, and assembly of the experiments.[3] Several additional diagrams and figures are included in this section to supplement the material published by GGA.

The types of fuel combinations in the recycle test elements and an indication of the reasons for including these combinations are given in Table 1. A more detailed breakdown of the loading combinations and planned irradiation conditions is given in Table 2. Odd-numbered elements are the primary source of material for the hot-cell head-end studies. When the experiments were planned emphasis was on particle combinations a, c, f, and g, which were the reference candidates; however, all fuel combinations are covered in each odd-numbered element. The six 15-in. sections of the odd-numbered elements are to be quartered lengthwise during postirradiation examination to obtain one sample of each fuel type, as indicated in Fig. 1.

Table 1. Fuel combinations in the recycle test element program

Particle combination	Particle makeup in combinations		Justification[a]
	Fissile particle and coating	Fertile particle and coating	
a	$(4Th,U)O_2$, Biso	ThC_2, Biso[b]	Reference recycle fuel
b	UO_2, Biso	ThC_2, Biso	Backup fuel type if economics indicate that Th should be eliminated from recycle fissile particle
c	$(2Th,U)O_2$, Biso	ThO_2, Biso	Th-to-U ratio of 2 to obtain reference burnup in three years; ThO_2 backup if oxide process is adopted for economic reasons; over a period of time, the desired Th-to-U ratio will move from 4 toward 2
d	$(2Th,U)O_2$, Biso	ThC_2, Biso	Reference-type recycle combination with a Th-to-U ratio of 2 for accelerated burnup in fissile particle
e	UC_2, Biso	ThC_2, Biso	Reference startup loading
f	UC_2, Triso	ThC_2, Biso	Reference B block makeup fuel loading; Triso coating necessary to permit required separation of particles during reprocessing
g	UO_2, Biso	ThO_2, Biso	Backup fertile particle if thorium is eliminated from recycle particle; backup fertile particle if sol-gel process is used
h	UC_2, Biso	ThO_2, Biso	Backup B block loading; possible particle separation by chemical processes (e.g., selective burning or leaching)
i	UC_2, Triso	ThC_2, Triso	Needed if cleaner primary heat exchanger circuit becomes requirement; FSV-type fuel
o	UO_2, Triso	ThO_2, Biso	Reference fuel for ^{235}U recycle

[a]All combinations will be evaluated for equipment and chemical process checkout, bed sticking, metallic fission-product behavior, and kernel migration.

[b]ThC_2 fertile particles were employed in this combination in blended beds. No fertile particles were used in bonded beds.

Table 2. Fuel body loading combinations

Element	Holes	Loading for each vertical position of fuel body[a]					
		6 (Top)	5	4[b]	3[b]	2	1 (Bottom)
RTE-1[c]	1, 5	d	d	a	a	a	a
	2, 6	e	e	f	f	f	f
	3, 7	i	h	c	c	c	c
	4, 8	o	o	g	g	g	g
RTE-2	All	f[d]	a[e]	e[d]	f[e]	d	e[e]
RTE-4	All	e[e]	d	f[d]	a[e,f]	f[e]	e[d]
RTE-5	1, 2	b	b	a	a	a	a
	3, 4	d	e	c	c	c	c
	5, 6	e	h	f	f	f	f
	7, 8	i	d	g	g	g	g
RTE-6	All	g	f[d]	f[d]	d	f[d]	e[d]
RTE-7	1, 2	a	a	b	b	b	b
	3, 4	c	c	g	d	d	d
	5, 6	f	f	h	g	g	g
	7, 8	g	g	d	i	i	i
RTE-8	All	f[d]	i[d]	d	e[d]	i[d]	f[e]

[a]Loadings are indicated by letters a through i and o as identified in Table 1.
[b]Positions of maximum flux.
[c]Renamed FTE-11 (Fuel Test Element).
[d]Fuel rods carbonized in fuel body.
[e]Blended beds.
[f]Actually (4.2Th,U)O_2 Biso + ThC_2 Biso.

Even-numbered elements will provide larger amounts of the various fuel combinations for additional hot-cell studies. They may also be the first irradiated specimens representative of 1 100-MW(e) HTGR fuel that will become available for use in reprocessing studies in TURF.

Several changes in terminology have occurred since Tables 1 and 2 were first published.[9] In the initial description[10] of the HTGR fuel element four types of particles were being considered for use in two types of elements, the "A" element and the "B" element. The four particle types were one fertile particle and three fissile particles:

(1) a ThC_2 fertile particle with a Biso pyrolytic carbon coating;

(2) a fissile particle containing $^{235}UC_2$ with a pyrolytic carbon coating, called the Biso fissile particle;

(3) a fissile particle containing $^{235}UC_2$ coated with both pyrolytic carbon and silicon carbide, called the Triso fissile particle; and

(4) a fissile particle containing (Th,^{233}U)O_2 with a pyrolytic carbon coating, called the recycle particle.

The various recycle loadings and alternatives to reference loadings are shown in Fig. 2. Only one type of fissile particle was to be used in any one fuel element. Fissile particles were to be mixed with fertile particles before the fuel stick was formed. Both types of element were to be used at one time in the core.

9. R. S. Lowrie and V. C. A. Vaughen, *GCR-TU Programs Semiannu. Progr. Rep. Sept. 30, 1970,* ORNL-4637, pp. 97-99; J. D. Sease, F. J. Furman, P. A. Haas, C. B. Pollock, and J. M. Robbins, ibid. pp. 104–9.

10. Oak Ridge National Laboratory and Gulf General Atomic, *National HTGR Fuel Recycle Development Program Plan,* ORNL-4702 (August 1971).

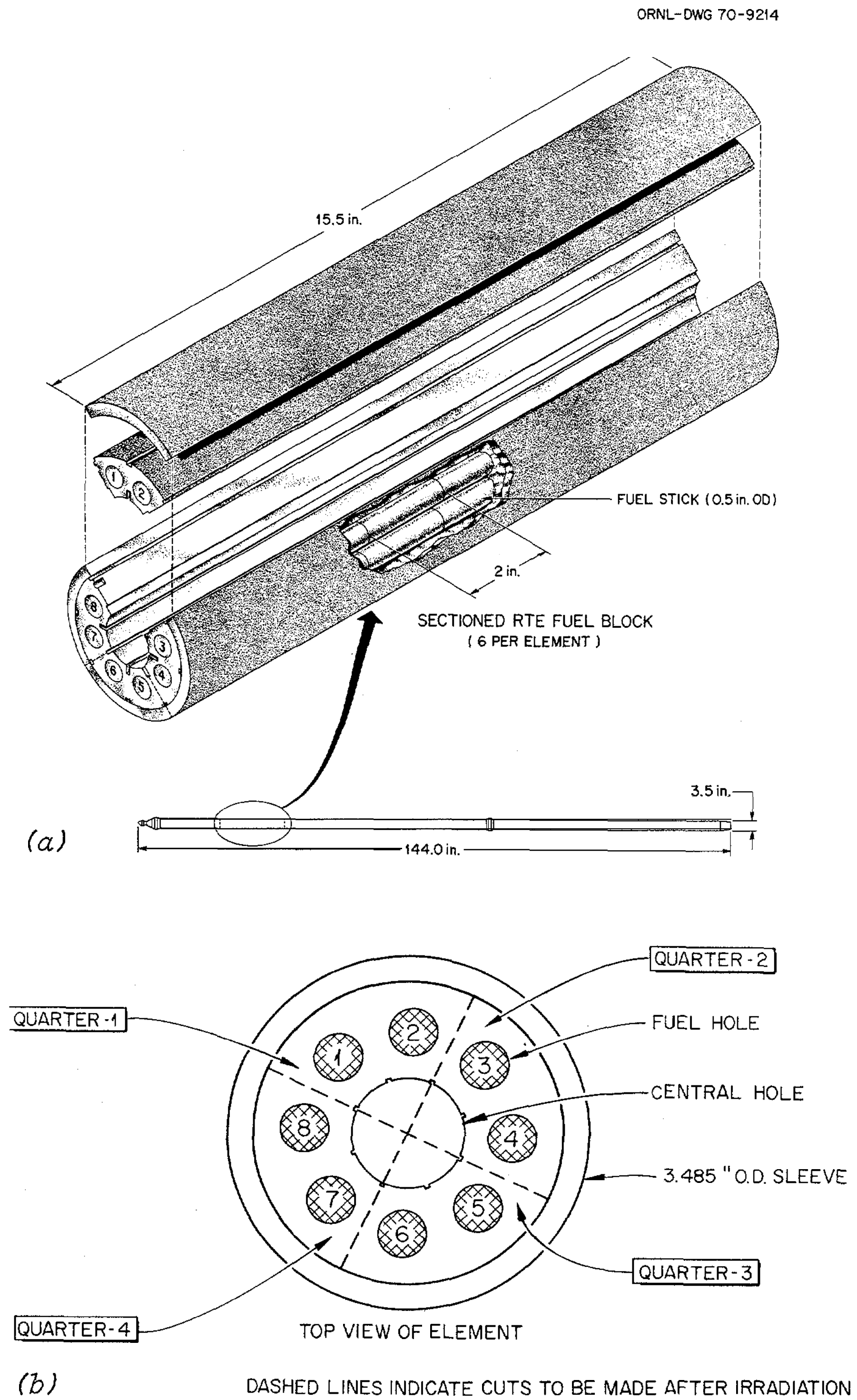

Fig. 1. (a) **Recycle test element showing single fuel body and end view of it.** (*b*) **End view of a fuel body from a recycle test element.**

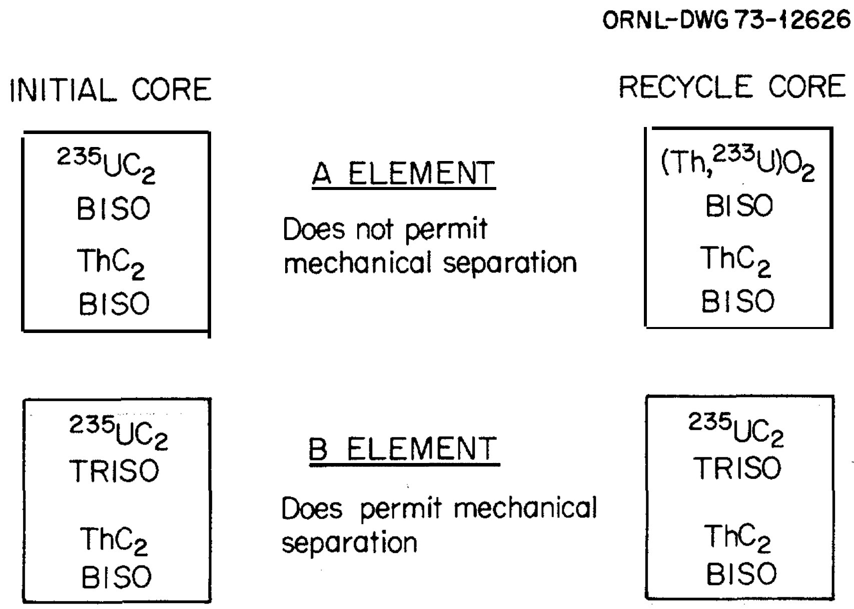

Fig. 2. Distribution of the four types of coated particles considered for the two types of elements in the original description of the 1100-MW(e) HTGR. The reference fuel in Fort. St. Vrain and in the 1 100-MW(e) HTGRs is in the form of bonded rods.

Every element was to contain the ThC_2 fertile particle. The Triso fissile particle would be contained in the "B" elements. Because of its SiC coating this particle containing ^{235}U could then be separated from the other particles by size classification. Initially, until ^{233}U became available, "A" elements were to contain the Biso fissile particle. Although this particle cannot be size classified from the fertile particle, most of these elements were to have been removed from the reactor before full burnup was achieved (four years for the reference fuel design). Thus significant quantities of ^{235}U would remain in the elements, and reprocessing these elements without separation of the particles would have been economically warranted. The penalty associated with neutron absorptions in ^{236}U formed in ^{235}U becomes large only when this nuclide builds up to large concentrations because of its continued production from makeup fuel. In later core loadings, the same "B" elements as those in the initial fueling were to be used, and the recycle particle was to be used in the "A" elements. Since this particle would contain only ^{233}U and thorium, no separation of particles would have been required.

Under the system described in the above paragraph, the reference fertile particle was ThC_2. The distinction between the "A" elements and "B" elements in this system was thought to be too cumbersome, and there was renewed interest in the possibility of a second burn of the ^{235}U discharged from the "B" elements, in spite of the high concentrations of the ^{236}U isotope, because the discharged uranium is still about 30% enriched. So a new system of nomenclature was devised. The four types of particle are now:

(1) a ThO_2 fertile particle (Biso),

(2) a fissile particle containing virgin $^{235}UC_2$ (Triso),

(3) a recycle ^{235}U particle containing recycle $^{235}UC_2$ (Triso), and

(4) a recycle particle containing $(Th,^{233}U)O_2$ (Biso).

As before, only one type of fissile particle is used in any one fuel element, and the fissile particles are mixed with fertile particles before the fuel rod is formed. Three types of elements have now been defined:

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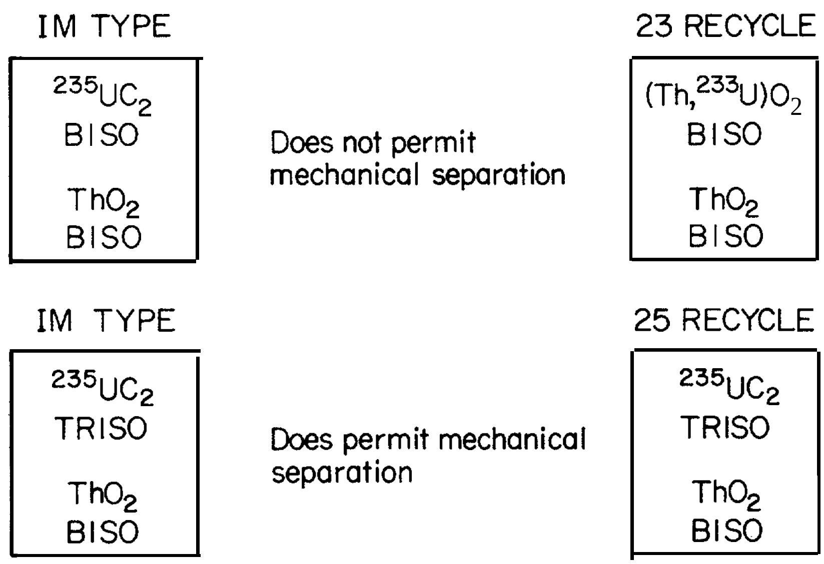

Fig. 3. Distribution of the four types of coated particles for the types of elements in current plans for 1100-MW(e) HTGR.

1. the IM (initial and makeup) element, which contains virgin ^{235}U and thorium and is to be used in initial and makeup fuel loadings;
2. the 23 recycle element, which contains ^{233}U and thorium and is to be used as the major recycle element; and
3. the 25 recycle element, which contains recycle ^{235}U and thorium and is to be used when it is desirable to pass ^{235}U through the reactor more than once.

Any combination of these elements may be used in a given reactor core. A schematic diagram of the current combinations is given in Fig. 3.

FABRICATION

Fuel for the RTE's was fabricated at ORNL and Gulf General Atomic. A fabrication report on the GGA fuel has been issued.[11] Detailed information on the fabrication of ORNL fuel is contained in the following appendices to this report.

Appendix A. Loading Plan for ORNL Fuel

Appendix B. Fabrication and Preirradiation Inspection Data on ORNL Fuel Rods

Appendix C. Fabrication Data for ORNL Loose Particle Fuel in RTE-2 and -4

Appendix D. Spine Samples Tested in RTE-5

Appendix E. Description of Coated Particles used in Fuel Fabricated at ORNL

Appendix F. Location of RTE Archive Samples

Appendix G. Preirradiation Metallography

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11. R. P. Morissette and K. P. Steward, *Recycle Test Element Program Design, Fabrication, and Assembly,* GA-10109 (September 1971).

Fabrication of Coated Particles

The fuel fabricated at ORNL contained approximately 15 kg of coated particles in 2000 in. of fuel rods and two segments (each one-sixth of an element) of loose particles. The types of fuel particles prepared are listed below:

Fuel type	Nominal kernel diameter (μ)	Designation
$(4Th,U)O_2$	350	Reference recycle particle
$(2Th,U)O_2$	350	Full-burnup particle
UO_2	100	Alternate recycle particle
ThO_2	400	Alternate fertile particle

The designations given above applied at the time the RTE's were being fabricated. The most recent draft of the program plan[12] specifies a slightly different design for the reference and alternate recycle particles.

Typical properties of the coated particles are listed in Table 3. The UO_2 particles were coated in graphite cone furnaces that have a 1¼- to 1¾-in. ID, and the other particles were coated in the prototype remotely operated coating furnace, which has a 5-in. ID. Acetylene diluted with helium was used for depositing the inner buffer coating on all particles, and propylene was used for depositing the outer isotropic coating. Typical ThO_2, $(Th,U)O_2$, nonspherical $(Th,U)O_2$, and UO_2 particles are shown in Fig. 4.

Table 3. Typical properties of RTE-ORNL coated particles

Particle type	Kernel		Buffer coating		Outer coating[a]	
	Diameter (μm)	Density (g/cm^3)	Thickness (μm)	Density (g/cm^3)	Thickness (μm)	Density[b] (g/cm^3)
$(4Th,U)O_2$	349	10.10	73	1.10	104	1.92
$(2Th,U)O_2$	350	10.10	82	1.16	130	1.88
$(2Th,U)O_2$ nonspherical	373	10.09	79	1.24	136	1.87
UO_2	111	10.06	54	1.20	68	1.89
ThO_2	400	9.92	54	1.30	70	1.92

[a]The anisotropy of the outer coatings was always such that the Bacon anisotropy factor was less than 1.09 as estimated from visual examination of metallographic mounts of the particles under polarized light.

[b]Determined by gradient-density column.

Fabrication of Fuel Rods

The particles were formed into fuel rods 0.490 in. in diameter and 2.14 in. long. The particles were bonded by injecting hot pitch with filler into a bed of particles held in a mold. The matrix material was 15V coal tar pitch from Allied Chemical Company mixed with ~35% graphite flour from Poco Graphite,

12. Oak Ridge National Laboratory, Gulf General Atomic, and Idaho Chemical Processing Plant, *National HTGR Fuel Recycle Development Program Plan,* ORNL-4702, Rev. 1, in publication.

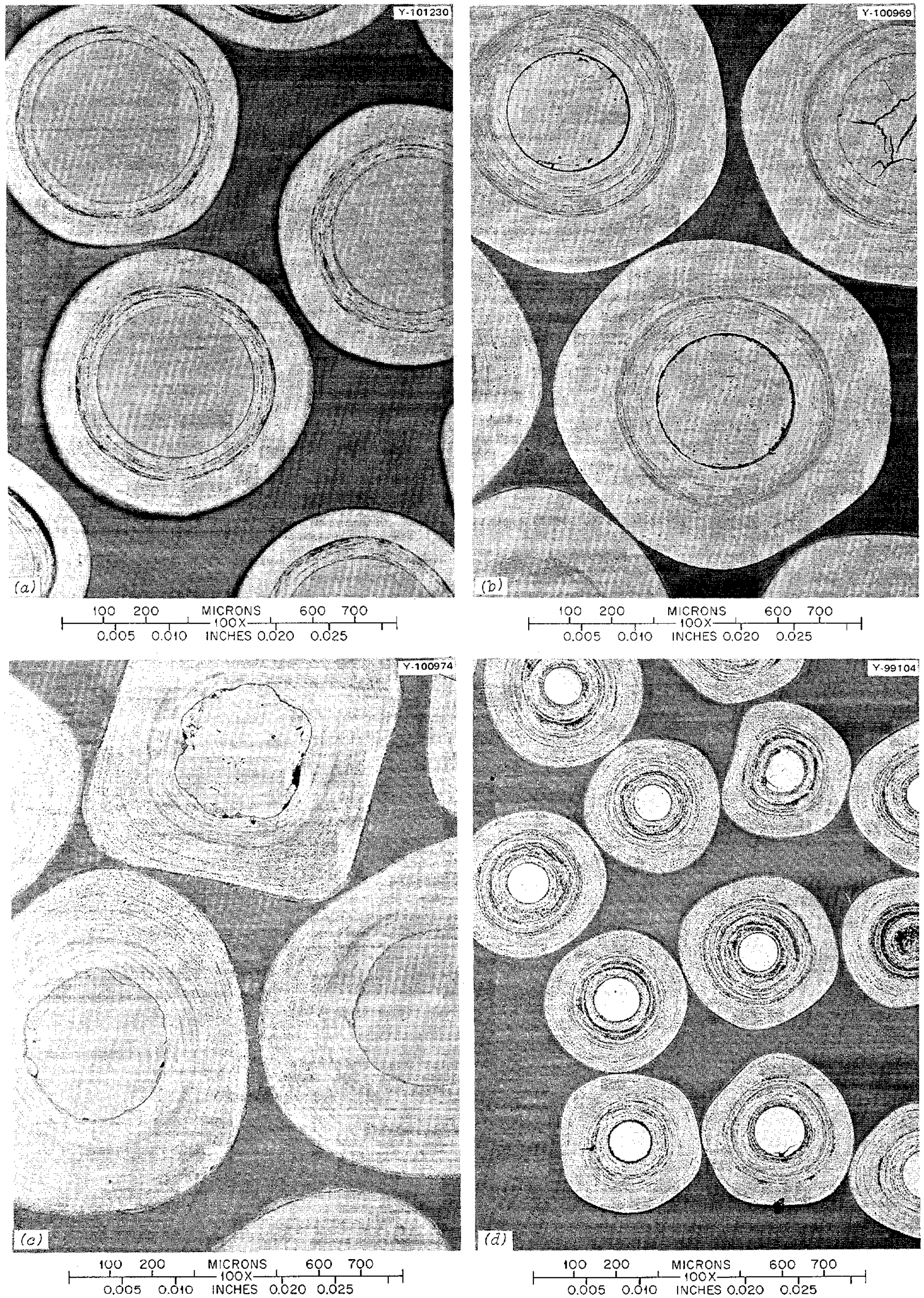

Fig. 4. Typical coated particles. (*a*) ThO_2. (*b*) $(Th,U)O_2$. (*c*) Nonspherical $(Th,U)O_2$. (*d*) UO_2.

Inc. The types of fuel rods and the number of each type produced are listed below:

Rod type	Number produced
(Th–20% U)O_2	180
(Th–33% U)O_2 + ThO_2	186
(Th–33% U)O_2 + ThC_2	330
UO_2 + ThO_2	228

The fabrication procedure follows:

1. Weigh fissile particles to provide the proper uranium concentration.
2. Weigh fertile particles to complete filling the mold.
3. Fill the mold by coincident feeding of the particles from vibrating horizontal trough feeders into a mixing funnel that leads into the vibrating mold.
4. Verify that the mold is filled properly, and affix the mold cap to restrain the packed particle bed.
5. Mix bonding material (35 wt % Poco graphite in 15V pitch) and load into injection gun shown in Fig. 5.

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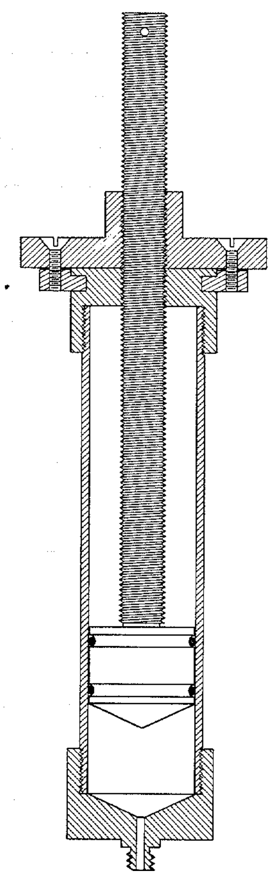

Fig. 5. Device for injecting particle bonding material.

6. Heat the filled mold and injection gun to 200°C.

7. Remove mold from furnace and attach to injection gun at the threaded nipple.

8. Apply pressure to the matrix material by turning the handle to drive the double-O-ring-sealed piston.

9. Apply pressure until excess bonding material is forced from exit end of mold.

10. Cool mold to room temperature and eject solidified rod.

11. Pack the rod in coarsely ground natural flake graphite flour for mechanical support during heat treatment.

12. Heat treat in argon to carbonize and partially graphitize the matrix: initial treatment, 58°C/hr for 6 hr, 29°C/hr for 12 hr, 75°C/hr for 4 hr; hold at 1000°C for 2 hr and allow furnace to cool in approximately 12 hr; final treatment, heat to 1800°C in 2 hr; hold at 1800°C for 0.5 hr and let furnace cool in approximately 16 hr.

13. Remove rod from graphite flour and inspect.

During fabrication of the rods for the RTE's, several problems were encountered. An early problem was that bonding material containing 40 wt % Poco AXM graphite flour could not be injected through the 2-in. fuel bed made from a blend of two sizes of coated particles (250 to 500 μm UO_2 and 600 to 1000 μm ThO_2). The reason was determined to be the high volume particle loading obtained with the two sizes of particles. Most previous work had been done with particles of a single size or a two-particle system with the particles fairly close to the same size and a resultant particle volume loading of about 62 to 65%. With the RTE particle blend, volume loadings as high as 70% were obtained, with the value depending on the sphericity of the particles. Also we found that a mix containing 35 wt % graphite flour instead of 40 wt % could be used.

Another problem with the bonding mix developed when the original batch of graphite flour was depleted and we had to start on a new supply. An identical mix made with the new batch of filler would inject only about 0.5 in. into the bed of particles. We then determined that the original batch of filler had ground to pass through a 325-mesh screen, and the new batch had been ground to pass through a nesh screen. Therefore, even though both flours were screened through a 40-μm precision screen before use, more fines were in the original batch of flour than in the second batch. This problem was solved by screening and using the particles smaller than 27 μm from the new batch of filler. However, this was wasteful of graphite flour and pointed up the need for developing a filler with optimum particle size distribution.

A problem that could not be eliminated entirely was the formation of a carbon cap on one end of the fuel rod. This cap formed on the injection end of the rod when the particles settled slightly during injection and left a thin layer, or cap, of bonding material without particles at the end of the rod. This happened even though the particles were vibrated into the molds and the bed of particles was restrained.

A blending problem was encountered in making the rods containing UO_2 and ThO_2. This problem was solved by feeding the particles simultaneously from the vibratory feeders into a double funnel leading into the mold. The double-funnel arrangement permitted feeding the particles directly into the bottom of the top funnel to prevent bouncing. The stem of the top funnel passed through a hole in a lid into the second funnel. The particles were directed against the angled wall of the second funnel so that they were mixed by bouncing and swirling. The lid on the second funnel kept the bouncing particles from being scattered. Radiographs indicated that this method of mixing gave a consistently good blend, as shown in Fig. 6(*d*). Figure 6(*a*) shows a fuel rod made from particles that were blended by pouring directly into a mold; the resulting swirl pattern may be seen. Figure 6(*b*) shows a blend formed with a momentary interruption in the feeding of the ThO_2 particles, which is indicated by the black band toward the bottom and the excess of ThO_2 at the top. Figure 6(*c*) shows what happened when UO_2 and ThO_2 particles were fed in separate

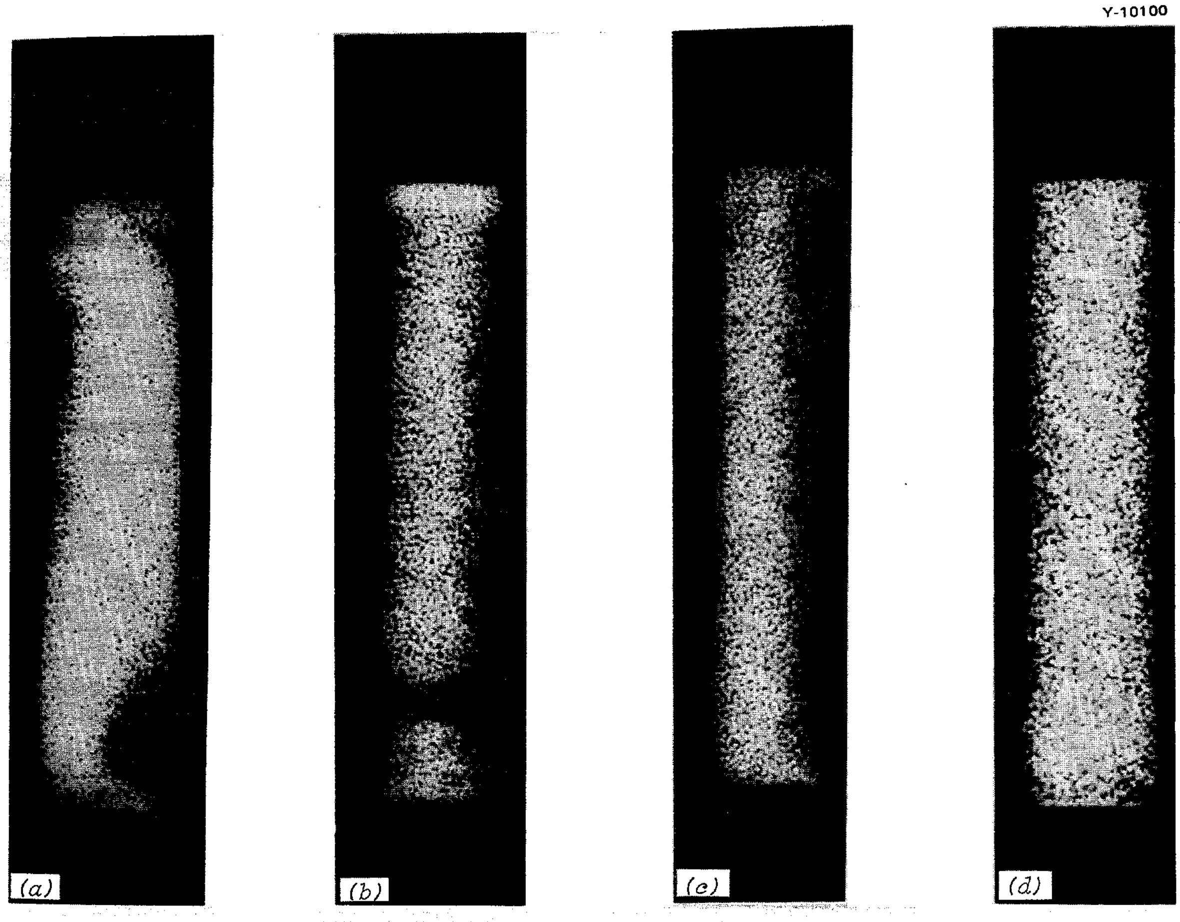

Fig. 6. Radiographs showing various degrees of blending obtained in HTGR fuel rods with two sizes of coated particles. *(a)* Particles poured directly into mold. (b) Blend formed with momentary interruption in feeding of ThO_2 particles. (c) Particles fed in separate streams down opposite sides of mold. *(d)* Particles loaded with double-funnel arrangement.

streams down opposite sides of the mold. There is an obvious concentration of UO_2 on one side of the mold and ThO_2 on the other. Unfortunately, many of the UO_2-ThO_2 sticks were produced before this problem of blending was discovered. Consequently, several rods were rejected, and others with less-than-ideal homogeneity were accepted to meet the schedule.

Two fuel bodies were loaded with mixtures of coated $(4Th,U)O_2$, coated ThC_2, and graphite flour. This particle mixture, at the time of fabrication, was the reference recycle fuel mixture; however, the reference fuel was and still is bonded together to form fuel rods, while this fuel was loaded as loose particles. In the loading of these loose particle segments, the three types of particles were loaded concurrently from three Syntron vibrators on which were mounted V-trough feeders. The filling rate was about 1 in./min. After all eight holes of the fuel segment were loaded, 65-g steel cylinders were placed on top of each hole to hold the particle bed in place, and the segment was vibrated by a Syntron vibrator to settle the bed. The method of mounting the segment onto the vibrator is shown in Fig. 7. A glass dummy fuel hole was mounted on the side and filled with low-density ($\sim$2.4 g/cm^3) coated particles and uncoated ThO_2. After extensive vibration, only a small area at the top of the column appeared to have partially segregated. This demonstrated the practicality of settling loose beds by vibration.

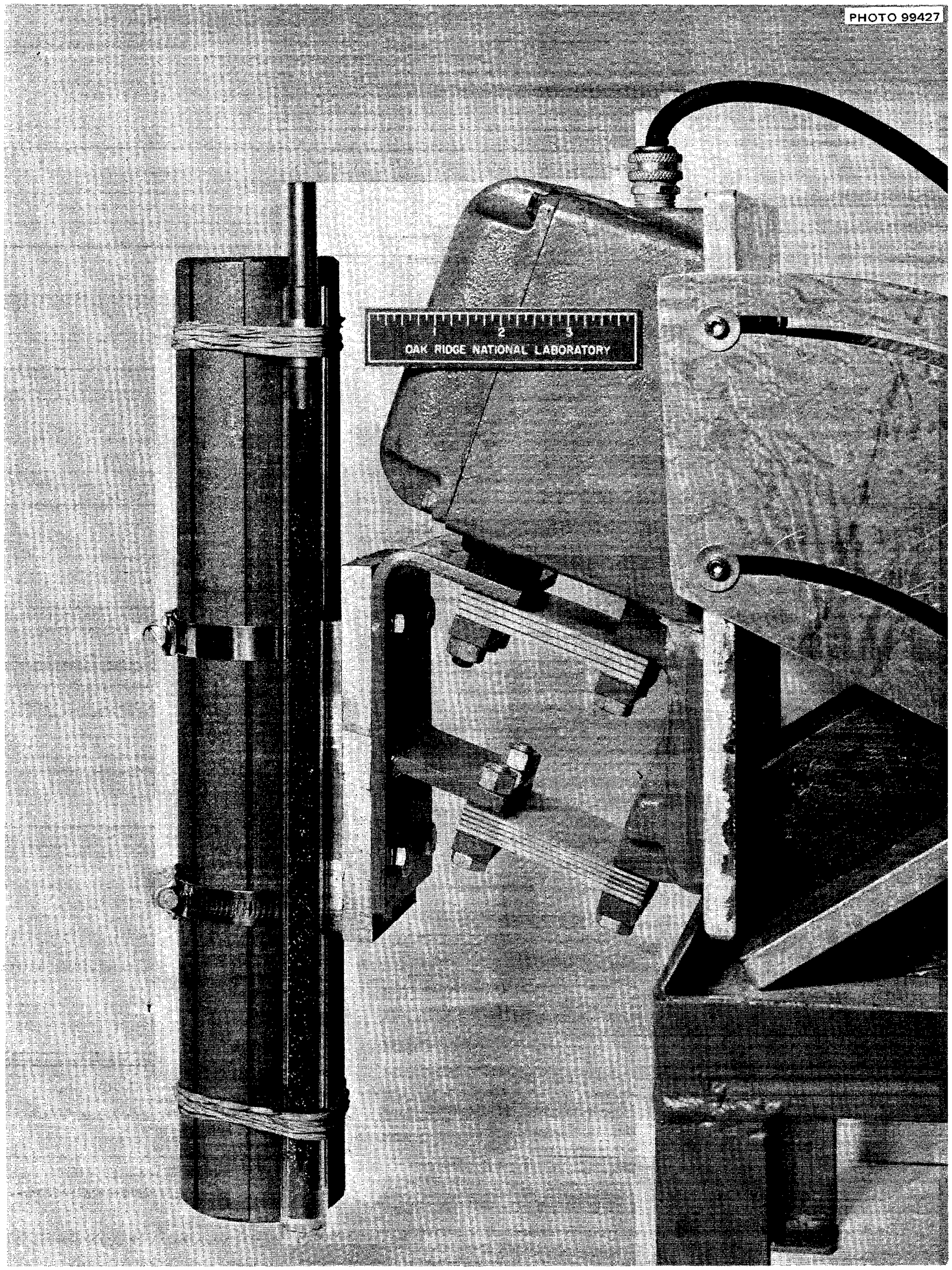

Fig. 7. RTE segment vibrator.

After the initial settling, additional graphite flour was added to fill the bed with graphite. (Loading all the graphite during the initial feeding caused the bed to expand beyond the volume required for the particles.)

When the filling was completed the beds were sealed in place by adding 2 cm^3 of methyl ethyl ketone and 10% polystyrene. After the sealing mixture dried, the segments were checked for contamination and shipped to Gulf General Atomic for loading into Peach Bottom fuel elements. A dummy hole for each segment was filled with the same mixture as that used for the segment holes and retained at ORNL for future cold reprocessing tests before testing the irradiated segments.

Spine Sample Fabrication

In addition to the recycle test elements themselves, a series of bonded-bed specimens with various graphite fillers were prepared for testing in the spine positions of RTE-5. All samples contained identical coated particles and were nominally 0.4 in. in diameter × 0.7 in. long; each was supported in a small H-327 graphite crucible. The compositions selected for testing are listed in Table 4. Two specimens of each type are being tested. The spine samples had 15V pitch as the binder.

Table 4. Bonding materials selected for irradiation testing in RTE-5

Type of graphite flour filler	Flour size (μm)	Amount of filler (wt %)	Manufacturer
Poco AXM	<27	35	Poco Carbon Company
Robinson	<27	40	Union Carbide Corporation
JOZ	<40	35	Great Lakes Carbon Corporation
Santa Maria	<40	40	Collier Carbon and Chemical Corporation
Asbury	<40	35	Asbury Graphite Company
Thermax	*a*	50	RT Vanderbilt Company

[a] Spherical particles of carbon black are submicron size.

The Santa Maria graphite flour is of interest because it is reported[13] to result in bodies with unirradiated properties similar to those of Poco grades of graphite. The JOZ grade of graphite flour is derived from a petroleum coke and is the base material for Great Lakes H-337 graphite. Interest in the JOZ graphite was evoked by the encouraging irradiation behavior of H-337 in HFIR experiments at 750°C and the availability of the material in large quantities. H-337 was a candidate graphite for the Molten Salt Reactor. The Robinson graphite flour is an air-blown graphite powder that does not form a needle-like structure and therefore may form an isotropic matrix. The Asbury flour is natural flake graphite. Additional details are given in Appendix D.

IRRADIATION SCHEDULE

The original scheme[14] called for eight RTE's: two discharged after irradiation for a year, two more discharged after irradiation for two years, and four discharged after irradiation for three years. As indicated earlier, only seven RTE's were built. The planning reflected[14] was not followed when the first elements

13. M. C. Smith, *CMF-13 Research on Carbon and Graphite, Report No. 9, Summary of Progress, February 1–April 30, 1969,* LA-4171 (May 13, 1969).
14. R. S. Lowrie and V. C. A. Vaughen, *GCR-TU Programs Semiannu. Progr. Rep. Sept. 30, 1970,* ORNL-4637, pp. 97-99; J. D. Sease, F. J. Furman, P. A. Haas, C. B. Pollock, and J. M. Robbins, ibid., pp. 104–9.

were discharged. Element RTE-7, initially scheduled for a three-year irradiation was discharged after only one year, and RTE-4, initially scheduled for a two-year exposure, was discharged after a year and a half. These changes were made to expedite other phases of the program.

Elements RTE-2 and -4 through -8 were charged into the Peach Bottom Reactor on July 14, 1970. In April 1971, RTE-7 was withdrawn and RTE-1 (renamed FTE-11) was inserted; RTE-4 was withdrawn in April 1972. Withdrawal of RTE-2 was scheduled for April 1973, but because of several reactor shutdowns the withdrawal was postponed until September 1973. The remaining RTE's are scheduled to remain in the reactor until the final shutdown, presently estimated to be September 1974. Table 5 summarizes the exposure schedule for each of the seven RTE's.

Table 5. Revised exposure schedule for Peach Bottom irradiation experiments

Element	Charged	Discharged	Exposure	
			Equivalent full-power days	(neutrons/cm') >0.18 MeV
RTE-1 (FTE-11)	April 1971	Aug. 1974[a]	648[a]	$2.6^a \times 10^{21}$
RTE-2	July 1970	Sept. 1973	700[a]	2.8[a]
RTE-4	July 1970	April 1972	384	1.5
RTE-5	July 1970	Aug. 1974[a]	900[a]	3.6[a]
RTE-6	July 1970	Aug. 1974[a]	900[a]	3.6[a]
RTE-7	July 1970	April 1971	252	1.0
RTE-8	July 1970	Aug. 1974[a]	900[a]	3.6[a]

[a]Projections. Fluence for projections based on 0.004×10^{21} neutrons/cm^2 (>0.18 MeV) per EFPD from RTE-7 and -4 calculations.

POSTIRRADIATION EXAMINATION AND ANALYSIS

Postirradiation examination of RTE-7 and -4 is nearly complete. RTE-7 received an exposure of about 1×10^{21} neutrons/cm^2 (>0.18 MeV) peak fluence, and an average burnup of about 2.4% FIMA in 252 equivalent full-power days (EFPD). For RTE-4 the exposure was 1.5×10^{21} neutrons/cm^2 fast fluence, 3.5% FIMA in 384 EFPD. Each RTE is composed of six fuel bodies, and each fuel body contains an array of eight fuel holes in a telephone-dial pattern. Each fuel hole contains either six fuel rods or blended beds of loose coated particles. Each fuel body is divided into quarters, holes 1 and 2 being a quarter, holes 3 and 4 another quarter, and so forth (see Fig. 1, p. 4). The fuel rods are all of the same composition in any given quarter in the odd-numbered RTE's, except for RTE-1 (FTE-11), as indicated in Table 2, p. 3. In the even-numbered RTE's all eight holes in any given fuel body are filled with the same fuel.

Examination of RTE-7

The combinations of particles in RTE-7 were described earlier in Table 2. The locations of the combinations within RTE-7 are shown in Table 6. Also given in this table are the operating temperatures for the fuel bodies within RTE-7. These temperatures are taken from the distribution shown in Fig. 8, which was calculated from a GGA analysis[15] using the physical model depicted in Fig. 9. The fuel columns are actually about 12.5 to 12.8 in. long, with a rapid temperature decrease at the ends of the columns. The

15. R. P. Morissette and K. P. Steward, *Recycle Test Element Program Design Fabrication, and Assembly,* GA-10109 (September 1971).

inside of the graphite body in which the fuel rods operate is 50 to 100°F cooler than the fuel, with substantial temperature decrease occurring within the fuel rods themselves.

During the examination of RTE-7 all six fuel bodies were separated from their end fittings. The sleeve and end fittings were stored in Building 3026D for future examination. Bodies 1, 2, 4, and 6 were stored intact for future use as needed. Bodies 3 and 5 were disassembled to recover five quarters for head-end reprocessing studies, and nine samples of fuel rods were examined metallographically. The head-end reprocessing samples include Triso-coated UC_2 and ThC_2 (combination i, Table 1), the accelerated burnup recycle fuel (combinations c and d), and the oxide fuel system (combination g) at the extremes of

Table 6. RTE-7 fuel loading

Body	Combination[a] of particles in holes specified				Operating temperature range (°C)[b]
	1,2	3,4	5,6	7,8	
6	a	c	f	g	900-1050
5	a	c	f	g	980-1150
4	b	g	h	d	950-1230
3	b	d	g	i	925-1230
2	b	d	g	i	900-1130
1	b	d	g	i	590-880

[a]Letter designation of combinations given in table 1.
[b]Temperatures taken from Fig. 3.

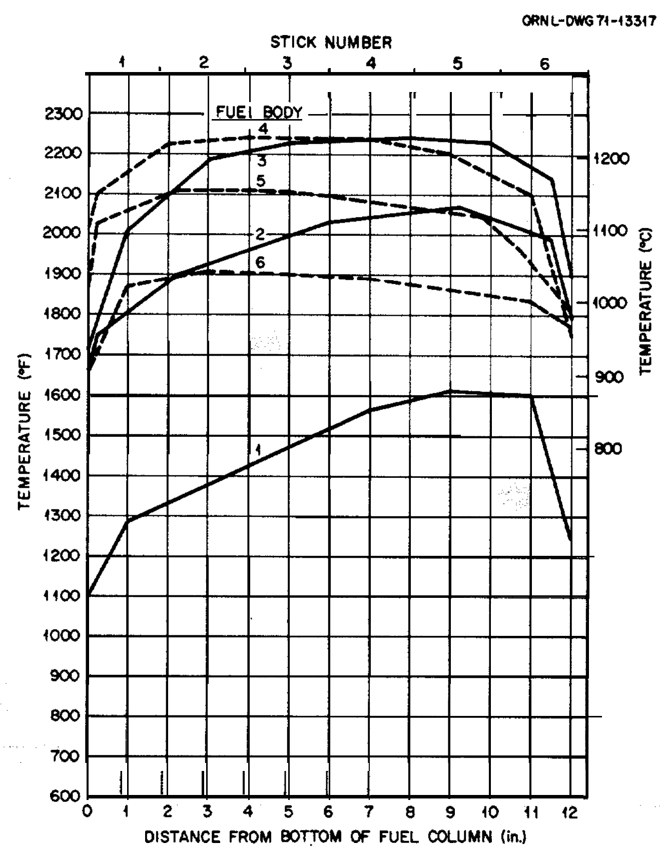

Fig. 8. Fuel stick temperature over the central 12 in. of fuel in each RTE-7 fuel body.

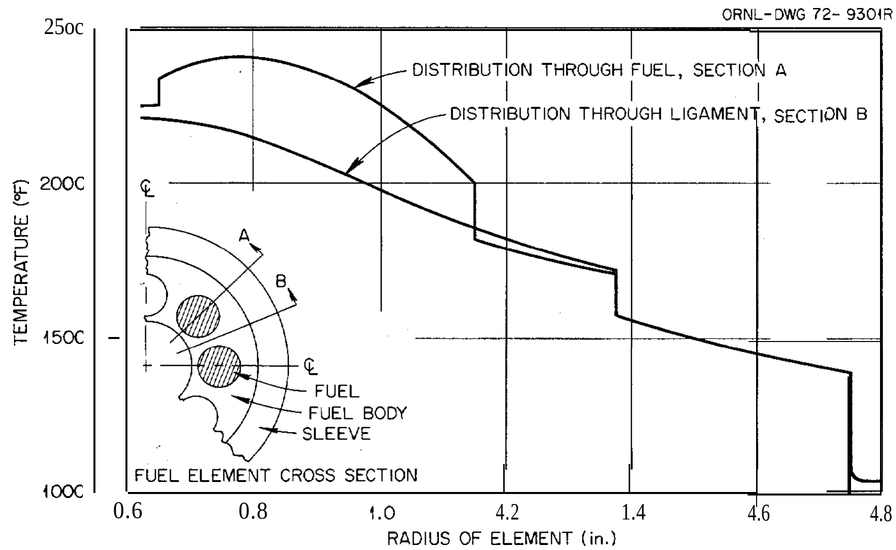

Fig. 9. Radial temperature profile at point of peak axial temperature for a body with bonded rods.

temperature reached in the experiment. The metallographic samples include each type of fuel particle tested at the peak temperature (about 1200°C) and intermediate temperature (about 1000°C) ranges.

The major points of interest in the postirradiation examination of RTE-7 are: (1) the ease of separating the fuel from the graphite bodies, (2) the dimensional stability of the graphite and the fuel rods, (3) the integrity and apparent stability of the coated particles, and (4) the distribution of fission products within the fuel bodies. Fuel rods were easily removed from the bodies in RTE-7 and exhibited excellent surface appearance. Fig. 10 shows typical end and side views of the fuel rods. The only apparent degradation was at the ends of the rods, where a small loss of material was occasionally observed.

Measurements on the graphite bodies revealed essentially no dimensional change. Measurements on 114 of the 288 fuel rods in this test revealed significant isotropic changes in the fuel rod dimensions. The average changes from these fuels are presented in Table 7 along with pertinent fabrication data. Many of the fuel rods from RTE-7 are smaller than would have been expected from earlier test data.[16] This may be because the expected dimensional changes extrapolated from data taken at significantly higher fast neutron doses ($>4 \times 10^{21}$ neutrons/cm^2). If this explanation is correct the rate of diametral change early in the irradiation must be higher than previously expected. Alternatively, these greater dimensional changes may be a result of the difference in flux level and flux energy distribution between this and previous tests, with different rates of fast-neutron-induced graphite densification. The previous tests were accelerated-rate tests conducted in environments not typical of the HTGR environment. Reasonable modification of the initial diametral change rate, in the present relationship between diameter change and fast fluence, will suffice to include the ORNL data for RTE-7 Biso particles with that from earlier tests. However, the RTE-7 data for the Triso-Triso (FSV-type) fuel system cannot be reconciled with the earlier data. Perhaps these fuel rods were below the specified diameter range as fabricated, but we have no indication from GGA that this was the case. The dimensional data from the ORNL rods appear to be providing useful information on low-fluence dimensional changes and, combined with data from the remaining RTE's, should yield information on differences in dimensional changes associated with different rates of fast neutron damage.

16. R. B. Fitts, J. H. Coobs, and R. A. Olstad, "Summary of Fuel Rod Dimensional Changes Under Irradiation," *ORNL Gas-Cooled Reactor Programs Annu. Progr. Rep. Oct. 1, 1971–Dec. 31, 1972*, ORNL-4911, pp. 142–44.

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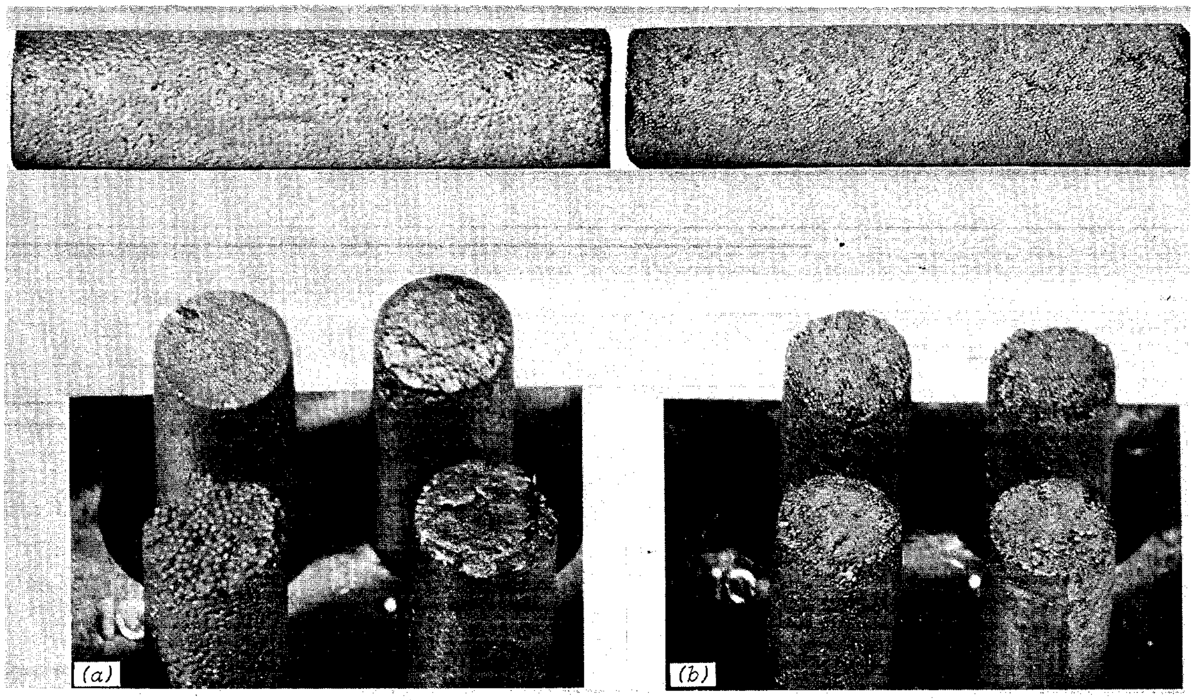

Fig. 10. Typical appearance of fuel rods from RTE-7. (*a*) ORNL rods. (*b*) GGA rods.

Table 7. Fuel rod dimensional change summary for RTE-7 irradiation

Rod type	Fabrication data[a]				Irradiation conditions[b]		Average[c] diameter decrease (%)
	Fuel body and hole	Fissile particle	Fertile particle	Average outer coating density (g/cm³)	Temp (°C)	Fast fluence (neutrons/cm²)	
a	5-1	$(4Th,U)O_2$ Biso	None	1.84	1100	0.97×10^{21}	2.10
a	6-1	$(4Th,U)O_2$ Biso	None	1.84	1000	0.60	1.29
a	6-2	$(4Th,U)O_2$ Biso	None	1.84	1000	0.60	1.42
c	5-4	$(2Th,U)O_2$ Biso	ThO_2 Biso	1.88	1100	0.97	2.09
c	6-3	$(2Th,U)O_2$ Biso	ThO_2 Biso	1.88	1000	0.60	1.58
c	6-4	$(2Th,U)O_2$ Biso	ThO_2 Biso	1.88	1000	0.60	1.61
g	3-5	UO_2 Biso	ThO_2 Biso	1.92	1200	1.26	2.30
g	1-5	UO_2 Biso	ThO_2 Biso	1.92	800	0.85	0.83
g	1-6	UO_2 Biso	ThO_2 Biso	1.92	800	0.85	0.90
g	5-8	UO_2 Biso	ThO_2 Biso	1.84	1100	0.97	2.05
g	6-7	UO_2 Biso	ThO_2 Biso	1.84	1000	0.60	1.57
g	6-8	UO_2 Biso	ThO_2 Biso	1.84	1000	0.60	1.42
d	3-4	$(2Th,U)O_2$ Biso	ThC_2 Biso	1.85	1200	1.26	2.64
b[d]	3-1	UO_2 Biso	ThC_2 Biso	1.85	1200	1.26	3.49[e]
f[d]	5-6	UC_2 Triso	ThC_2 Biso	1.77	1100	0.97	2.69[e]
i[d]	3-8	UC_2 Triso	ThC_2 Triso	1.75	1200	1.26	2.30[e]
i[d]	1-8	UC_2 Triso	ThC_2 Triso	1.75	800	0.85	0.97[e]

[a] Oxide kernels made and coated at ORNL, carbide kernels at GGA.
[b] Estimated average value for six rods.
[c] Average of data from six fuel rods in a fuel hole.
[d] Made at GGA using natural flake graphite filler and carbonization in a split mold. All others made at ORNL using Poco graphite filler and packed-bed carbonization.
[e] No preirradiation data available. Changes based on nominal specification diameter of 0.490 in.

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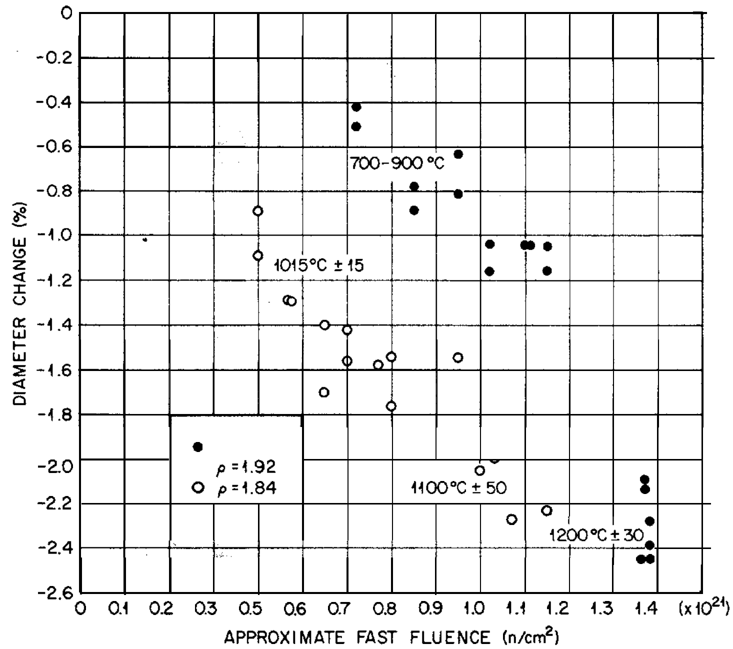

Fig. 11. Dimensional changes in (UO_2 Biso + ThO_2 Biso) fuel rods from RTE-7 as a function of fast fluence (>0.18 MeV).

We examined in some detail the shrinkage of two sets of fuel rods that contained UO_2 Biso + ThO_2 Biso fuel particles (particle combination g). The two sets differed only in the outer coating density, ρ of the Biso-coated particles, and both had approximately equal volume loadings of fissile and fertile coated particles. Portions of each of these two groups of rods were irradiated over the full range of temperatures and fluences obtained in RTE-7, and thus they provided a potential source of information on the combined effects of fluence and temperature at low exposure levels. The data from these 36 fuel rods are plotted in Fig. 11. The general trend of dimensional change with fluence and coating density is consistent with that from earlier tests with Biso-type fuel rods.[16] The most interesting point revealed by these data is the apparent effect of irradiation temperature on the diametral change for the fuels with an average particle outer coating density of 1.92. The data at 1200°C are significantly below the trend established by the data at 700 to 900°C. Unfortunately, the RTE's are not instrumented, so the temperatures are calculated. Despite the fact that the variation of temperature and fluence in them should be uniform and thus provide reasonable confidence in these results, we shall have to look for and verify the temperature effect in other tests before placing too much emphasis on this result.

Metallographic examination has been completed on six of the fuel rods from this experiment. These rods, containing samples of all the fissile and fertile particles in RTE-7 except the UC_2 Biso material, are listed in Table 8.

Typical radial cross sections of fuel rods[17] 7-3-6-3 and 7-3-2-3 are shown on Fig. 12. The matrix density of the fuel rods bonded at ORNL was typically higher (0.7 g/cm³) than in those bonded at GGA (~0.5 g/cm³), as illustrated in this figure. The difference is primarily due to the type and amount of filler used in the rods. About 27 wt % natural flake 6353 graphite filler in 15V pitch (reference FSV matrix) was used at GGA to form the matrix, but about 35 wt % fine Poco graphite in 15V pitch was used at ORNL.

17. 7-3-6-3 designates RTE-7, fuel body 3, fuel hole 6, third rod from bottom.

Table 8. Metallography samples from RTE-7

Fuel type	Fuel particles		Fuel rod	Design operating temperature (°C)
	Fissile	Fertile		
a	(4 Th,U)O_2	None	7-5-2-5[a]	1160
c	(2 Th,U)O_2	ThO_2	7-5-3-5	1160
g	UO_2	ThO_2	7-3-6-3	1220
b	UO_2	ThC_2	7-3-2-3	1220
d[b]	(2 Th,U)O_2	ThC_2	7-3-3-3	1220
f	UC_2[b]	ThC_2	7-5-5-5	1160
i	UC_2[b]	ThC_2[c]	7-3-7-3	1220

[a] 7-5-2-3 indicates RTE-7, fuel body 5, hole 2, rod 5.
[b] Not yet examined.
[c] Triso coated, others Biso coated.

Other than the difference in matrix morphology, the metallographic examination revealed no significant differences between the six types of fuel rods except, of course, particle types.

The fuel particles in RTE-7 all performed satisfactorily. Figures 13 and 14 show typical photomicrographs of each type of particle examined. The only indication of potential difficulty with these particles was the presence of numerous cracks in the outer LTI layers of the Triso-coated particles in fuel rod 7-3-7-3. [(Fig. 14(*b*)]. No broken SiC layers were visible in over 200 particles examined in this cross section, and the same type of UC_2 Triso fissile particles examined in fuel rod 7-5-5-5 contained no failed carbon or SiC coatings.

One of the fuel bodies from RTE-7, body 3, was autoradiographed and chemically analyzed on the safety program[18] to determine the fission product activity remaining in the graphite after removal of the fuel. An autoradiograph of a thin section of the body, shown in Fig. 15, revealed a marked difference in the fission product activity around the individual holes. The activity around holes 7 and 8, which contained the Triso-coated fuel, was low, as would be expected. The other six holes, which all contained similar particles, showed significant variations in fission product activity. It is clear that there was higher release of fission products from the fuel in holes 1 and 2, and that this difference was related to rod fabrication in some way. Possibly particles were broken during rod fabrication, but no failed coatings were observed during metallographic examination of one of the fuel rods from this hole [see Fig. 14(*a*)]. It is known that these rods were less well bonded with matrix and were smaller in diameter than normal and thus operated at higher temperatures than did the others. Chemical analysis of the graphite body showed that the ^{137}Cs content was markedly higher adjacent to holes 1 and 2 than elsewhere and that the ^{90}Sr content was markedly lower near holes 7 and 8.

Examination of RTE-4

The second Recycle Test Element removed from the Peach Bottom Reactor is presently undergoing postirradiation examination. This element, RTE-4, received 384 equivalent full-power days of irradiation. The peak fast fluence (>0.18 MeV) exposure was about 1.5×10^{21} neutrons/cm^2, and the average fuel burnup was about 3.5% FIMA. This element differed from RTE-7 in that each 15-in.-long fuel body contained a single fuel mixture. In addition, three of the six bodies contained loose beds of fuel particles mixed with calcined coke powder, and the fuel rods in two of the remaining three bodies were carbonized in place. The fuel loading and estimated operating temperatures for RTE-4 are described in

18. F. S. Dyer et *al.*, "Postirradiation Examination of Special Peach Bottom Element RTE-7," *ORNL Nucl. Safety Res. Development Program Bimonthly Rep. March-April* 1972, ORNL-TM-3831 (July 1972), p. 79.

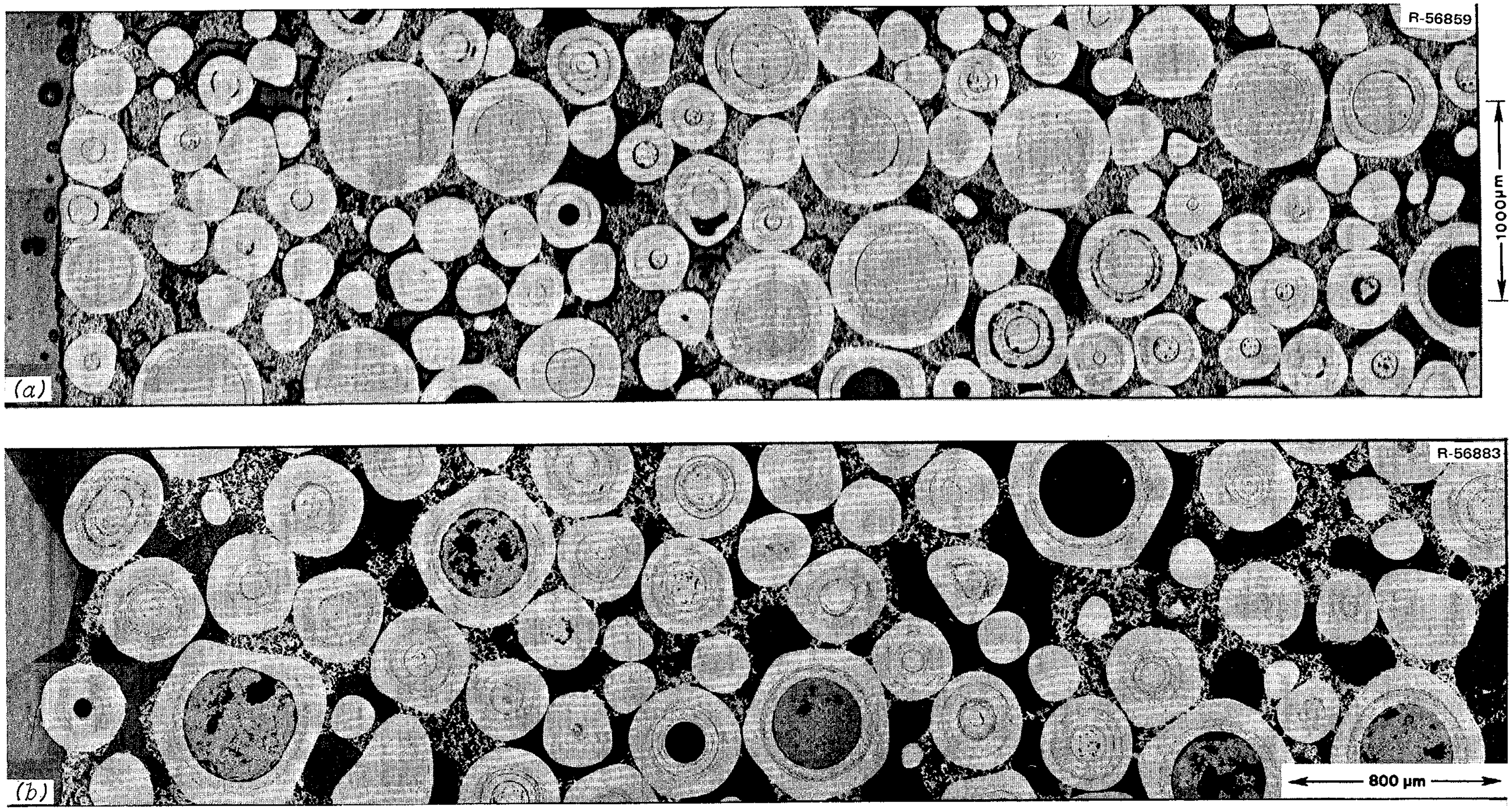

Fig. 12. Cross sections of bonded fuel rods from RTE-7. (*a*) ORNL-prepared rod 7-3-6-3, which contained Biso UO_2 fissile particles and Biso ThO_2 fertile particles. (*b*) GGA-prepared rod 7-3-2-3, which contained Biso UO_2 fissile particles and Biso ThC_2 fertile particles.

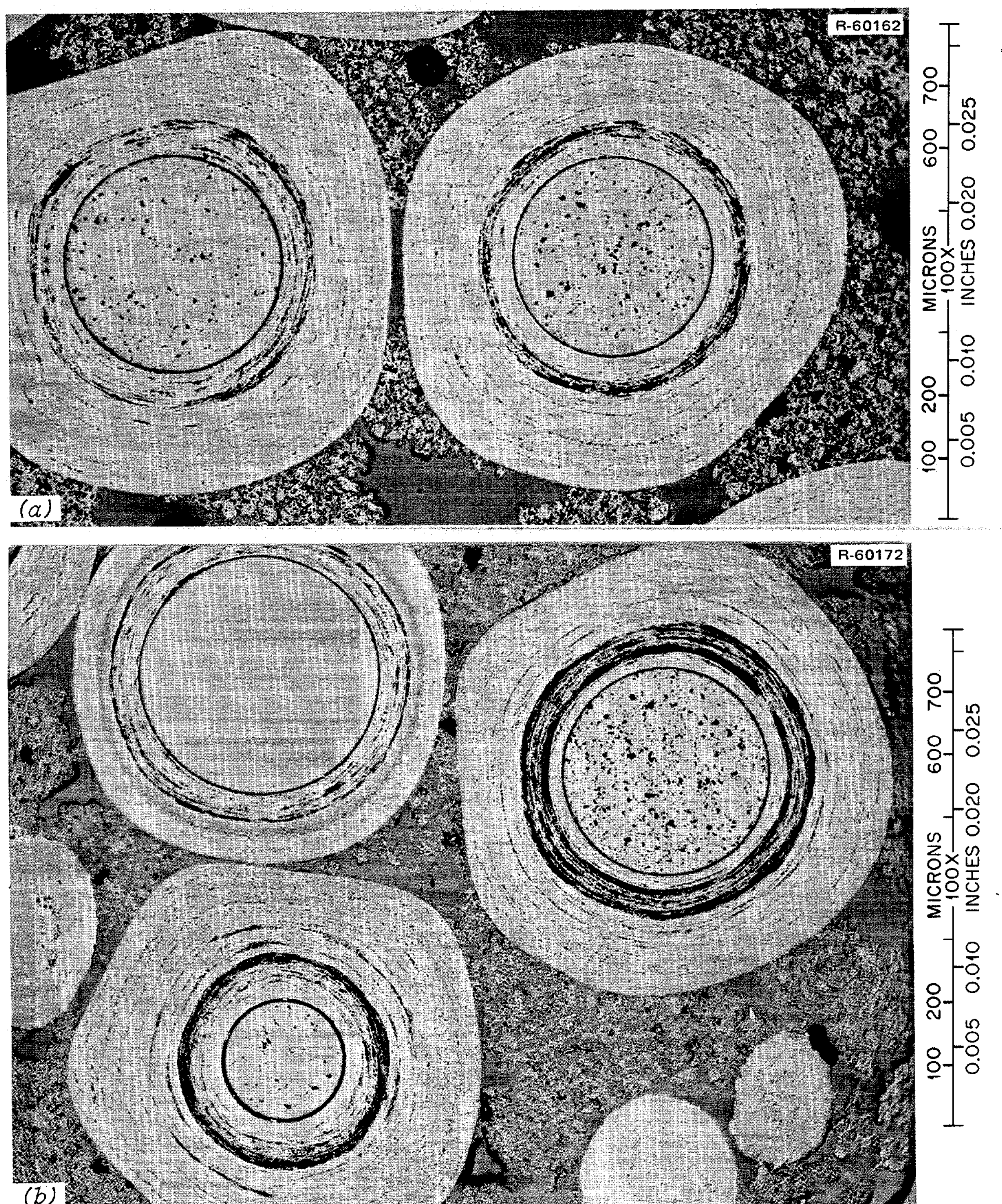

Fig. 13. Coated-particle fuels irradiated **in RTE-7.** (a) **$(4Th,U)O_2$ Biso-coated** particles from fuel rod 7-5-2-S. (b) $(2Th,U)O_2$ and **ThO_2** Biso-coated particles from fuel rod 7-5-3-S. **ThO_2** particle shows no porosity in kernel.

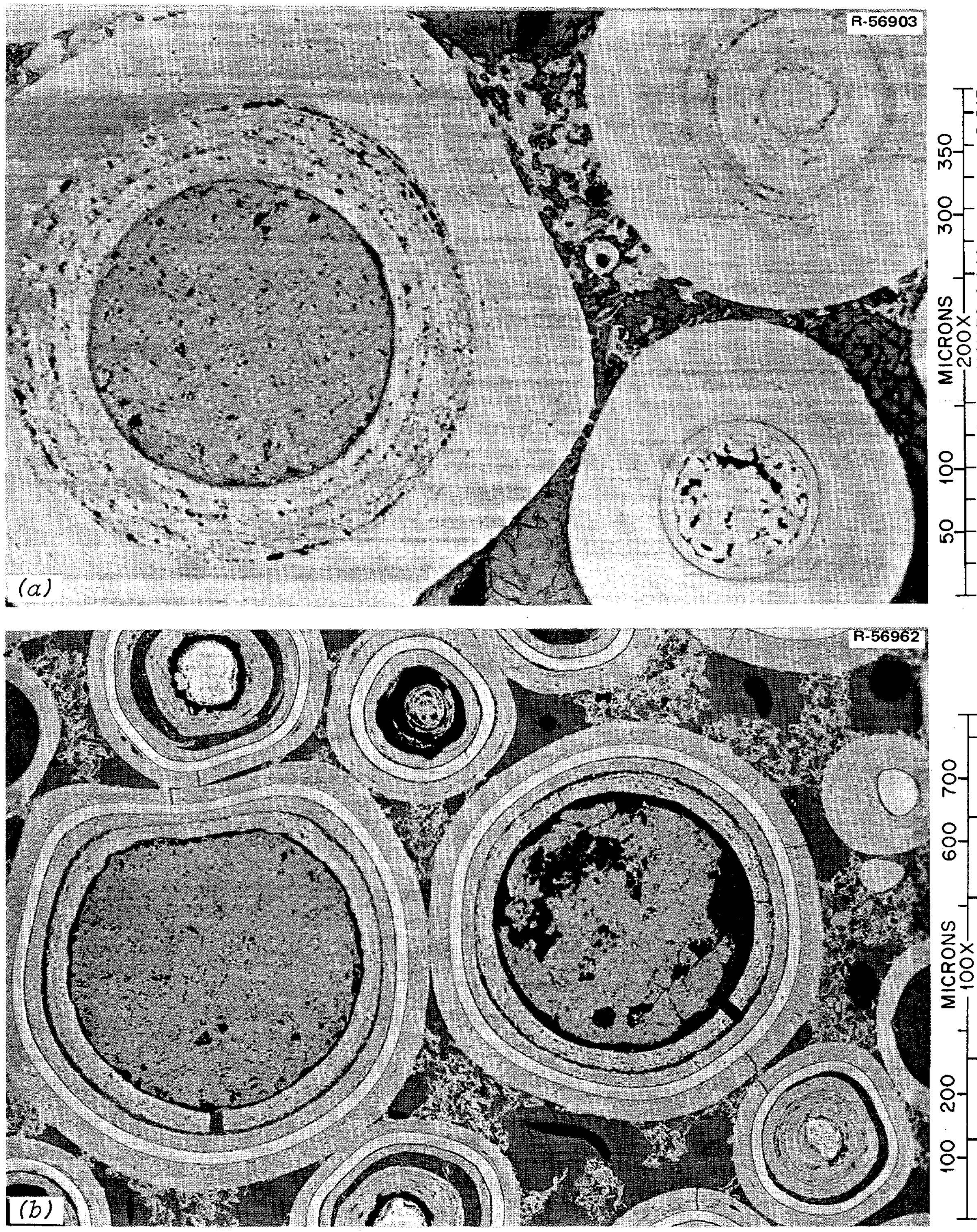

Fig. 14. Coated-particle fuels irradiated in RTE-7. (a) UO_2 and ThC_2 Biso-coated particles from fuel rod 7-3-2-3. ThC_2 is the largest; particle on lower left is ThC_2 polished near top of kernel. (b) UC_2 and ThC_2 Triso-coated particles from fuel rod 7-3-7-3. ThC_2 is the largest; note cracks in outer LTI layer and intact SiC layers.

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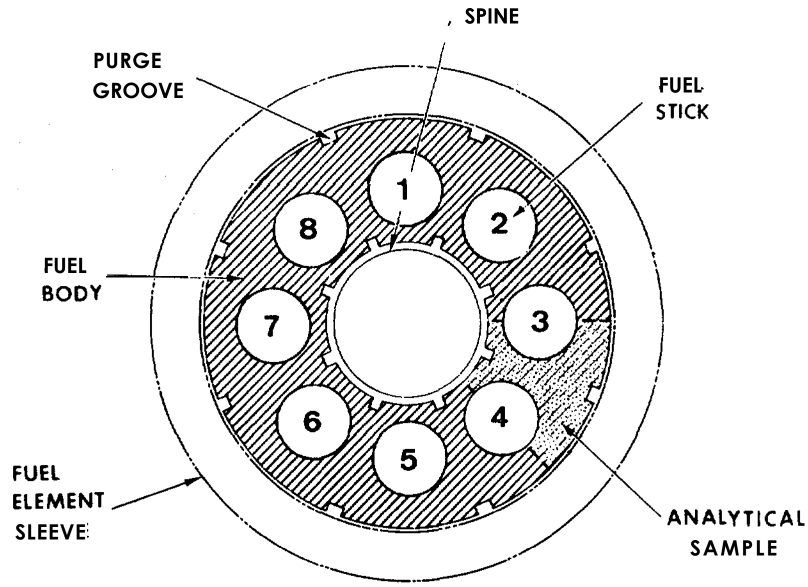


HOLE NOS.	FUEL TYPES
1 - 2	BISO UO_2, BISO ThC_2
3 - 4	BISO $(Th,U)O_2$ (2:1), BISO ThC_2
5 - 6	BISO UO_2, BISO ThO_2
7 - B	TRISO UC,, TRISO ThC_2

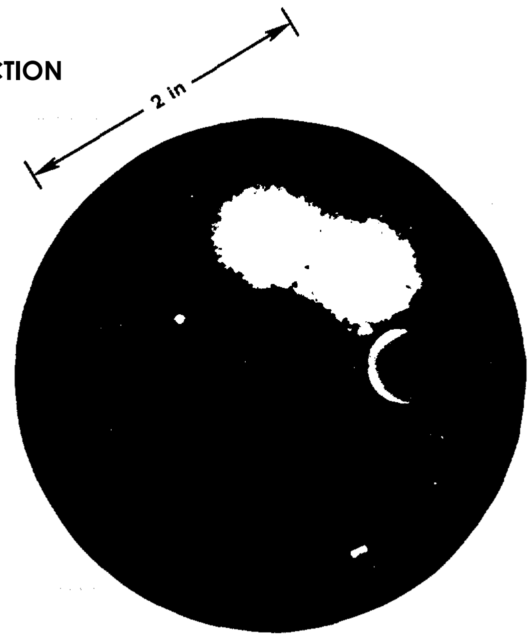


Fig. 15. Section through fuel body 3 from RTE-7.

Table 9. Fuel from each body will be examined for performance. The body graphite and the filler powder from the loose particle beds will be analyzed for fission product content and distribution.

The fuel bodies were removed from the graphite sleeve of the test element in the Bldg 3026-D hot cells and transferred to the HRLEL cells for fuel removal and physical examination. Since each fuel body contained only one type of fuel combination and there was a total length of about 52 ft of fuel in the element, we elected to remove fuel from about one-fourth of the holes for detailed examination. All the

Table 9. RTE-4 fuel loading and design operating temperatures

Fuel body	Estimated fuel center line temperature (°C)	Fuel type	Bed type	Coated particles	
				Fissile	Fertile
6	1065–1120	e	Loose[a]	UC_2 Biso	ThC_2 Biso
5	1120-1230	d	Rod[b,c]	$(2Th,U)O_2$ Biso	ThC_2 Biso
4	1230-1260	f	Rod	UC_2 Triso	ThC_2 Biso
3	1120-1230	a	Loose[a,c]	$(4Th,U)O_2$ Biso	None
2	900-1120	f	Loose[a]	UC_2 Triso	ThC_2 Biso
1	570-900	e	Rod	UC_2 Biso	ThC_2 Biso

‘Loose beds contain simultaneously loaded calcined coke powder as a bed stabilizer.

[b]Carbonized before loading. All other rods carbonized in the body.

‘Fabricated at ORNL; all other fuel rods and blended beds prepared by GGA.

fuel rods were removed by tapping the individual fuel bodies onto the cell floor. All the ORNL fuel rods removed from body 5 were intact, with some evidence of slight debonding at the ends of a few of the rods; the general physical condition of the rods was good. Detailed stereo examination of the fuel rods revealed eight broken particles. However, all visual evidence indicated that they were broken during removal of the rods.

The GGA fuel rods were contained in bodies 1 and 4. Removal of the fuel rods from body 1 was considerably more difficult than from body 4. Removal of fuel rods from body 4 was no more difficult than from body 5. The GGA rods had been carbonized in place; and since body 1 was in a lower flux position, this was an indication that, as expected, the rods in body 4 underwent more shrinkage than those in body 1. Adjacent rods from bodies 1 and 4 had bonded together during carbonization and separated near the original rod interfaces when removed from the bodies. The general condition of the rods was good. Stereo examination of the surfaces of the fuel rods revealed only one broken fertile particle; no broken fissile particles were noted.

Since the GGA rods were carbonized in place, no postirradiation dimensions were taken. However, since the ORNL rods had been carbonized and dimensionally inspected before assembly into body 5, we made a dimensional inspection after irradiation. Diameters were measured at 0° and 90° at the top, midlength, and bottom of 24 fuel rods; lengths were measured also. The results of this inspection are shown in Table 10. The dimensional change for each fuel rod – e.g., No. 1 – is actually an average value for four rods at the same axial location within body 5, which represents an average value from 24 diametral measurements per rod position.

Table 10. Dimensional changes of ORNL fuel rods from RTE-4, body 5

Fuel rod position	Average decrease, % in			$(\Delta D/D)/(\Delta L/L)$
	Diameter	Length	Volume[a]	
Top 1	2.50	2.45	7.34	1.02
2	2.63	3.25	8.19	0.81
3	2.55	2.80	7.69	0.91
4	2.48	2.98	7.72	0.83
5	2.67	2.90	8.03	0.92
6	2.56	2.95	7.87	0.87

‘Calculated from length and diameter changes.

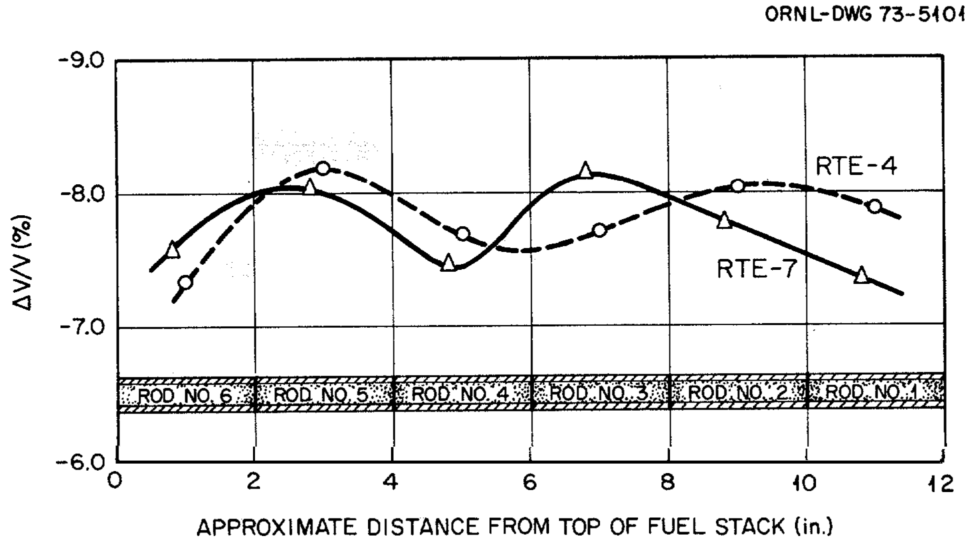


Fig. 16. Correlation of volume change with distance from top of fuel stack.

The above data appear to fit reasonably well with those from RTE-7. However, we are awaiting a flux distribution map for this particular element before attempting to correlate these data with fluence. An attempt to compare data obtained from fuel rods from RTE-4, body 5, and RTE-7, body 3, is shown in Fig. 16. The examination of volume changes in fuel rods along the stack length resulted in a surprisingly similar wave form, which could partially explain some of the apparent scatter in data when a correlation is attempted between dimensional changes and fluence. We will continue to look for this effect in future test elements.

Fuel bodies 2, 3, and 5 contained blended beds of loose coated particles plus small coke particles intermixed to act as a bed stabilizer. By using a vacuum pickup coupled with a collection trap and canister-type filter, we were able to collect samples near the top and midlength of the fuel stack. The small graphite particles were collected on the canister filters for future fission-product distribution analysis. The loose particles from these samplings were examined for failed coatings. Stereo examination revealed only two broken coatings on fertile particles from body 2. Samples from the other two bodies revealed no failed coatings. An estimated 1500 coated particles were examined from each sample.

Samples have been selected from each of the fuel bodies and have been scheduled for metallographic examination. The fuel rods from a hole in body 4, the blended beds from body 3, and body 3 itself have been forwarded to the Unit Operations Section of the Chemical Technology Division for reprocessing studies. In addition to the coke samples mentioned above, empty fuel bodies 4 and 5 and the six spines from the fuel bodies have been forwarded to the HTGR Fuel Chemistry and Fission Product Technology Group. The remaining graphite components and fuels have been identified and stored in Bldg 3026-D.

SUMMARY

A brief description of the Recycle Test Elements has been given, including the types of fuel irradiated in each element, planned exposure, and irradiation conditions. Detailed descriptions of the fuel fabricated at the Oak Ridge National Laboratory are contained as appendices to this report, including fabrication and preirradiation data for fuel rods, loose particle beds, and spine samples. The location of archive samples has been documented, and preirradiation metallography included, also in appendices. Postirradiation

examination and data analysis for RTE-4 and -7 have been included in this report as well. The fuel in each of these elements performed well, although the exposures ranged from only 12 to 20% of the exposure planned for large HTGR's. Dimensional changes in the rods from RTE-7 were greater at the low exposure than were anticipated from an extrapolation of data at higher exposure from accelerated irradiation experiments in the HFIR. This has caused some concern that the data from accelerated tests was estrapolated incorrectly, or that the behavior of the fuel rods in the typically HTGR spectrum of the Peach Bottom is different from behavior in the higher and more energetic flux characteristic of the HFIR. Dimensional changes of RTE rods taken to higher exposure need to be examined before this question can be resolved. Broken particles were observed on the surfaces of the fuel rods from both RTE-7 and -4, but evidence suggests that the particles were broken during removal of the rods from the fuel bodies.

ACKNOWLEDGMENTS

Since the preparation, fabrication, and characterization of the components for the recycle test elements involved such a large number of people at ORNL, the authors would prefer to acknowledge the entire staff of the Thorium Utilization and HTGR base program rather than attempt to recognize each contributor individually.

APPENDIX A

Loading Plan for ORNL Fuel

There are six fuel bodies in each RTE. Each fuel body contains eight fuel holes (and a center hole), and each hole contains six fuel rods. Table A1 describes the location of the fuel fabricated at ORNL in the various fuel bodies and fuel holes of the seven RTE's. Only fuel bodies and fuel holes loaded with fuel fabricated at ORNL are described here. Information on fuel fabricated at GGA is reported elsewhere.[1]

1. R. P. Morisette and K. P. Steward, *Recycle Test Element Program Design, Fabrication, and Assembly,* GA-10109 (September 1971).

Table Al. ORNL fuel in recycle test elements

Fuel body	Fuel hole'	Fuel type[b]	Stack[c]
	RTE-1 (FTE-11)		
1	1	a	139
1	3	c	103
1	4	g	130
1	5	a	140
1	7	c	104
1	8	g	131
2	1	a	141
2	3	c	105
2	4	g	132
2	5	a	142
2	7	c	106
2	8	g	133
3	1	a	143
3	3	c	107
3	4	g	134
3	5	a	144
3	7	c	108
3	8	g	135
4	1	a	145
4	3	c	109
4	4	g	136
4	5	a	146
4	7	c	110
4	8	g	
5	1	d	137 99
5	5	d	100
6	1	d	101
6	5	d	102
	RTE-2		
2	1	d	90
2	2	d	91
2	3	d	92
2	4	d	93
2	5	d	94
2	6	d	95
2	7	d	96
2	8	d	97
5	1-8	a	*d*
	RTE-4		
3	1-8	a	*d*
5	1	d	77
5	2	d	78
5	3	d	79
5	4	d	80
5	5	d	81
5	6	d	82
5	7	d	83
5	8	d	84
	RTE-5[e]		
1	1	a	22
1	2	a	23
1	3	c	64
1	4	c	65
1	7	g	9
1	8	g	10
2	1	a	24
2	2	a	25
2	3	c	66
2	4	c	67
2	7	g	11
2	8	g	12
3	1	a	26
3	2	a	27
3	3	c	68
3	4	c	69
3	7	g	13
4	8	g	14
4	1	a	30
4	2	a	31
4	3	c	74
4	4	c	75
4	7	g	17
4	8	g	18
5	7	d	51
5	8	d	52
6	3	d	53
6	4	d	54

Table Al (continued)

Fuel body	Fuel hole’	Fuel type[b]	Stack[c]
		RTE-6	
3	1	d	35
3	2	d	36
3	3	d	37
3	4	d	38
3	5	d	39
3	6	d	40
3	7	d	41
3	8	d	42
		RTE-8	
4	1	d	43
4	2	d	44
4	3	d	45
4	4	d	46
4	5	d	47
4	6	d	48
4	7	d	49
4	8	d	50
		RTE-7	
1	3	d	55
1	4	d	56
1	5	g	121
1	6	g	122
2	3	d	57
2	4	d	59
2	5	g	123
2	6	g	124
3	3	d	60
3	4	d	58
3	5	g	125
3	6	g	126
4	3	g	127
4	4	g	128
4	7	d	61
4	8	d	62
5	1	a	32
5	2	a	33
5	3	c	72
5	4	c	73
5	7	g	19
5	8	g	20
6	1	a	28
6	2	a	29
6	3	c	70
6	4	c	71
6	7	g	15
6	8	g	16

‘Fuel bodies and holes not identified on this table were filled with fuel produced at GGA.

[b]Described in Table 1, p. 2.

‘Detailed characteristics of the fuel stacks are given in Appendix B.

[d]Loose beds of fuel described in Appendix C.

[e]In addition to the fuel in the fuel holes, bodies 2 and 4 of RTEJ contained spine samples described in Appendix D.

APPENDIX B

Fabrication and Preirradiation Inspection Data on ORNL Fuel Rods

This Appendix is intended to be used in conjunction with Appendix A. The characteristics of the fuel by stack number is described in Table B1. Appendix A describes the location of fuel from a given stack within the RTE's.

Table B1. Fabrication data for ORNL fuel rods for recycle test elements[a]

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
9, 5, g	JF-161-9	15.7222	0.490–0.492	2.164	Mixed 1	4.948	Mixed	8.759	35	AXM
5	JF-161-10	15.4018	0.487–0.489	2.140			OR-1256	8.759		
5	JF-161-11	15.3858	0.487–0.489	2.155			OR-1257	8.759		
5	JF-161-13	15.4164	0.489-0.491	2.134			OR-1258	8.759		
7	JF-163-1	14.2403	0.486-0.491	2.136			PR-48	7.661		
7	JF-163-2	14.1621	0.487-0.492	2.110			PR-48	7.661		
10, 7, g	JF-163-5	14.4625	0.487-0.489	2.169	Mixed 1	4.948	PR-48	7.661	35	AXM
	JF-163-7	14.1203	0.485-0.489	2.146						
	JF-163-13	14.4972	0.489-0.492	2.144						
	JF-163-14	14.1218	0.486-0.488	2.124						
	JF-163-20	14.1359	0.486-0.493	2.121						
	JF-165-1	1.4.2813	0.486-0.489	2.142						
11, 7, g	JF-165-4	14.1039	0.486-0.488	2.142	Mixed 1	4.948	PR-48	7.661	35	AXM
	JF-165-20	14.6429	0.489-0.490	2.146						
	JF-165-7	14.2074	0.486-0.491	2.145						
	JF-165-8	14.2277	0.486-0.489	2.137						
	JF-165-9	13.9332	0.487-0.489	2.117						
	JF-165-10	13.9820	0.487-0.489	2.115						
12, 7, g	JF-165-11	14.2643	0.486-0.490	2.146	Mixed 1	4.948	PR-48	7.661	35	AXM
5	JF-165-12	15.2155	0.489-0.493	2.111						
5	JF-165-13	15.2396	0.488-0.489	2.123						
5	JF-165-15	15.2267	0.489-0.492	2.115						
5	JF-165-16	15.1391	0.487-0.489	2.108			Mixed OR-1256 OR-1257 OR-1258	8.759 8.759 8.759 8.759		
7	JF-165-19	14.3436	0.486-0.488	2.140			PR-48	7.661		
13, 7, g	JF-163-3	14.235	0.486-0.489	2.141	Mixed 1	4.948	PR-48	7.661	35	AXM
	JF-167-l	14.291	0.485-0.492	2.149						
	JF-167-2	14.259	0.485-0.492	2.136						
	JF-167-3	14.349	0.489-0.494	2.167						
	JF-167-4	14.143	0.487-0.490	2.145						
	JF-167-6	14.254	0.485-0.489	2.146						
14, 7, g	JF-167-7	14.398	0.489-0.491	2.145	Mixed 1	4.948	PR-48	7.661	35	AXM
7	JF-167-8	14.364	0.487-0.491	2.137						
7	JF-167-10	14.146	0.487-0.489	2.122						
7	JF-167-11	14.487	0.486-0.489	2.164						
8	JF-167-12	14.563	0.486-0.490	2.146						
8	JF-167-13	14.273	0.484-0.489	2.140	Mixed 2					
15, 10, g	JF-171-7	14.206	0.486-0.489	2.144	Mixed 2	4.948	PR-5 1	7.700	35	AXM
	JF-171-8	14.949	0.488-0.494	2.134						
	JF-171-9	14.115	0.486-0.490	2.136						
	JF-171-10	14.152	0.488-0.490	2.146						
	JF-171-12	14.399	0.488-0.489	2.135						
	JF-171-15	14.459	0.486-0.491	2.164						

Table B 1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
16, 10, g	JF-171-16	14.162	0.486–0.490	2.132	Mixed 2	4.948	PR-51	7.700	35	AXM
	JF-171-17	14.361	0.486–0.489	2.159						
	JF-171-18	14.186	0.486-0.488	2.136						
	JF-171-19	14.360	0.486-0.489	2.158						
	JF-1 71-20	14.147	0.486-0.488	2.142						
	JF-171-21	13.851	0.489-0.491	2.107						
17, 10, g	JF-171-22	14.029	0.486-0.490	2.121	Mixed 2	4.948	PR-5 1	7.700	35	AXM
	JF-173-1	14.228	0.488-0.490	2.130						
	JF-173-2	13.756	0.486-0.490	2.108						
	JF-173-3	13.944	0.486–0.490	2.123						
	JF-173-4	14.299	0.487-0.490	2.148						
	JF-173-5	14.535	0.487-0.489	2.162						
18, 10, g	JF-173-6	14.128	0.484-0.489	2.140	Mixed 2	4.948	PR-51	7.700	35	AXM
	JF-173-7	14.133	0.486-0.489	2.138						
	JF-173-8	13.644	0.487-0.491	2.091						
	JF-173-9	14.225	0.486-0.490	2.138						
	JF-173-10	14.471	0.489-0.491	2.151						
	JF-173-11	14.210	0.486-0.491	2.146						
19, 10, g	JF-173-12	14.057	0.489-0.493	2.126	Mixed 2	4.948	PR-51	7.700	35	AXM
	JF-173-14	14.2168	0.486-0.490	2.135						
	JF-173-15	14.412	0.486-0.493	2.146						
	JF-173-19	14.154	0.486-0.489	2.135						
	JF-173-20	14.253	0.486-0.489	2.143						
	JF-173-21	14.251	0.489-0.492	2.150						
20, 10, g	JF-173-22	14.403	0.488-0.491	2.144	Mixed 2	4.948	PR-51	7.700	35	AXM
	JF-175-1	13.893	0.486-0.490	2.110						
	JF-175-2	14.037	0.486-0.493	2.130 .						
	JF-183-20	14.369	0.489-0.494	2.131						
	JF-183-21	14.700	0.490-0.494	2.172						
	JF-183-22	14.485	0.487-0.493	2.161						
22, 9, a	JF-175-3	12.020	0.486-0.495	2.121	PR-57-1	10.757			35	AXZ
	JF-175-4	12.176	0.485-0.491	2.121						
	JF-175-5	12.143	0.488-0.495	2.140						
	JF-175-6	12.375	0.486-0.493	2.150						
	JF-175-7	12.344	0.487-0.491	2.152						
	JF-175-12	12.377	0.485-0.492	2.141						
23, 9, a	JF-175-14	12.384	0.488-0.493	2.155	PR-57-1	10.757			35	AXZ
	JF-175-15	12.180	0.487-0.489	2.137						
	JF-175-16	12.292	0.484-0.491	2.149						
	JF-175-17	12.226	0.484-0.491	2.138						
	JF-175-22	12.379	0.487-0.494	2.148						
	JF-177-2	12.156	0.487-0.490	2.142						
24, 9, a	JF-177-3	12.190	0.487-0.494	2.100	PR-57-1	10.757			35	AXZ
	JF-177-4	12.260	0.487-0.491	2.115						
	JF-177-5	12.481	0.487-0.494	2.162						
	JF-177-6	12.408	0.484-0.494	2.168						
	JF-177-8	12.311	0.485-0.492	2.144						
	JF-177-9	12.269	0.486-0.493	2.135						
25, 9, a	JF-177-10	12.194	0.485-0.491	2.145	PR-57-1	10.757			35	AXZ
	JF-177-11	12.218	0.484-0.490	2.135						
	JF-177-12	12.181	0.485-0.489	2.135						
	JF-177-13	12.263	0.485-0.490	2.140						
	JF-177-14	12.406	0.488-0.494	2.141						
	JF-177-15	12.305	0.485-0.489	2.141						

Table B1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
26, 9, a	JF-171-6	12.365	0.485-0.491	2.161	PR-57-l	10.757			35	AXZ
	JF-177-17	12.550	0.486-0.493	2.160						
	JF-179-2	12.264	0.486-0.492	2.135						
	JF-179-3	12.321	0.486-0.491	2.139						
	JF-179-4	12.401	0.485-0.489	2.149						
	JF-179-5	12.299	0.485-0.492	2.158						
27, 9, a	JF-179-6	12.323	0.485-0.491	2.147	PR-57-l	10.757			35	AXZ
	JF-179-7	12.393	0.485-0.493	2.155						
	JF-179-8	12.257	0.487-0.490	2.136						
	JF-179-9	12.404	0.485-0.488	2.149						
	JF-179-10	12.386	0.485-0.489	2.141						
	JF-179-11	12.385	0.484-0.490	2.158						
28, 9, a	JF-179-12	12.249	0.484-0.489	2.145	PR-57-l	10.757			35	AXZ
	JF-179-13	12.403	0.487-0.489	2.150						
	JF-179-14	12.294	0.485-0.489	2.139						
	JF-179-15	12.421	0.484-0.489	2.149						
	JF-179-16	12.387	0.486-0.489	2.159						
	JF-179-17	12.308	0.486-0.490	2.147						
29, 9, a	JF-179-18	12.315	0.484-0.490	2.154	PR-57-1	10.757			35	AXZ
	JF-179-19	12.277	0.484-0.492	2.141						
	JF-179-20	12.266	0.484-0.489	2.143						
	JF-179-21	12.345	0.484-0.490	2.150						
	JF-179-22	12.324	0.485-0.489	2.145						
	JF-181-l	12.356	0.484-0.489	2.148						
30, 9, a	JF-169-11	12.311	0.484-0.487	2.141	PR-57-1	10.757			35	AXZ
	JF-169-10	12.257	0.484-0.488	2.148						
	JF-169-2	12.190	0.486-0.501	2.139						
	JF-181-2	12.306	0.485-0.489	2.141						
	JF-181-3	12.331	0.484-0.489	2.146						
	JF-181-4	12.420	0.485-0.489							
31, 9, a	JF-181-5	12.316	0.485-0.488	2.142	PR-57-1	10.757			35	AXZ
	JF-181-6	12.340	0.484-0.489	2.146						
	JF-181-7	12.222	0.485-0.489	2.144						
	JF-181-8	12.243	0.485-0.489	2.142						
	JF-181-9	12.330	0.484-0.488	2.139						
	JF-181-10	12.254	0.485-0.489	2.141						
32, 9, a	JF-181-11	12.218	0.484-0.490	2.141	PR-57-1	10.757			35	AXZ
	JF-181-12	12.173	0.484-0.489	2.138						
	JF-181-13	12.370	0.484-0.490	2.149						
	JF-181-14	12.266	0.484-0.491	2.143						
	JF-181-15	12.355	0.484-0.489	2.159						
	JF-181-16	12.312	0.484-0.491	2.142						
33, 9, a	JF-181-17	12.393	0.485-0.489	2.148	PR-57-6	10.757			35	AXZ
	JF-181-18	12.402	0.484-0.494	2.143						
	JF-181-19	12.301	0.484-0.493	2.147						
	JF-181-20	12.194	0.484-0.490	2.148						
	JF-181-21	12.384	0.485-0.490	2.162						
	JF-181-22	12.190	0.487-0.490	2.125						
35, 12, d	JF-187-7	14.052	0.486-0.491	2.162	PR-60	5.8720’	4000-225[f]	6.6291	40	AXZ
	JF-187-8	14.012	0.486-0.490	2.147						
	JF-187-9	14.319	0.487-0.493	2.169						
	JF-187-10	13.989	0.485-0.490	2.147						
	JF-187-11	14.064	0.488-0.493	2.150						
	JF-187-12	13.968	0.486-0.491	2.148						

Table **B1** (continued)

Fuel stack, lot, and type[b]	Fuel rod[c] Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Fissile particle Batch	Weight (g)	Fertile particle Batch	Weight (g)	Filler[e] Content (wt %)	Type
36, 12, d	JF-187-13	14.107	0.486-0.491	2.152	PR-60	5.8720	4000-225[f]	6.6291	40	AXZ
	JF-187-14	14.118	0.488–0.493	2.133						
	JF-187-16	13.770	0.487–0.491	2.141						
	JF-187-17	13.915	0.488–0.491	2.150						
	JF-187-18	13.949	0.487-0.491	2.130						
	JF-187-19	14.011	0.486-0.491	2.143						
37, 12, d	JF-187-21	14.241	0.488–0.493	2.143	PR-60	5.8720	4000-225[f]	6.6291	40	AXZ
	JF-187-22	14.108	0.487–0.489	2.152						
	JF-189-l	14.048	0.486-0.493	2.149						
	JF-189-3	14.061	0.486-0.491	2.143						
	JF-189-4	14.333	0.487–0.494	2.149						
	JF-189-5	13.964	0.485-0.494	2.142						
38, 11, d	JF-177-15	14.102	0.487–0.491	2.143	PR-60	5.8720	4000-225[f]	6.8791	40	AXZ
11	JF-177-19	14.179	0.487-0.492	2.145						
12	JF-189-6	13.968	0.486-0.494	2.143				6.6291		
12	JF-189-7	13.942	0.488-0.494	2.110						
12	JF-189-8	14.249	0.487–0.494	2.175						
12	JF-189-9	14.037	0.487-0.494	2.145						
39, 13, d	JF-189-14	14.197	0.486–0.492	2.162	PR-60	5.8720	4000-225[f]	6.6291	38	AXZ
	JF-189-15	14.311	0.488–0.492	2.149						
	JF-189-16	14.147	0.486–0.493	2.152						
	JF-189-17	14.193	0.488–0.493	2.144						
	JF-189-18	14.226	0.488-0.491	2.161						
	JF-189-19	14.170	0.487–0.492	2.164						
40, 13, d	JF-1 89-20	14.145	0.487-0.491	2.142	PR-60	5.8720	4000-225[f]	6.6291	38	AXZ
	JF-189-21	14.293	0.488–0.492	2.167						
	JF-189-22	14.221	0.486-0.492	2.150						
	JF-191-1	14.128	0.486–0.492	2.141						
	JF-191-2	14.112	0.487–0.491	2.151						
	JF-191-3	14.152	0.487–0.493	2.154						
41, 13, d	JF-191-4	14.245	0.487-0.494	2.145	PR-60	5.8720	4000-225[f]	6.6291	38	AXZ
	JF-191-5	14.128	0.488–0.494	2.137						
	JF-191-6	14.237	0.488-0.492	2.160						
	JF-191-7	14.168	0.486–0.492	2.145						
	JF-191-8	14.172	0.485-0.493	2.141						
	JF-191-9	14.164	0.487–0.493	2.155						
42, 13, d	JF-191-10	14.229	0.489-0.493	2.134	PR-60	5.8720	4000-225[f]	6.6291	38	AXZ
12	JF-187-15	13.585	0.486–0.492	2.137					40	AXZ
11	JF-179-1	14.055	0.486–0.491	2.145						
11	JF-177-20	14.220	0.488–0.493	2.143						
11	JF-177-21	14.146	0.486-0.493	2.150						
11	JF-177-22	14.034	0.486–0.491	2.146						
43, 14, d	JF-191-11	13.898	0.485–0.490	2.148	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-191-12	14.045	0.486-0.492	2.150						
	JF-191-13	14.044	0.486–0.490	2.141						
	JF-191-14	14.047	0.486–0.490	2.160						
	JF-191-15	14.263	0.491-0.492	2.163						
	JF-191-16	14.026	0.485-0.490	2.150						
44, 14, d	JF-191-17	14.073	0.487–0.494	2.144	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-191-18	14.107	0.489-0.492	2.148						
	JF-191-19	14.023	0.485-0.489	2.146						
	JF-191-20	14.046	0.484–0.490	2.146						
	JF-191-21	14.019	0.487-0.490	2.139						
	JF-191-22	13.960	0.487–0.490	2.143						

Table **B1** (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
45, 14, d	JF-193-1	13.999	0.486-0.490	2.149	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-193-2	13.830	0.481-0.491	2.151						
	JF-193-3	13.638	0.486-0.490	2.093						
	JF-193-4	14.063	0.486-0.492	2.145						
	JF-193-5	14.050	0.486-0.490	2.157						
	JF-193-6	14.044	0.486-0.489	2.148						
46, 14, d	JF-193-7	14.226	0.488-0.491	2.152	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-193-8	14.173	0.490-0.492	2.159						
	JF-193-9	14.085	0.486-0.489	2.162						
	JF-193-10	14.120	0.486-0.490	2.157						
	JF-193-11	14.133	0.488-0.491	2.155						
	JF-193-12	14.111	0.488-0.491	2.147						
47, 4, d	JF-193-13	14.064		2.153	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-193-14	14.006	0.487-0.491	2.144						
	JF-193-15	14.029	0.486-0.489	2.139						
	JF-193-16	14.154	0.488-0.490	2.168						
	JF-193-17	14.013	0.487-0.490	2.143						
	JF-193-18	14.228	0.488-0.492	2.155						
48, 14, d	JF-193-19	14.013	0.486-0.490	2.147	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-193-20	14.135	0.488-0.490	2.156						
	JF-193-21	14.091	0.486-0.491	2.154						
	JF-193-22	14.265	0.488-0.491	2.162						
	JF-195-1	14.023	0.486-0.490	2.147						
	JF-195-2	14.045	0.486-0.490	2.147						
49, 14, d	JF-195-3	14.122	0.486-0.490	2.145	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-195-4	14.099	0.487-0.490	2.148						
	JF-195-5	14.097	0.487-0.490	2.159						
	JF-195-6	14.087	0.486-0.490	2.140						
	JF-195-7	14.190	0.487-0.490	2.158						
	JF-195-8	14.108	0.486-0.490	2.151						
50, 14, d	JF-195-9	14.090	0.486-0.490	2.154	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-195-10	14.120	0.486-0.490	2.152						
	JF-195-11	14.106	0.487-0.492	2.151						
	JF-195-12	14.180	0.488-0.490	2.160						
	JF-195-13	14.117	0.490-0.491	2.155						
	JF-195-14	14.176	0.489-0.490	2.164						
51, 11, d	JF-183-1	14.372	0.487-0.493	2.154	PR-60	5.8720	4000-225	6.8791	40	AXZ
11	JF-183-2	14.262	0.485-0.492	2.149						
11	JF-183-3	14.053	0.486-0.491	2.142						
11	JF-183-4	14.287	0.487-0.493	2.148						
11	JF-183-5	14.129	0.486-0.491	2.143						
14	JF-195-15	13.999	0.489-0.491	2.148				6.6291	35	AXZ
52, 14, d	JF-195-16	14.141	0.485-0.489	2.146	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-195-17	14.019	0.486-0.490	2.132						
	JF-195-18	14.021	0.486-0.490	2.151						
	JF-195-19	14.089	0.488-0.490	2.167						
	JF-195-20	14.137	0.486-0.490	2.161						
	JF-195-21	14.124	0.488-0.492	2.150						
53, 14, d	JF-195-22	14.310	0.489-0.492	2.145	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-197-1	14.280	0.488-0.492	2.181						
	JF-197-2	14.097	0.486-0.494	2.139						
	JF-197-3	14.122	0.486-0.494	2.145						
	JF-197-4	14.149	0.488-0.493	2.142						
	JF-197-5	13.679	0.492-0.494	2.145						

Table B 1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
54, 14, d	JF-197-6	14.085	0.487-0.492	2.162	PR-60	5.8720	4000-225	6.6291	35	AXZ
	JF-197-7	14.119	0.488-0.494	2.139						
	JF-197-8	14.153	0.488-0.494	2.158						
	JF-197-9	13.752	0.486-0.494	2.142						
	JF-197-10	14.140	0.487-0.494	2.141						
	JF-197-11	14.248	0.486-0.498	2.162						
55, 14, d	JF-197-18	14.242	0.490-0.492	2.156	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-197-19	14.009	0.486-0.491	2.163						
	JF-197-20	13.995	0.487-0.491	2.146						
	JF-197-21	13.854	0.487-0.491	2.150						
	JF-197-22	14.148	0.488-0.491	2.168						
	JF-199-1	14.120	0.487-0.491	2.155						
56, 14, d	JF-199-2	14.125	0.486-0.490	2.152	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-199-3	13.928	0.488-0.490	2.150						
	JF-199-4	14.129	0.488-0.491	2.144						
	JF-199-5	14.046	0.486-0.491	2.148						
	JF-199-6	13.965	0.486-0.492	2.133						
	JF-199-7	14.035	0.485-0.493	2.145						
57, 14, d	JF-199-8	14.073	0.490-0.492	2.164	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-199-9	14.104	0.490-0.493	2.143						
	JF-199-10	13.994	0.488-0.492	2.141						
	JF-199-11	14.068	0.488-0.492	2.149						
	JF-199-12	14.051	0.488-0.493	2.150						
	JF-199-13	14.073	0.487-0.492	2.153						
58, 14, d	JF-199-14	14.000	0.487-0.492	2.153	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-199-15	14.046	0.486-0.491	2.144						
	JF-199-16	13.921	0.487-0.492	2.133						
	JF-199-17	14.025	0.486-0.490	2.150						
	JF-199-18	14.050	0.486-0.494	2.147						
	JF-199-19	14.050	0.489-0.493	2.146						
59, 14, d	JF-199-20	14.136	0.487-0.491	2.165	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-199-21	14.098	0.490-0.492	2.143						
	JF-199-22	14.005	0.488-0.493	2.136						
	JF-201-1	14.041	0.486-0.492	2.136						
	JF-201-2	14.049	0.487-0.491	2.146						
	JF-201-4	14.305	0.488-0.493	2.158						
60, 14, d	JF-201-5	14.007	0.488-0.492	2.158	PR-60	‘5.872	4000-225	6.629	35	AXZ
	JF-201-6	14.153	0.488-0.492	2.155						
	JF-201-7	14.055	0.486-0.492	2.154						
	JF-201-8	13.719	0.485-0.492	2.133						
	JF-201-9	14.239	0.487-0.491	2.149						
	JF-201-10	14.033	0.487-0.491	2.153						
61, 14, d	JF-201-11	14.050	0.486-0.490	2.148	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-20 l-l 2	14.040	0.486-0.491	2.141						
	JF-201-13	13.988	0.486-0.492	2.130						
	JF-201-14	14.069	0.486-0.493	2.142						
	JF-201-15	14.031	0.486-0.491	2.151						
	JF-201-16	14.155	0.489-0.494	2.150						
62, 14, d	JF-201-17	13.827	0.485-0.493	2.138	PR-60	5.872	4000-225	6.629	35	AXZ
	JF-201-18	14.015	0.486-0.490	2.139						
	JF-201-19	14.085	0.487-0.491	2.142						
	JF-201-20	14.031	0.486-0.491	2.138						
	JF-201-21	13.851	0.486-0.492	2.134						
	JF-201-22	13.914	0.487-0.493	2.146						

Table B 1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
64, 15, c	JF-203-16	14.011	0.487-0.494	2.108	PR-61	6.0909	PR-51	6.3221	35	AXZ
	JF-203-17	14.117	0.486-0.490	2.140						
	JF-203-18	14.306	0.487–0.495	2.142						
	JF-203-19	14.180	0.486-0.492	2.138						
	JF-203-20	13.346	0.487-0.494	2.140						
	JF-203-21	14.274	0.484-0.490	2.164						
65, 15, c	JF-203-22	14.027	0.488-0.493	2.110	PR-61	6.0909	PR-51	6.3221	35	AXZ
	JF-205-1	14.175	0.485–0.491	2.140						
	JF-205-2	14.338	0.485-0.492	2.142						
	JF-205-3	14.289	0.484-0.490	2.155						
	JF-205-4	14.264	0.484-0.494	2.147						
	JF-205-5	14.123	0.484-0.489'	2.152						
66, 15, c	JF-205-6	14.193	0.486-0.492	2.143	PR-61	6.0909	PR-51	6.3221	35	AXZ
	JF-205-7	14.357	0.486-0.491	2.157						
	JF-205-8	14.211	0.484–0.490	2.149						
	JF-205-9	14.175	0.486-0.492	2.145						
	JF-205-10	14.079	0.484-0.492	2.144						
	JF-205-11	14.291	0.487-0.491	2.160						
67, 15, c	JF-205-12	14.192	0.485-0.491	2.137	PR-61	6.0909	PR-51	6.3221	35	AXZ
	JF-205-13	14.185	0.486-0.490	2.162						
	JF-205-14	14.139	0.484-0.490	2.155						
	JF-205-15	14.042	0.484–0.491	2.135						
	JF-205-16	14.400	0.488-0.491	2.159						
	JF-205-17	14.151	0.485-0.493	2.143						
68, 15, c	JF-205-18	14.123	0.486-0.491	2.161	PR-61	6.0909	PR-51	6.3221	35	AXZ
	JF-205-19	14.426	0.487–0.491	2.156						
	JF-205-20	14.180	0.486-0.491	2.156						
	JF-205-21	14.089	0.484-0.491	2.143						
	JF-205-22	14.002	0.485-0.491	2.132						
	JF-207-I	14.109	0.484-0.491	2.143						
69, 15, c	JF-207-2	14.226	0.485-0.494	2.149	PR-61	6.0909	PR-51	6.3221	35	AXZ
15	JF-205-3	14.132	0.485-0.490	2.143						
16	JF-207-10	14.528	0.484-0.490	2.145			PR-48	6.6853		
16	JF-207-11	14.549	0.485-0.490	2.148						
16	JF-207-12	14.624	0.486-0.490	2.148						
16	JF-207-13	14.444	0.485-0.490	2.140						
70, 16, c	JF-207-14	14.729	0.487-0.492	2.148	PR-61	6.0909	PR-48	6.6853	35	AXZ
	JF-207-15	14.721	0.485–0.489	2.160						
	JF-207-16	14.552	0.486-0.489	2.140						
	JF-207-17	14.580	0.485-0.490	2.148						
	JF-207-18	14.572	0.485-0.490	2.162						
	JF-207-19	14.308	0.485-0.490	2.127						
71, 16, c	JF-207-20	14.458	0.484-0.491	2.142	PR-61	6.0909	PR-48	6.6853	35	AXZ
	JF-207-21	14.709	0.487-0.491	2.155						
	JF-207-22	14.555	0.485-0.490	2.145						
	JF-209-l	14.619	0.488-0.492	2.158						
	JF-209-2	14.335	0.485-0.491	2.135						
	JF-209-3	14.505	0.484-0.491	2.149						
72, 16, c	JF-209-4	14.642	0.486-0.488	2.157	PR-61	6.0909	PR-48	6.6853	35	AXZ
	JF-209-5	14.490	0.485-0.491	2.145						
	JF-209-6	14.443	0.484-0.490	2.141						
	JF-209-7	14.511	0.485-0.492	2.140						
	JF-209-8	14.579	0.486-0.489	2.130						
	JF-209-9	14.521	0.484–0.491	2.148						

Table B1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
73, 16, c	JF-209-10	14.484	0.485-0.491	2.132	PR-61	6.0909	PR-48	6.6853	35	AXZ
16	JF-209-11	14.461	0.484-0.491	2.145						
16	JF-209-12	14.522	0.485-0.490	2.142						
16	JF-209-13	14.599	0.487-0.490	2.142						
16	JF-209-14	14.425	0.484-0.490	2.123						
17	JF-209-20	14.690	0.487-0.491	2.158			PR-47, -50	6.6803		
74, 17, c	JF-209-21	14.486	0.486-0.490	2.142	PR-61	6.0909	PR-47, -50	6.6803	35	AXZ
	JF-209-22	14.544	0.487-0.492	2.146						
	JF-211-1	14.442	0.487-0.492	2.152						
	JF-211-2	14.543	0.486-0.490	2.140						
	JF-211-3	14.464	0.487-0.491	2.135						
	JF-211-4	14.425	0.484-0.489	2.140						
75, 17, c	JF-21 l-5	14.509	0.485-0.491	2.144	PR-61	6.0909	PR-47, -50	6.6803	35	AXZ
	JF-21 l-6	14.454	0.487-0.490	2.150						
	JF-21 l-7	14.456	0.485-0.491	2.148						
	JF-211-8	14.239	0.484-0.490	2.150						
	JF-211-9	14.455	0.488-0.490	2.151						
	JF-211-10	14.499	0.485-0.490	2.151						
77, 18, d	JF-213-S	14.055	0.486-0.492	2.148	PR-61	6.0909	4000-225[f]	6.3842	35	AXZ
	JF-213-6	13.875	0.486-0.490	2.145						
	JF-213-7	13.974	0.485-0.490	2.155						
	JF-213-8	14.027	0.487-0.492	2.155						
	JF-213-9	14.053	0.487-0.492	2.150						
	JF-213-10	14.076	0.487-0.491	2.150						
78, 18, d	JF-213-11	13.736	0.485-0.491	2.160	PR-61	6.0909	4000-225	6.3842	35	AXZ
	JF-213-12	13.870	0.485-0.491	2.132						
	JF-213-13	14.100	0.487-0.490	2.153						
	JF-213-14	13.866	0.486-0.490	2.152						
	JF-213-15	13.950	0.486-0.490	2.144						
	JF-213-16	14.089	0.487-0.491	2.146						
79, 18, d	JF-213-17	13.854	0.486-0.490	2.141	PR-61	6.0909	4000-225	6.3842	35	AXZ
	JF-213-18	14.121	0.487-0.490	2.158						
	JF-213-19	14.029	0.486-0.490	2.150						
	JF-213-20	14.042	0.487-0.491	2.152						
	JF-213-21	14.126	0.487-0.491	2.176						
	JF-213-22	14.160	0.488-0.491	2.148						
80, 18, d	JF-215-1	13.986	0.486-0.490	2.140	PR-61	6.0909	4000-225[f]	6.3842	35	AXZ
	JF-215-2	14.078	0.486-0.490	2.143						
	JF-215-3	13.908	0.486-0.491	2.153						
	JF-215-4	13.989	0.486-0.490	2.144						
	JF-215-5	14.053	0.486-0.491	2.141						
	JF-215-6	14.117	0.488-0.491	2.158						
81, 18, d	JF-215-7	13.966	0.490-0.491	2.152	PR-61	6.0909	4000-225	6.3842	35	AXZ
	JF-215-8	14.019	0.486-0.491	2.148						
	JF-215-9	14.034	0.486-0.491	2.138						
	JF-215-10	14.050	0.486-0.490	2.152						
	JF-215-11	14.036	0.485-0.490	2.148						
	JF-215-12	13.846	0.487-0.491	2.171						
82, 18, d	JF-215-13	14.079	0.489-0.491	2.154	PR-6 1	6.0909	4000-225	6.3842	35	AXZ
	JF-215-14	14.081	0.487-0.492	2.148						
	JF-215-15	13.936	0.486-0.490	2.143						
	JF-215-16	14.021	0.486-0.491	2.141						
	JF-215-17	14.048	0.486-0.491	2.142						
	JF-215-18	13.948	0.486-0.493	2.143						

Table B1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
83, 18, d	JF-215-19	14.038	0.486–0.490	2.146	PR-61	6.0909	4000-225	6.3842	35	AXZ
	JF-215-20	13.851	0.485-0.491	2.140						
	JF-215-21	14.190	0.489-0.491	2.145						
	JF-215-22	13.984	0.486-0.491	2.145						
	JF-217-1	13.857	0.485-0.492	2.142						
	JF-217-2	13.923	0.485-0.490	2.145						
84, 18, d	JF-217-3	13.957	0.488-0.492	2.145	PR-61	6.0909	4000-225[f]	6.3842	35	AXZ
	JF-217-4	14.008	0.484-0.492	2.149						
	JF-217-5	14.081	0.486-0.494	2.142						
	JF-217-6	14.112	0.488-0.495	2.142						
	JF-217-7	14.167	0.488-0.495	2.140						
	JF-217-8	14.120	0.488-0.495	2.144						
90, 20, d	JF-221-13	12.402	0.486-0.490	2.139	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-221-14	12.667	0.486-0.494	2.155						
	JF-221-15	12.351	0.485-0.491	2.152						
	JF-221-16	12.816	0.489-0.492	2.168						
	JF-221-17	12.390	0.485-0.490	2.153						
	JF-221-18	12.363	0.485-0.490	2.141						
91, 20, d	JF-221-19	12.424	0.486-0.490	2.151	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-221-20	12.612	0.487-0.492	2.150						
	JF-221-21	12.544	0.486-0.492	2.139						
	JF-221-22	12.298	0.486-0.490	2.147						
	JF-223-1	12.392	0.486-0.492	2.162						
	JF-223-2	12.548	0.486-0.492	2.162						
92, 20, d	JF-223-3	12.403	0.485-0.492	2.147	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-223-4	12.320	0.484-0.490	2.162						
	JF-223-5	12.376	0.487 -0.493	2.132						
	JF-223-6	12.597	0.488-0.492	2.134						
	JF-223-7	12.455	0.485-0.491	2.144						
	JF-223-8	12.410	0.485-0.490	2.144						
93, 20, d	JF-223-9	12.376	0.484-0.492	2.144	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-223-10	12.420	0.485-0.491	2.147						
	JF-223-12	12.414	0.485-0.492	2.142						
	JF-223-13	12.505	0.485-0.489	2.144						
	JF-223-14	12.470	0.485-0.490	2.147						
	JF-229-9	12.532	0.488-0.491	2.141						
94, 20, d	JF-223-15	12.436	0.487-0.494	2.145	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-223-16	12.471	0.485-0.491	2.140						
	JF-223-17	12.489	0.487-0.490	2.156						
	JF-223-18	12.459	0.484-0.490	2.138						
	JF-223-19	12.627	0.487-0.491	2.161						
	JF-223-20	12.457	0.485-0.490	2.154						
95, 20, d	JF-223-21	12.558	0.487-0.492	2.154	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-223-22	12.586	0.487-0.489	2.152						
	JF-225-1	12.631	0.487-0.491	2.152						
	JF-225-2	12.497	0.486-0.492	2.132						
	JF-225-3	12.647	0.488-0.492	2.140						
	JF-225-4	12.517	0.485-0.490	2.144						
96, 20, d	JF-225-5	12.714	0.489-0.492	2.153	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-225-6	12.647	0.485-0.493	2.137						
	JF-225-7	12.555	0.484-0.489	2.148						
	JF-225-8	12.533	0.485-0.493	2.142						
	JF-225-9	12.539	0.486-0.490	2.147						
	JF-225-10	12.455	0.486-0.490	2.140						

Table B 1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
97, 20, d	JF-225-11	12.565	0.485–0.490	2.142	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-225-12	12541	0.485–0.490	2.144						
	JF-225-13	12.341	0.484-0.491	2.143						
	JF-225-14	12.496	0.484-0.491	2.134						
	JF-225-15	12.558	0.488-0.493	2.141						
	JF-225-16	12.541	0.486-0.490	2.139						
99, 20, d	JF-227-1	12.570	0.485–0.490	2.147	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-227-2	12.564	0.487-0.493	2.138						
	JF-227-3	12.506	0.485-0.491	2.139						
	JF-227-4	12.459	0.485-0.488	2.147						
	JF-227-5	12.520	0.485-0.490	2.146						
	JF-227-6	12.624	0.486-0.490	2.149						
100, 20, d	JF-227-7	12.451	0.484-0.490	2.148	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-227-8	12.634	0.485-0.490	2.155						
	JF-227-9	12.576	0.485-0.490	2.154						
	JF-227-10	12.571	0.485-0.490	2.139						
	JF-227-11	12.479	0.485-0.491	2.142						
	JF-227-12,	12.602	0.487-0.492	2.141						
101, 20, d	JF-227-13	12.658	0.486-0.491	2.150	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-227-14	12.519	0.485-0.491	2.132						
	JF-227-15	12.483	0.485-0.491	2.139						
	JF-227-16	12.542	0.485-0.491	2.139						
	JF-227-17	12.630	0.485-0.491	2.142						
	JF-227-18	12.341	0.484-0.492	2.134						
102, 20, d	JF-227-19	12.473	0.485-0.490	2.144	PR-66	8.3938	9T-980-BL	2.5245	35	AXZ
	JF-227-20	12.624	0.488-0.491	2.145						
	JF-227-21	12.460	0.484-0.490	2.143						
	JF-227-22	12.639	0.487-0.491	2.154						
	JF-229-1	12.611	0.487-0.490	2.168						
	JF-229-2	12.491	0.487-0.490	2.147						
103, 21, c	JF-229-13	13.395	0.484-0.494	2.151	PR-66	8.3938	Mixed A	3.1538	35	AXZ
	JF-229-14	13.132	0.486-0.492	2.149						
	JF-229-15	13.182	0.486-0.493	2.148						
	JF-229-16	13.189	0.486-0.493	2.146						
	JF-229-17	13.300	0.487-0.491	2.146						
	JF-229-18	13.111	0.485-0.491	2.143						
104, 21, c	JF-229-19	13.145	0.486-0.493	2.146	PR-66	8.3938	Mixed A	3.1538	35	AXZ
	JF-229-20	13.271	0.486-0.494	2.152						
	JF-229-21	13.015	0.485-0.490	2.138						
	JF-229-22	12.954	0.485-0.489	2.135						
	JF-231-1	13.156	0.487-0.491	2.142						
	JF-231-2	13.126	0.485-0.494	2.136						
105, 21, c	JF-231-3	13.247	0.487-0.492	2.146	PR-66	8.3938	Mixed A	3.1538	35	AXZ
	JF-231-4	13.125	0.486-0.491	2.147						
	JF-231-5	13.190	0.487-0.494	2.140						
	JF-231-6	13.327	0.487-0.491	2.160						
	JF-231-7	13.137	0.488-0.494	2.143						
	JF-231-8	13.322	0.487-0.497	2.162						
106, 21, c	JF-231-9	13.374	0.489-0.492	2.157	PR-66	8.3938	Mixed A	3.1538	35	AXZ
21	JF-231-10	13.237	0.486-0.494	2.147						
21	JF-231-11	13.030	0.487–0.492	2.161						
21	JF-231-12	13.228	0.489-0.494	2.133						
22	JF-231-13	12.477	0.485-0.491	2.152	PR-67	8.4287		2.3001		
22	JF-231-14	12.614	0.485-0.493	2.127						

Table B 1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
107, 22. c	JF-231-15	12.616	0.486–0.490	2.157	PR-67	8.4287	Mixed A	2.3001	35	AXZ
	JF-231-16	12.523	0.485–0.490	2.120						
	JF-231-17	12.437	0.484-0.491	2.138						
	JF-231-18	12.550	0.485-0.490	2.122						
	JF-231-19	12.471	0.484-0.493	2.122						
	JF-231-20	12.438	0.485 -0.490	2.131						
108, 22, c	JF-231-21	12.315	0.485-0.490	2.138	PR-67	8.4287	Mixed A	2.3001	35	AXZ
	JF-231-22	12.397	0.484-0.489	2.130						
	JF-233-1	12.395	0.485-0.490	2.141						
	JF-233-2	12.614	0.487-0.492	2.143						
	JF-233-3	12.454	0.486-0.489	2.141						
	JF-233-4	12.218	0.484-0.490	2.140						
109, 22, c	JF-233-5	12.485	0.484-0.491	2.142	PR-67	8.4287	Mixed A	2.3001	35	AXZ
	JF-233-6	12.462	0.485-0.490	2.140						
	JF-233-7	12.415	0.484-0.489	2.146						
	JF-233-8	12.680	0.484-0.489	2.152						
	JF-233-9	12.444	0.485-0.489	2.144						
	JF-233-10	12.287	0.485-0.490	2.123						
110, 22, c	JF-233-11	12.520	0.486-0.489	2.145	PR-67	8.4287	Mixed A	2.3001	35	AXZ
	‘JF-233-12	12.327	0.485-0.489	2.140						
	JF-233-13	12.412	0.484-0.49 1	2.136						
	JF-233-14	12.712	0.487-0.490	2.146						
	JF-233-15	12.778	0.484-0.489	2.140						
	JF-233-16	12.452	0.484-0.489	2.126						
121, 24, g	JF-239-20	15.516	0.487–0.492	2.149	Mixed 2	4.9480	Mixed A	8.9000	35	AXM
	JF-239-21	15.630	0.487-0.491	2.168						
	JF-239-22	15.495	0.486-0.490	2.147						
	JF-241-1	15.180	0.486-0.491	2.150						
	JF-241-2	15.568	0.485-0.490	2.151						
	JF-241-3	15.874	0.489-0.490	2.169						
122, 24, g	JF-241-4	15.610	0.489-0.491	2.155	Mixed 2	4.9480	Mixed A	8.9000	35	AXM
	JF-241-5	15.656	0.485-0.492	2.143						
	JF-241-6	15.480	0.486-0.489	2.157						
	JF-241-7	15.379	0.486-0.490	2.147						
	JF-241-8	15.616	0.488-0.489	2.165						
	JF-241-9	15.424	0.486-0.490	2.148						
123, 24, g	JF-241-10	15.343	0.486-0.490	2.145	Mixed 2	4.9480	Mixed A	8.9000	35	AXM
	JF-241-11	15.662	0.488-0.490	2.158						
	JF-241-12	15.355	0.486-0.490	2.145						
	JF-241-13	15.440	0.486-0.490	2.147						
	JF-241-14	15.473	0.486-0.496	2.143						
	JF-241-15	15.034	0.486-0.492	2.103						
124, 24, g	JF-241-16	15.455	0.487-0.492	2.146	Mixed 2	4.9480	Mixed A	8.9000	35	AXM
	JF-241-17	14.914	0.486-0.489	2.113						
	JF-241-18	15.676	0.488-0.492	2.134						
	JF-241-19	15.499	0.486-0.490	2.157						
	JF-241-20	15.162	0.486-0.491	2.127						
	JF-241-21	14.638	0.486-0.491	2.152						
125, 24, g	JF-241-22	14.959	0.490-0.492	2.151	Mixed 2	4.9480	Mixed A	8.9000	35	AXM
25	JF-243-1	14.915	0.489-0.492	2.154	Mixed 3			8.2400		
25	JF-243-2	15.271	0.490-0.492	2.155						
25	JF-243-3	14.841	0.487-0.492	2.156						
25	JF-243-4	14.727	0.488-0.492	2.162						
25	JF-243-5	14.691	0.486-0.493	2.146						

Table B1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
126, 25, g	JF-243-6	14.768	0.487-0.490	2.158	Mixed 3	4.9480	Mixed A	8.2400	35	AXM
	JF-243-7	14.962	0.488-0.491	2.161						
	JF-243-8	14.972	0.486-0.492	2.157						
	JF-243-9	14.828	0.486-0.492	2.156						
	JF-243-10	14.823	0.487-0.491	2.148						
	JF-243-11	14.579	0.486-0.491	2.148						
127, 25, g	JF-243-12	14.772	0.486-0.491	2.140	Mixed 3	4.9480	Mixed A	8.2400	35	AXM
	JF-243-13	14.800	0.487-0.491	2.149						
	JF-243-14	14.801	0.487-0.491	2.151						
	JF-243-15	14.888	0.488-0.491	2.151						
	JF-243-16	14.301	0.486-0.493	2.110						
	JF-243-17	14.761	0.486-0.492	2.145						
128, 25, g	JF-243-18	14.698	0.487-0.492	2.160	Mixed 3	4.9480	Mixed A	8.2400	35	AXM
25	JF-243-19	14.777	0.486-0.493	2.159						
25	JF-243-20	14.765	0.486-0.492	2.154						
25	JF-243-21	15.005	0.489-0.493	2.166						
25	JF-243-22	15.085	0.488-0.495	2.144						
7	JF-183-12	14.508	0.487-0.494	2.157	Mixed 1	4.9480	PR-48	7.661		
130, 26, g	JF-245-1	13.902	0.489-0.491	2.160	Mixed 3	6.0000	Mixed A	6.1325	35	AXM
	JF-245-2	13.678	0.487-0.493	2.153						
	JF-245-3	13.302	0.487-0.491	2.120						
	JF-245-4	13.717	0.487-0.491	2.159						
	JF-245-5	13.573	0.485-0.492	2.141						
	JF-245-6	13.879	0.485-0.490	2.162						
131, 26, g	JF-245-7	13.787	0.489-0.494	2.145	Mixed 3	6.0000	Mixed A	6.1325	35	AXM
26	JF-245-8	13.556	0.488-0.492	2.144					35	
26	JF-245-9	13.377	0.487-0.493	2.153					35	
27	JF-245-11	13.516	0.487-0.492	2.133					30	
27	JF-245-12	13.625	0.487-0.492	2.129					30	
27	JF-245-13	13.726	0.490-0.492	2.148					30	
132, 27, g	JF-245-14	13.610	0.486-0.491	2.139	Mixed 3	6.0000	Mixed A	6.1325	30	AXM
	JF-245-15	13.720	0.488-0.491	2.150						
	JF-245-16	13.517	0.486-0.492	2.141						
	JF-245-17	13.698	0.487-0.492	2.157						
	JF-245-18	13.538	0.486-0.491	2.156						
	JF-245-19	13.550	0.486-0.491	2.158						
133, 27, g	JF-245-20	13.666	0.486-0.491	2.139	Mixed 3	6.0000	Mixed A	6.1325	30	AXM
	JF-245-21	13.776	0.488-0.494	2.151						
	JF-245-22	13.389	0.486-0.491	2.143						
	JF-247-1	13.749	0.486-0.492	2.152						
	JF-247-2	13.540	0.486-0.492	2.143						
	JF-247-3	13.687	0.486-0.492	2.150						
134, 27, g	JF-247-4	13.633	0.486-0.491	2.148	Mixed 3	6.0000	Mixed A	6.1325	30	AXM
	JF-247-5	13.709	0.487-0.491	2.158						
	JF-247-6	13.751	0.486-0.492	2.153						
	JF-247-7	13.630	0.487-0.490	2.160						
	JF-247-8	13.615	0.487-0.493	2.152						
	JF-247-9	13.680	0.486-0.491	2.144						
135, 27, g	JF-247-10	13.558	0.487-0.492	2.150	Mixed 3	6.0000	Mixed A	6.1325	30	AXM
	JF-247-11	13.634	0.486-0.492	2.138						
	JF-247-12	13.844	0.488-0.491	2.145						
	JF-247-13	13.669	0.487-0.490	2.157						
	JF-247-14	13.514	0.490-0.493	2.158						
	JF-247-15	13.588	0.488-0.492	2.131						

Table B1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
136, 27, g	JF-247-16	13.744	0.486-0.496	2.150	Mixed 3	6.0000	Mixed A	6.1325	30	AXM
27	JF-247-17	13.427	0.486-0.496	2.131						
27	JF-247-18	13.631	0.487-0.492	2.155						
27	JF-247-19	13.742	0.487-0.490	2.151						
28	JF-249-1	13.911	0.485-0.492	2.138	Mixed 1					
28	JF-249-2	13.945	0.487-0.489	2.138						
137, 28, g	JF-249-3	14.043	0.485-0.490	2.141	Mixed 1	6.0000	Mixed A	6.1325	30	AXM
	JF-249-4	13.726	0.485-0.489	2.140						
	JF-249-5	14.026	0.486-0.490	2.162						
	JF-249-6	14.316	0.488-0.492	2.150						
	JF-249-7	13.712	0.485-0.490	2.152						
	JF-249-8	13.687	0.485-0.491	2.141						
139, 29, a	JF-249-19	12.372	0.486-0.493	2.141	PR-56	10.7574			35	AXZ
	JF-249-20	12.409	0.487-0.493	2.141						
	JF-249-21	12.369	0.484-0.492	2.137						
	JF-249-22	12.424	0.486-0.494	2.145						
	JF-251-1	12-489	0.486-0.493	2.150						
	JF-251-2	12.343	0.486-0.493	2.138						
140, 29, a	JF-25 l-3	12.356	0.485-0.491	2.142	PR-56	10.7574			35	AXZ
	JF-251-4	12.386	0.488-0.493	2.142						
	JF-251-5	12.296	0.486-0.489	2.139						
	JF-251-6	12.304	0.484-0.493	2.144						
	JF-251-7	12.477	0.488-0.492	2.150						
	JF-251-8	12.430	0.485-0.489	2.153						
141, 29, a	JF-251-9	12.328	0.485-0.494	2.137	PR-56	10.7574			35	AXZ
	JF-251-10	12.379	0.486-0.490	2.153						
	JF-251-11	12.331	0.486-0.492	2.162						
	JF-251-12	12.398	0.484-0.492	2.148						
	JF-251-13	12.431	0.486-0.490	2.137						
	JF-251-14	12.351	0.484-0.491	2.142						
42, 29, a	JF-251-15	12.477	0.488-0.492	2.155	PR-56	10.7574			35	AXZ
	JF-251-16	12.519	0.488-0.492	2.152						
	JF-251-17	12.362	0.485-0.490	2.141						
	JF-251-18	12.385	0.486-0.490	2.148						
	JF-251-19	12.342	0.487-0.494	2.144						
	JF-251-20	12.489	0.485-0.490	2.154						
143, 29, a	JF-251-21	12.471	0.487-0.490	2.148	PR-56	10.7574			35	AXZ
	JF-251-22	12.337	0.488-0.492	2.151						
	JF-253-l	12.312	0.488-0.493	2.146						
	JF-253-2	12.426	0.486-0.494	2.148						
	JF-253-3	12.398	0.487-0.490	2.150						
	JF-25 3-4	12.463	0.487-0.492	2.165						
144, 29, a	JF-253-5	12.400	0.487-0.492	2.148	PR-56	10.7574			35	AXZ
	JF-253-6	12.586	0.488-0.492	2.156						
	JF-253-7	12.317	0.485-0.490	2.148						
	JF-253-8	12.392	0.484-0.489	2.145						
	JF-253-9	12.391	0.485-0.491	2.142						
	JF-253-10	12.482	0.486-0.493	2.150						
145, 29, a	JF-253-11	12.336	0.485-0.490	2.140	PR-56	10.7574			35	AXZ
	JF-253-12	12.528	0.488-0.494	2.152						
	JF-253-13	12.472	0.485-0.491	2.152						
	JF-253-14	12.495	0.487-0.491	2.161						
	JF-253-15	12.343	0.486-0.492	2.153						
	JF-253-16	12.334	0.484-0.491	2.144						

Table B 1 (continued)

Fuel stack, lot, and type[b]	Fuel rod[c]				Fissile particle		Fertile particle		Filler[e]	
	Number	Weight (g)	Diameter (in.)[d]	Length (in.)	Batch	Weight (g)	Batch	Weight (g)	Content (wt %)	Type
146, 29, a	JF-253-17	12.417	0.487-0.491	2.156	PR-56	10.7574			35	AXZ
	JF-253-18	12.362	0.486-0.493	2.145						
	JF-213-19	12.372	0.485-0.490	2.150						
	JF-213-20	12.373	0.488-0.492	2.144						
	JF-213-21	12.459	0.486-0.494	2.142						
	JF-213-22	12.371	0.485-0.492	2.142						

[a]Entries common to all six fuel rods in one stack are given only on the first line for that stack.

[b]Fuel types are described in Table 1, p. 2.

[c]The locations of the rods in the RTE's is given in Table Al. Fuel rods were loaded into holes in numerical order with the lowest numbered rod at the bottom.

[d]Minimum–maximum.

[e]Fuel rod matrix composed of 15V pitch containing the indicated amount of filler. Filler is Poco graphite, either AXM with particle size below 27 μm or AXZ with particle size below 40 μm.

[f]Made at GGA and described in report GA-10109.

APPENDIX C

Fabrication Data for ORNL Loose Particle Fuel in RTE-2 and -4

A general description of the contents of the loose fuel bodies is given in Table C1, and a more detailed description of the loading of the bodies is given in Tables C2 and C3.

In the loading of these bodies, the three types of particles were loaded concurrently from three V-troughs mounted on syntron vibrators. After all eight fuel holes and a glass dummy hole were filled with particles a 65-g steel cylinder was placed in the top of each hole, and the bodies were vibrated with a syntron vibrator to settle the beds. The method of mounting the bodies onto the vibrators and attaching the glass dummy hole is shown on Fig. 7, p. 12. After the initial settling, additional graphite flour was added to fill the beds. (Loading all the graphite during the initial filling caused the beds to settle improperly, resulting in a final volume greater than that required for the coated particles alone.)

Table C1. Fabrication and inspection data on ORNL RTE loose particle fuel bodies[a]

RTE Body	RTE-2-5	RTE-4-3
ORNL body identification	Body A	Body C
GGA body identification	No. 54	No. 51
Fuel type	a	a
Fissile particle: Type	(4th,U)O_2	(4Th,U)O_2
Batch[b]	PR-55	PR-54
Fertile particle: Type	ThC_2	ThC_2
Batch[b]	9T-980-BL	9T-980-BL
Coke particle	Great Lakes Carbon calcined . petroleum coke, 61 to 125 μm	
Total uranium in body[c], g	33.83	27.66
Av uranium density in hole, g/in.	0.332	0.268
Total thorium in body, g	241.21	262.65
Thorium-to-uranium ratio	7.13	9.50

[a]Note 2 cm^3 of methyl ethylketone + 10 wt % polystyrene poured into loaded hole to stabilize fuel bed during shipping.

[b]See Appendix E for further data on particles.

[c]Also about 0.12 μCi (-10 ppb) ^{239}Pu included in oxide kernels in each body.

Table C2. Loading data for body 51 (RTE-U-3)

Hole[a]	Fissile particle content (g)	Fissile particle content (wt %)[b]	Fertile particle content (g)	Fertile particle content (wt %)[b]	Coke content Loaded (g)	Coke content Added (g)[d]	Coke content (wt %)[b]	Bed height (in.)	Vibration time, hr Bed settling	Vibration time, hr Coke infiltration	Average weight (g) U/in.	Average weight (g) Th/hole	Average weight (g) U/hole
Dummy Hole[e]	39.32	45.38	34.16	40.12	6.07	6.49	14.50	12.56	4	2	0.260	31.77	3.26
1	40.84	45.80	36.11	40.50	8.36	3.86	13.70	12.89	4	2	0.263	33.00	3.39
2	41.51	46.46	35.70	39.96	8.84	3.29	13.58	12.89	4	2	0.261	33.01	3.44
3	41.57	46.90	34.52	38.95	8.70	3.84	14.15	12.94	4	2	0.267	32.40	3.45
4	39.07	43.79	37.38	41.90	8.70	4.07	14.31	12.94	4	2	0.250	33.07	3.24
5	42.66	41.67	34.92	39.02	8.13	3.78	13.31	12.83	4	2	0.276	32.98	3.54
6	42.17	47.94	34.15	38.28	7.84	4.45	13.78	12.90	4	2	0.274	32.61	3.54
7	42.01	46.94	35.17	39.30	8.08	4.24	13.76	12.94	4	2	0.269	32.90	3.48
8	43.21	48.18	34.02	37.94	8.27	4.18	13.88	12.89	4	2	0.278	32.69	3.58

[a]Hole identification as on Fig. 1, p. 4.
[b]Percent of total material in hole.
[c]Loaded simultaneously with fuel.
‘Infiltrated into loaded fuel bed.
[e]Diameter of glass dummy hole is 0.515 in., compared with 0.500 in. for RTE holes.

Table C3. Loading data for body 54 (RTE-2-5)

Hole[a]	Fissile particle content (g)	Fissile particle content (wt %)[b]	Fertile particle content (g)	Fertile particle content (wt %)[b]	Coke content Loaded (g)[c]	Coke content Added (g)[d]	Coke content (wt %)[b]	Bed height (in.)	Vibration time, hr Bed settling	Vibration time, hr Coke infiltration	Average weight (g) U/in.	Average weight (g) Th/hole	Average weight (g) U/hole
Dummy Hole[e]	48.60	58.20	23.49	28.13	9.28	2.14	13.68	11.78[e]	3	4	0.347	29.18	4.09
1	48.60	56.64	25.68	29.93	9.26	2.26	13.43	12.75	3	4	0.321	30.34	4.09
2	48.60	57.39	25.55	30.17	9.48	1.06	12.45	12.66	3	4	0.323	30.27	4.09
3	49.44	58.48	25.53	30.20	7.65	1.92	11.32	12.73	3	4	0.327	30.55	4.16
4	51.24	60.15	22.24	26.37	9.21	1.60	12.89	12.81	3	4	0.336	29.43	4.31
5	50.78	60.02	25.35	29.96	1.55	0.93	10.02	12.80	3	4	0.334	30.92	4.27
6	50.94	59.21	25.12	29.20	7.95	2.03	11.60	12.75	3	4	0.336	30.85	4.28
7	49.33	58.92	24.77	29.59	8.47	1.15	11.49	12.76	3	4	0.325	30.11	4.15
8	53.27	64.17	19.62	23.85	8.29	1.07	11.38	12.69	3	4	0.353	28.74	4.48

[a]Hole identification as on Fig. 2, p. 5.
[b]Percent of total material in hole.
[c]Loaded simultaneously with fuel.
[d]Infiltrated into loaded fuel bed. (May be slightly high from overfilling coke and vacuuming out excess; during which some coke may have been lost.).
[e]Diameter of glass dummy hole is 0.515 in., compared with 0.500 in. for RTE holes.

APPENDIX D

Spine Samples Tested in RTE-5

Six small fuel rods (0.4 in. diam, 0.7 in. long) are being tested in the central hole of fuel bodies 2 and 4 of RTE-5 inside individual graphite crucibles described in Fig. D1. These samples, described in Tables D1 and D2, were all made with Biso-coated UO_2 and ThO_2 particles in the same concentration used for mixture g in the standard RTE hole. The principal test variables are the bonding matrix, which is different for each of the six sample types, and the irradiation temperature. The irradiation temperature is about 1100°C for the samples in fuel body 2 and about 1200°C for those in fuel body 4. The details of spine sample location in the RTE bodies are given elsewhere.[1]

1. R. P. Morissette and K. P. Steward, *Recycle Test Element Program Design, Fabrication, and Assembly,* GA-10109, p. 47 (September 1971).

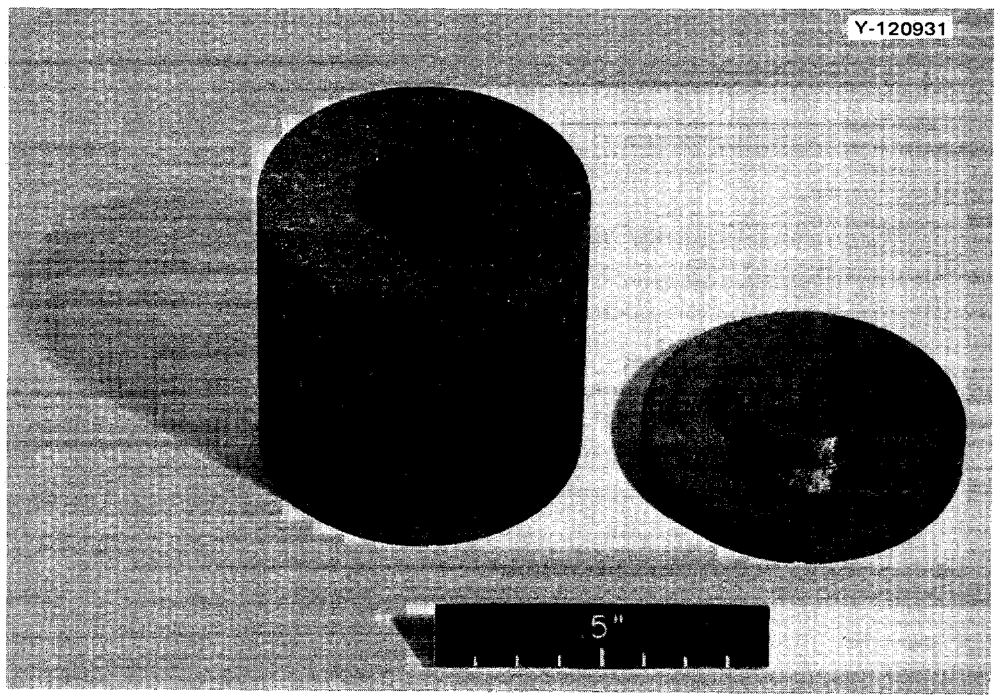


Fig. D1. Graphite crucibles used in the spine positions of fuel bodies 2 and 4 of RTE-5.

Table D1. Fabrication data for spine samples

Samples[a]	Matrix filler (%)[b]	Matrix filler Material	UO_2 fissile particle batch[c]	ThO_2 fertile particle[c] Batch	ThO_2 fertile particle[c] Wt, g
1A, 1B	35	<40 μm JOZ graphite	Mixed 3	Mixed A	1.8544
2A, 2B	50	Thermax carbon black	Mixed 3	Mixed A	1.8544
3A, 3B	40	<27 pm Robinson graphite	Mixed 3	Mixed A	1.8544
4A, 4C	35	<27 μm Poco graphite	Mixed 2	PR-5 1	1.6475
5A, 5C	40	<40 μm Santa Maria graphite	Mixed 2	PR-5 1	1.6475
6A, 6B	35	<40 μm Asbury graphite	Mixed 3	Mixed A	1.8544

[a]All samples bonded with a matrix composed of 15V pitch and the indicated amount and type of filler.
[b]Weight percent of filler in matrix.
[c]See Appendix E for description of coated particles. Each sample contained 1.1555 g fissile particles.

Table D2. Characterization data for spine samples

'Sample	Diameter (in.)[a] Top	Diameter (in.)[a] Middle	Diameter (in.)[a] Bottom	Length (in.) Overall	Length (in.) Near edge[a]	Weight (g) Sample	Weight (g) Loaded crucible
1A	0.4110	0.4111	0.4115	0.7180	0.6908	3.2111	26.1314
	0.4118	0.4113	0.4118		0.7075		
1B	0.4109	0.4111	0.4113	0.7145	0.6983	3.3551	26.449
	0.4114	0.4114	0.4117		0.7050		
2A	0.4110	0.4110	0.4100	0.7150	0.7088	3.4783	26.4902
	0.4113	0.4118	0.4110		0.7110		
2B	0.4105	0.4106	0.4103	0.7165	0.7038	3.5148	26.4396
	0.4125	0.4124	0.4112		0.7075		
3A	0.4111	0.4113	0.4110	0.7173	0.7078	3.4426	26.4044
	0.4123	0.4122	0.4123		0.7163		
3B	0.4105	0.4108	0.4115	0.7210	0.7050	3.4124	26.2892
	0.4118	0.4120	0.4120		0.7100		
4A	0.4100	0.4100	0.4103	0.7173	0.7035	3.2694	26.3456
	0.4110	0.4110	0.4110		0.7070		
4c	0.4110	0.4110	0.4110	0.7093	0.6950	3.1930	26.1937
	0.4123	0.4118	0.4108		0.7065		
5A	0.4098	0.4100	0.4096	0.7190	0.6990	3.3223	26.3862
	0.4110	0.4110	0.4108		0.7104		
5C	0.4098	0.4100	0.4098	0.7253	0.7045	3.3194	26.1196
	0.4108	0.4108	0.4103		0.7190		
6A	0.4113	0.4111	0.4110	0.7190	0.7053	3.3707	26.3080
	0.4122	0.4119	0.4119		0.7084		
6B	0.4108	0.4108	0.4113	0.7182	0.7082	3.4232	26.4834
	0.4112	0.4118	0.4123		0.7182		

[a]Minimum and maximum.

APPENDIX E

Description of Coated Particles Used in Fuel Fabricated at ORNL

The coated particle batches prepared at ORNL for use in the Recycle Test Elements are listed in Table E1, and the detailed fabrication and characterization data for each batch are given in Tables E2 through E4.

Table E1. ORNL coated particle batches[a] used in recycle test element

Batch numbers for various kernel compositions[b]			
ThO_2	UO_2	$(2Th,U)O_2$	$(4Th,U)O_2$
OR-1256	Mixed 1	PR-60	PR-54
OR-l 25 7	Mixed 2	PR-61	PR-55
OR-1258	Mixed 3	PR-66	PR-56
Mixed A		PR-67	PR-57
PR-47			
PR-48			
PR-50			
PR-51			

[a] All other particles used in ORNL fuel rods were fabricated at Gulf General Atomic and are described in report GA-10109.

[b] All ORNL particles had Biso coatings.

Table E2. Coated particles – kernel data

Particle batch	Kernel type	Preparation batches	Kernel diameter (μm)		Kernel density (g/cm^3)	Content (wt %)		Uranium Isotopic Analysis (at. %)				
			Average	Standard deviation		Th	U	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U
PR-54, -55	$(4Th,U)O_2$	SX-MIX	343.2	31.2	10.10	70.40	17.23	0.015	1.004	92.91	0.374	5.70
PR-56, -57	$(4Th,U)O_2$	SX-MIX	355.0	29.1	10.10	70.40	17.23	0.015	1.004	92.91	0.374	5.70
PR-60, -61	$(2Th,U)O_2$	UX-14, 15, 16	352.9	40.85	10.18	61.51	27.68	0.008	1.008	93.21	0.511	5.26
PR-66, -67	$(2Th,U)O_2$	UX-11, 12, 13, 17, 18	347.1	37.7	10.02	59.96	27.00	0.008	1.008	93.21	0.511	5.26
Mixed 1, 2, 3[a]	UO_2	K-l, 2, 3, 4	75-125	*b*	-10.5		87.0	<0.0005	1.008	93.20	0.501	5.29
OR-1256, 1257, 1258	ThO_2	c	350-500	*b*	*10.0*							
Mixed A[d]	ThO_2											
PR47, -48	ThO_2	ThO_2 No. 1	409.7	10.6	9.96							
PR-50, -51	ThO_2	ThO_2 No. 2	390.9	14.2	9.89							

‘Mixed batches 1 and 2 were from batches OR-1189, -1199, -1203, -1204, -1209, -1211, -1222, -1223, -1224, -1225, -1226, -1227. Mixed batch 3 was from batches OR-1232, -1234, -1241, -1244, -1248.

[b]Not determined.

[c]Not available.

[d]Mixed batch A was from batches OR-1268, -1270, -1271, -1272, and -1273.

Table E3. Coated **particles** – buffer coating data

Particle batch	Kernel type	Coating run	Coater[a]	Charged weight (g)	Flux, cm^3/(cm^2/min)		Coating time (min)	Yield weight (g)	Buffer coating			Buffer-coated particle		
									Thickness (μm)					
					Acetylene	Helium			Average	Standard deviation	Density[b] (g/cm^3)	Density (g/cm^3)	Carbon (wt %)	Diameter[c] (μm)
PR-54, -55	$(4Th,U)O_2$	53	5 in.	1156	2.0	0.8	8.3	1407	72.1	13.1	1.103	4.060	18.25	452.7–617.7
PR-56, -57	$(4Th,U)O_2$	52	5 in.	1137	2.0	0.8	8.3	1362	73.5	15.0	1.101	4.055	18.25	431.2-696.9
PR-60, -61	$(2Th,U)O_2$	58	5 in.	1178	2.0	0.8	8.3	1447	76.3	17.1	1.159	4.12	18.90	*d*
PR-66, -67	$(2Th,U)O_2$	65	5 in.	1019	2.0	0.8	8.3	1209	87.0	16.5	1.172	3.61	22.92	
Mixed 1, 2, 3[e]	UO_2	1215	Lab	30	2.1	0.9	10	51	-54	*d*	-1.4	*d*	*d*	-155
OR-1256	ThO_2		Lab	200	3.3	1.3	2		44	*d*	-1.1	*d*	*d*	350-500
OR-l 257	ThO_2													
OR-l 25 8	ThO_2													
Mixed A[e]	ThO_2		Lab						41-45	*d*				
PR-47, -48	ThO_2	44	5 in.	1200	2.0	0.[illegible]	6.8	1344	55.6	14.5	1.26	5.545	11.54	520.8
PR-50, -51	ThO_2	46	5 in.	1200	2.0	0.8	6.8	1280	51.4	13.1	1.33	5.645	11.81	493.7

‘Prototype coater with 5-in.-diam cone operated at 1100°C; laboratory coater with 1.5-in.-diam cone operated at 1050°C.

[b]Calculated from bum-off weight loss and radiographic data.

‘Standard deviation for buffer-coated particles on PR-47 and PR-48 (Run 44) is 22.9; on PR-50 and PR-51 (Run 46) 23.0; balance not determined.

[d]Not determined.

‘Estimated from individual batches; identified in footnotes to Table E2.

Table E4. Coated particles – outer coating and final particle data

Particle batch	Kernel type	Run	Coating Temp (°C)	Coater	Charged weight (g)	Propene flux [$cm^3/(cm^2/min)$]	Coating time (min)	Yield weight (g)	Outer coating[a]: Thickness (µm)	Outer coating[a]: Standard deviation (µm)	Outer coating[a]: Density[b] (g/cm^3)	Final coated particle: Density[c] (g/cm^3)	Final coated particle: Diameter (µm) Average	Final coated particle: Diameter (µm) Standard deviation	Final coated particle: content (wt %) Carbon	Final coated particle: content (wt %) Uranium[c]	Final coated particle: content (wt %) Thorium[c]	Final coated particle: content (wt %) Oxygen	Content (ppm) Equivalent boron	Content (ppm) Iron
PR-54	$(4Th,U)O_2$	54	1420	5 in.	688	2.0	10.2	1133	73.2	d	1.94	2.805	656.3	37.8	51.75	7.90	31.19	5.65	d	d
PR-55	$(4Th,U)O_2$	55	1420	5 in.	687	2.0	10.2	1145	81.1	d	1.90	2.77	675.5	32.7	51.10	8.0	31.61	5.73	d	d
PR-56	$(4Th,U)O_2$	56	1420	5 in.	664	2.0	17.4	1265	129.1	d	1.91	2.46	772.5	44.2	61.40	6.41	25.31	4.58	d	d
PR-57	$(4Th,U)O_2$	57	1420	5 in.	664	2.0	17.4	1570	134.6	d	1.92	2.48	783.5	44.7	61.40	6.32	24.95	4.52	16	30
PR-60	$(2Th,U)O_2$	60	1420	5 in.	705	2.0	17.0	1431	123.2	d	1.91	2.51	751.0	44.1	59.99	11.07	24.61	4.91	d	d
PR-61	$(2Th,U)O_2$	61	1420	5 in.	707	2.0	17.5	1429	122.2	d	1.91	2.50	754.2	40.9	61.31	10.71	23.80	4.75	d	d
PR-66	$(2Th,U)O_2$	66	1420	5 in.	586	2.0	17.5	1396	128.6	d	1.86	2.36	793.5	34.9	65.29	9.37	20.81	4.28	d	d
PR-67	$(2Th,U)O_2$	67	1420	5 in.	586	2.0	17.0	1279	141.1	d	1.85	2.27	805.8	40.6	65.45	9.33	20.72	4.26	<6	100
Mixed 1[e]	UO_2		1300	Lab	} 30															
Mixed 2	UO_2		1300	Lab			1.7	85	-60	d	1.89	2.06	213	d	84.15			1.85	<10	5
Mixed 3	UO_2		1300	Lab																
OR-1256	ThO_2		1300	Lab		2.3[f]	8	258	63	d		4.2[c]			28.3		63.0	8.7		
OR-1257	ThO_2		1300	Lab		2.3[f]	8	251	63	d		4.2[c]								
OR-1258	ThO_2		1300	Lab		2.3-f	8	220	63	d		4.2[c]								
Mixed A[e]	ThO_2		1300	Lab					60-74	d	1.99						63.0			
PR-47	ThO_2	47	1350	5 in.	647	2.0	9.8	962	17.1	11.9	1.93	3.58	675.0	28.4	36.96		55.41	7.64	d	d
PR-48	ThO_2	48	1350	5 in.	647		9.3	885	62.2	d	1.94	3.67	645.2	20.2	35.35		56.83	7.84	d	d
PR-50	ThO_2	50	1350	5 in.	603		9.3	830	70.9	15.2	1.91	3.62	635.5	31.5	35.86		56.39	7.78	d	d
PR-51	ThO_2	51	1350	5 in.	603		9.3	817	69.8	d	1.91	3.57	633.3	20.7	36.40		55.90	7.71	110	300

[a]The Bacon Anisotropy Factor was less than 1.1 in all batches.
[b]From gradient density column.
[c]Calculated from kernel composition and amount of coating. AU other values measured.
[d]Not determined.
[e]Estimated from individual batches, which are identified in footnotes to Table E2.

APPENDIX F

Location of RTE Archive Samples

Archive fuel rods and loose particles are stored in the Main SS Material Storage Vault at ORNL, held in the name of R. B. Fitts. Table F1 identifies the location of fuel rods by lot number and the number of rods from that lot stored in a given box in the vault. All fuel rods are stored in container 13. Table F2 identifies the location of loose particle archives by particle composition, batch number, grams of particles stored, item number, and container number.

Table F 1. Fuel rod archives

Lot	Number of rods stored	Box[a]	Lot	Number of rods stored	Box[a]
1	3		16	5	3
2	5	1	17	5	3
3	5	1	18	4	3
4	5	1	19	5	4
5	5	2	20	5	4
6	4	2	22	5	4
7	3	2	23	2	4
9	5	2	26	1	4
10	3	2	27	3	4
12	5	2	28	4	5
14	5	3	29	5	5
15	5	3			

[a]In Container 13 in SS Material Storage Vault, ORNL.

Table F2. Loose particle archives

Particle composition	Batch	Amount stored (g)	Item	Container
$(4Th,U)O_2$	PR-56	7.5	6	16
$(4Th,U)O_2$	PR-57	6.6	1	16
$(2Th,U)O_2$	PR-60	6.2	5	16
$(2Th,U)O_2$	PR-61	93.9	4	16
$(2Th,U)O_2$	PR-66	48.83	3	16
$(2Th,U)O_2$	PR-67	176.2	2	16
UO_2	Mixed 1	2.1	13	15
UO_2	Mixed 2	10.4	4	15
UO_2	Mixed 3	54.0	5	15
UO_2	Mixed 3	26.1	6	15
UO_2	Mixed 3	96.5	8	15

APPENDIX G

Preirradiation Metallography of ORNL Fuels

The preirradiation metallography of typical fuel rods is described by Table G1. A similar compilation on the various coated particle batches is given in Table G2. Figures G1–G14 show microstructures of coated particles typical of those used in the RTE's. Matrix microstructures in fuel rods are shown in Figs. G15–G17.

Polaroid prints have been made of microradiographs of the following batches of loose coated particles: (1) Biso-coated $(2Th,U)O_2$, batches PR-60, -61, -66, and -67; (2) Biso-coated ThC_2 batch 4000-225.

Metallography specimen P-386 represents uncoated $(2Th,U)O_2$ kernels of batches UX-14, -15, and -16. Typical photomicrographs are Y-100472 at 17X and Y-100471 at 100X. Similar batches UX-11, -12, -13, -17, and -18, represented by specimen P-401, are shown in Y-100473 at 17X and Y-100474 at 100X.

Table G1. RTE fuel rod preirradiation metallography

Metallography specimen	Photograph	Magnification	Description
Fuel rod JF-169-3, type a: (4.2Th,U)O_2			
P-424	Polaroid only	40×	Longitudinal pan
P-425(3A)	Polaroid only	40×	Transverse pan
P-423	Polaroid only	40×	Transverse pan
P424	Y-100576	200×	Matrix
P-423	Y-100575	200×	Matrix
P-425	Y-100577	200×	Matrix
Fuel rod JF-207-4, type c: (2Th,U)O_2[a]			
P-431(15-3A)	Polaroid only	~40×	Transverse pan
P-430(15-2)	Polaroid only	~40×	Transverse pan
P-429(151A)	Polaroid only	~40×	Longitudinal pan
P-431(15-3A)	Y-100580-91	75x	Transverse pan
P-429(15-1A)	Y-l 00578	200×	Matrix
P-430(15-2)	Y-100579	200×	Matrix
P-431(15-3A)	Y-103116	500×	Matrix
Fuel rod JF-201-3, type d: (2Th,U)O_2 + ThC_2[b]			
P-427(14-2)	Polaroid only	40×	Longitudinal pan
P-426(14-Al)	Polaroid only	40×	Transverse pan
P-428(14-3A)	Polaroid only	40×	Transverse pan
P-426(14-1A)	Polaroid only	200×	Matrix
P-427(14-2)	Polaroid only	200×	Matrix
P-428(14-3A)	Polaroid only	200×	Matrix
Fuel rod JF-173-18, type g: UO_2 + ThO_2			
68721	Y-100276	7.5x	Longitudinal plan
68721	Y-100277	7.5x	Transverse pan
68721	Y-100275	7.5x	Transverse pan
68370	Y-99376	7.5x	Transverse cross section
68370	Y-99377	7.5x	Transverse cross section
68370	Y-99378	7.5x	Transverse cross section
68371	Y-99375	7.5x	Transverse cross section
68371	Y-99373	7.5x	Transverse cross section
68371	Y-99374	7.5x	Transverse cross section
68721	Y-100664	200×	Matrix
68721	Y-100663	200×	Matrix
68721	Y-100662	200×	Matrix
68721	Y-100665	200×	Matrix
68721	Y-100666	500×	Matrix
68721	Y-100651-62	100x	Pan shot

[a]We have several photos made at GGA on an ORNL-type c fuel rod, identified as GGA-76, probably from ORNL stack 76.

[b]We have several photos made at GGA on an ORNL-type d fuel rod, identified as GGA-89, probably from ORNL stack 89.

Table G2. Preirradiation metallography of coated particle batches used in RTE's

Batch	Kernel type	Metallography specimen	Photograph	Magnification	Description
PR-47	ThO_2	68226	Y-101230	100x	Bright field
			Y-10-1228	50×	Polarized light
			Y-101227	50×	Bright field
PR-48	ThO_2	68227	Y-101232	50×	Polarized light
			Y-101231	50×	Bright field
			Y-101234	100x	Polarized light
			Y-101233	100x	Bright field
PR-5 0	ThO_2	68238	Y-101235	50×	Bright field
			Y-101236	50×	Polarized light
			Y-101238	100×	Bright field
			Y-101237	100x	Polarized light
PR-5 1	ThO_2	68230	Y-101239	50×	Bright field
			Y-101240	50×	Polarized light
			Y-101242	100×	Bright field
PR-54	$(4Th,U)O_2$	P-376	Y-99640	50×	Bright field
			Y-99643	50×	Polarized light
			Y-99641	100x	Bright field
			Y-99642	100x	Polarized light
PR-55	$(4Th,U)O_2$	P-377	Y-99644	50×	Bright field
			Y-99647	50×	Polarized light
			Y-99645	100×	Bright field
			Y-99646	100×	Polarized light
PR-56	$(4Th,U)O_2$	P-378	Y-99648	50×	Bright field
			Y-9965 1	50×	Polarized light
			Y-99649	100×	Bright field
			Y-99650	100×	Polarized light
PR-57	$(4Th,U)O_2$	P-379	Y-99652	50×	Bright field
			Y-99655	50×	Polarized light
			Y-9965 3	100×	Bright field
			Y-99654	100×	Polarized light
PR-60	$(2Th,U)O_2$	P-395	Y-100477	50×	Bright field
			Y-100476	50×	Polarized light
			Y-100475	100×	Bright field
PR-61	$(2Th,U)O_2$	P-396	Y-101041	50×	Bright field
			Y-101042	50×	Polarized light
			Y-101044	100×	Bright field
			Y-101043	100×	Polarized light
PR-66	$(2Th,U)O_2$	P-408	Y-100966	50×	Bright field
			Y-100967	50×	Bright field
			Y-100969	100×	Bright field
			Y-100968	100×	Polarized light
PR-67	$(2Th,U)O_2$	P-409	Y-100970	50×	Bright field
			Y-100971	50×	Polarized light
			Y-100973	100×	Bright field
			Y-100972	100×	Polarized light
Mixed 1, 2	UO_2	68248	Y-99084	100×	Bright field
			Y-99085	200×	Bright field
			Y-99086	200×	Polarized light
			Y-99087	500×	
			Y-99088	500×	Polarized light
			Y-99089	500×	Coating
Mixed A	ThO_2	68619	Y-100696	100x	Bright field
			Y-100697	200×	Bright field
			Y-100698	200×	Polarized light
			Y-100699	500×	Coating

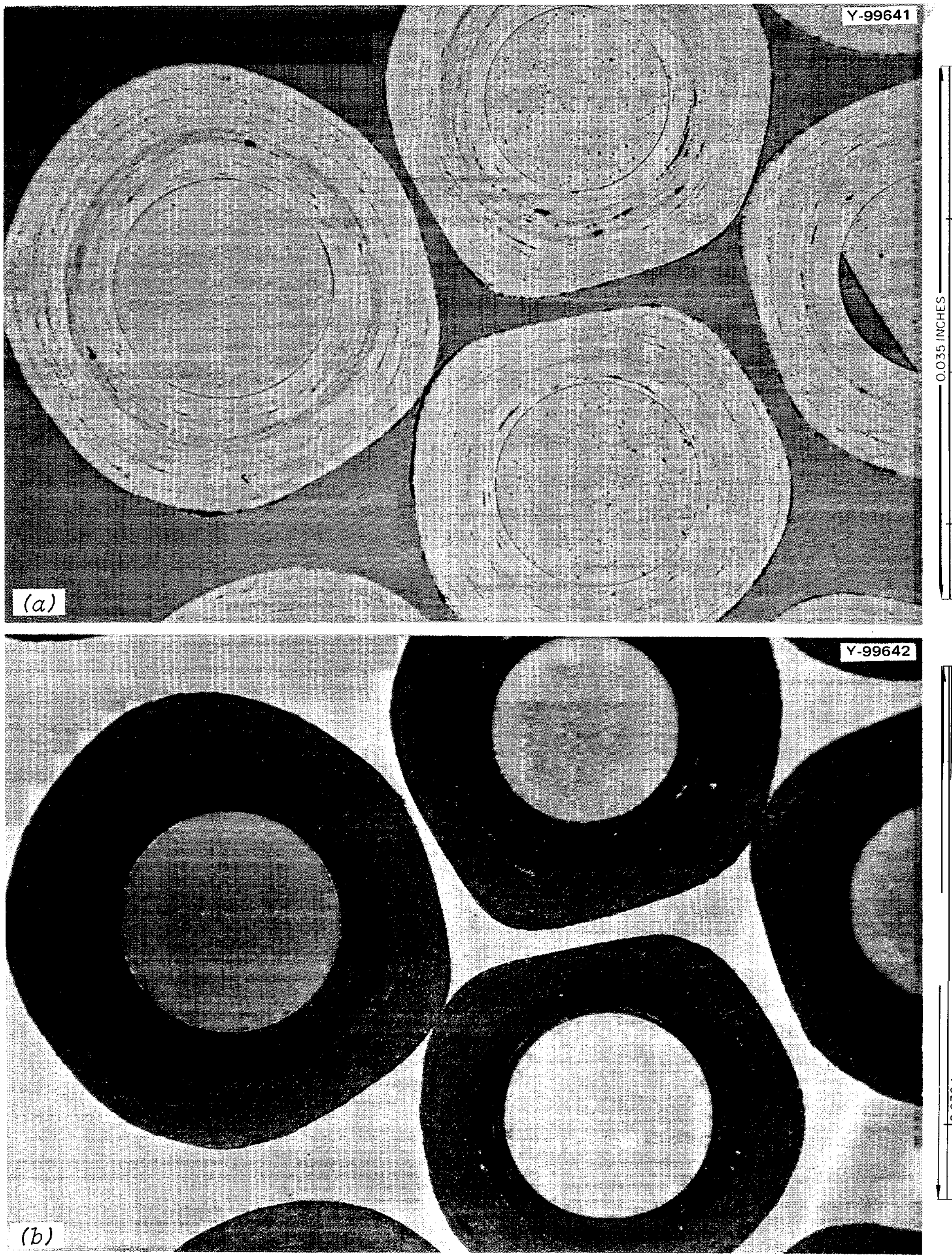


Fig. G1. Loose Biso-coated (4.2Th,U)O_2 kernels used in type a RTE fuel (PR−54). 100X. (a) Bright field. (b) Polarized light.

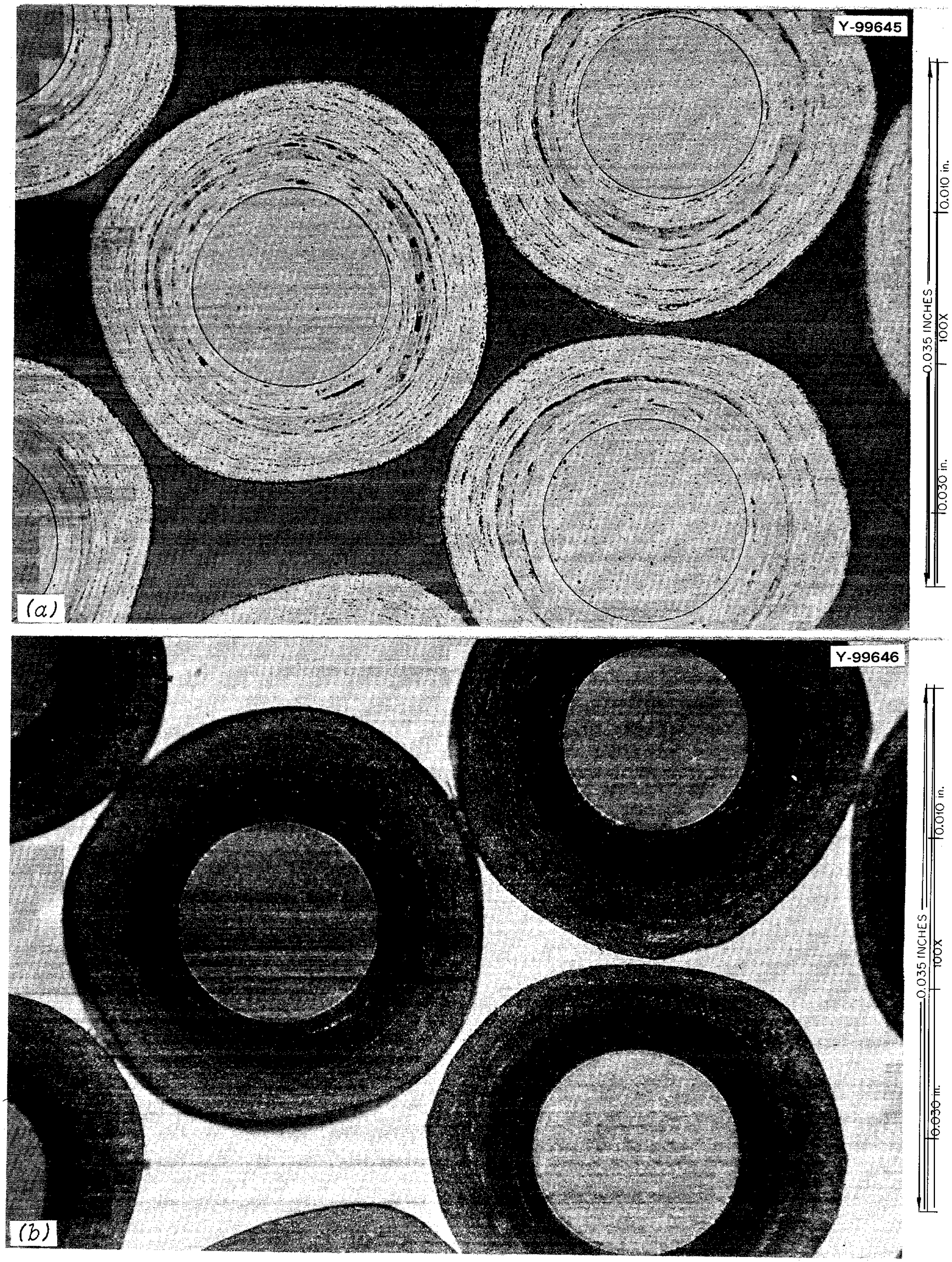


Fig. G2. Loose Biso-coated (4.2Th,U)O_2 kernels used in type a RTE fuel (PR-55). 100×. (*a*) Bright field. (*b*) Polarized light.

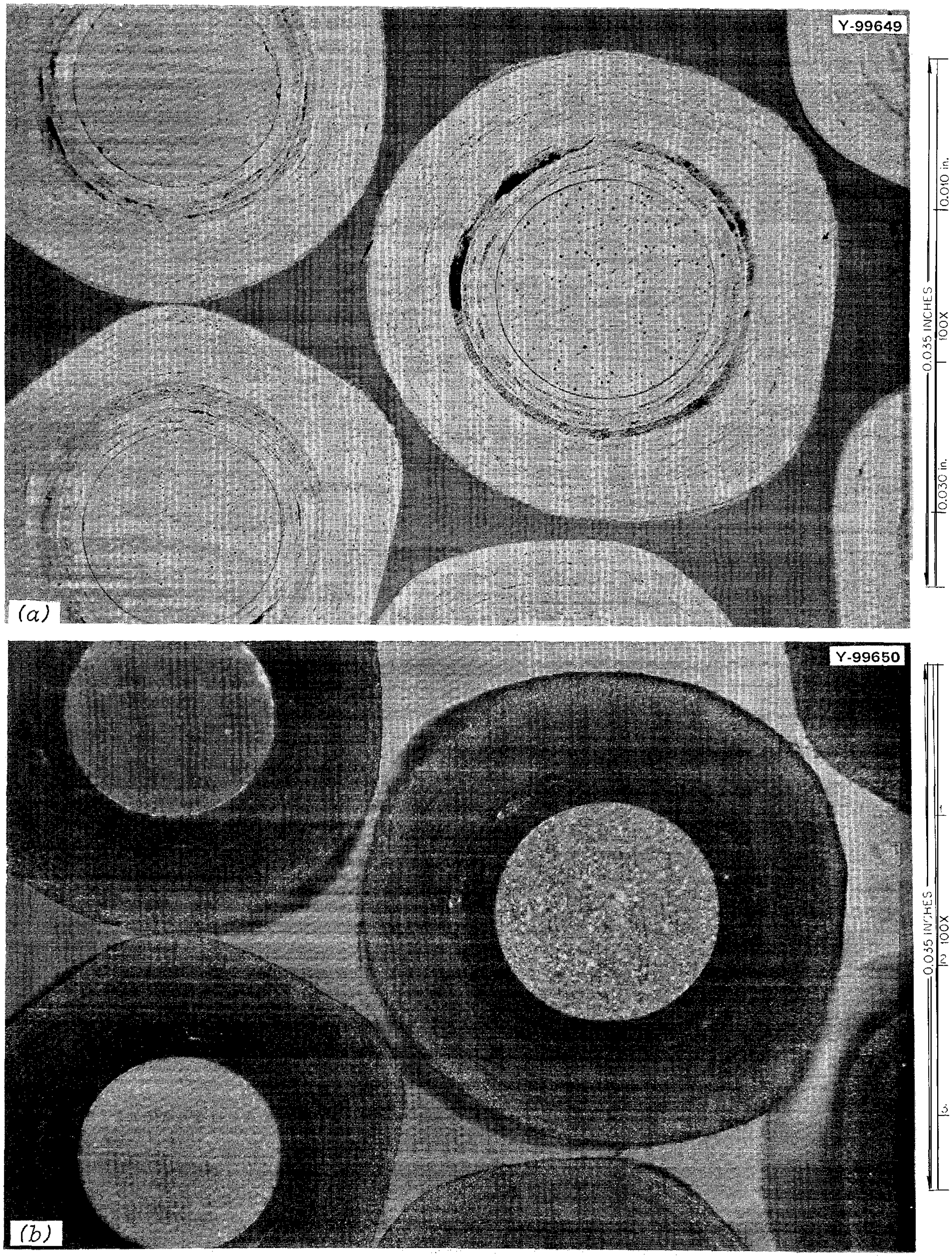


Fig. G3. Loose Biso-coated (4.2Th,U)O_2 kernels used in type a RTE fuel (PR-56). 100X. (a) Bright field. (*b*) Polarized light.

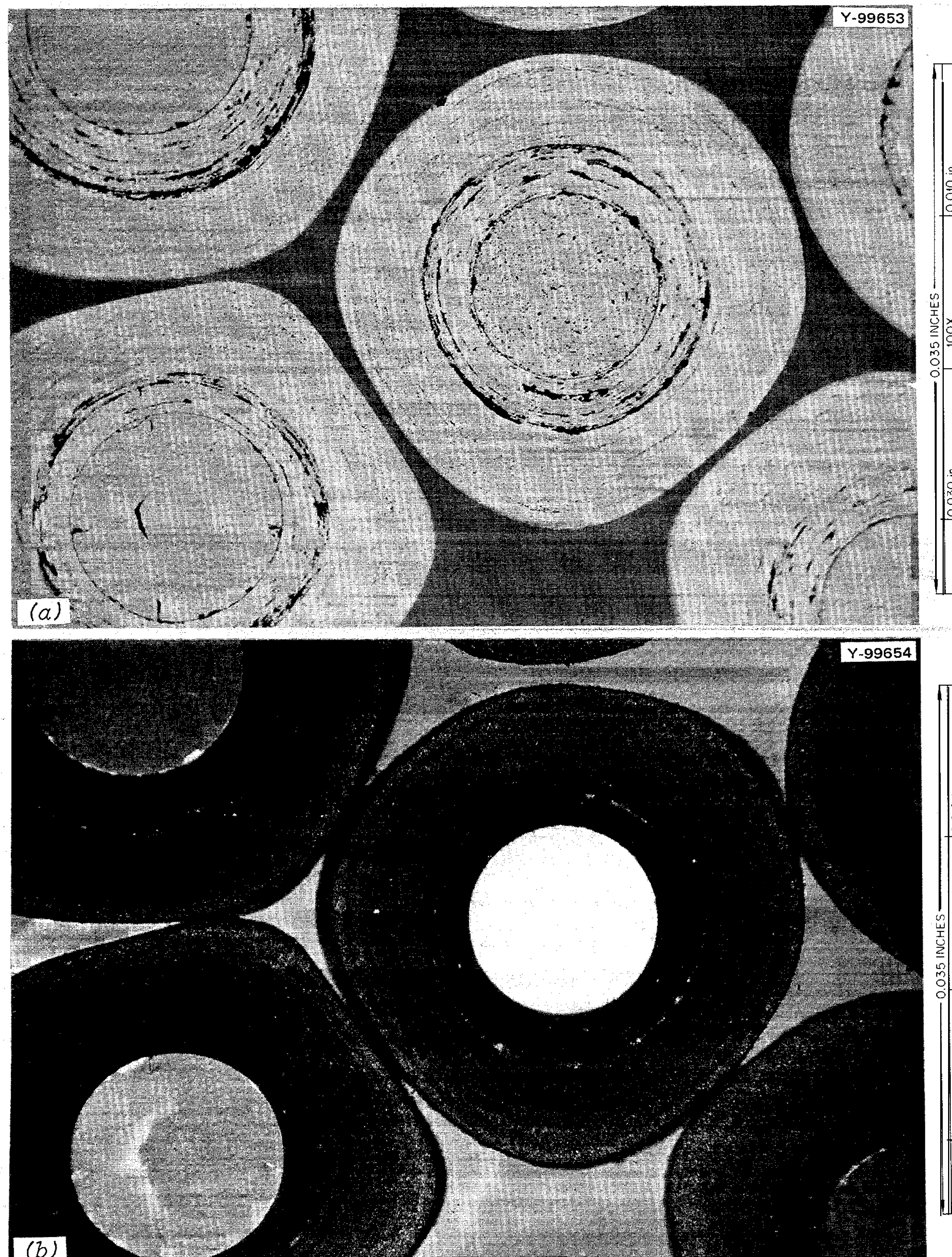


Fig. G4. Loose Biso-coated (4.2Th,U)O_2 kernels used in type a RTE fuel (PR-57). 100X. (a) Bright field. (*b*) Polarized light.

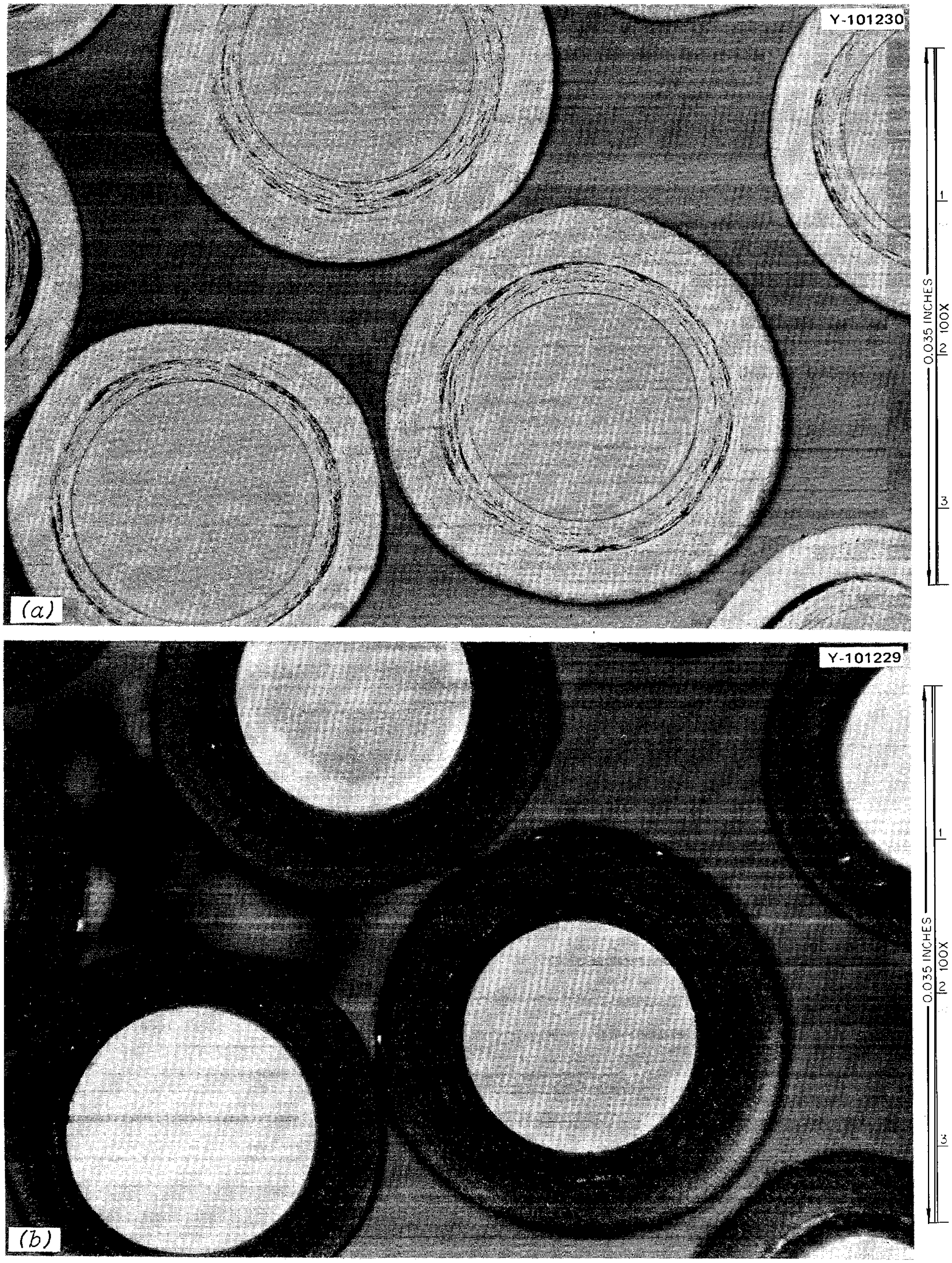


Fig. G5. Loose Biso-coated ThO_2 kernels used in types c and g RTE fuel (PR-47). 100×. (a) Bright field. (6) Polarized light.

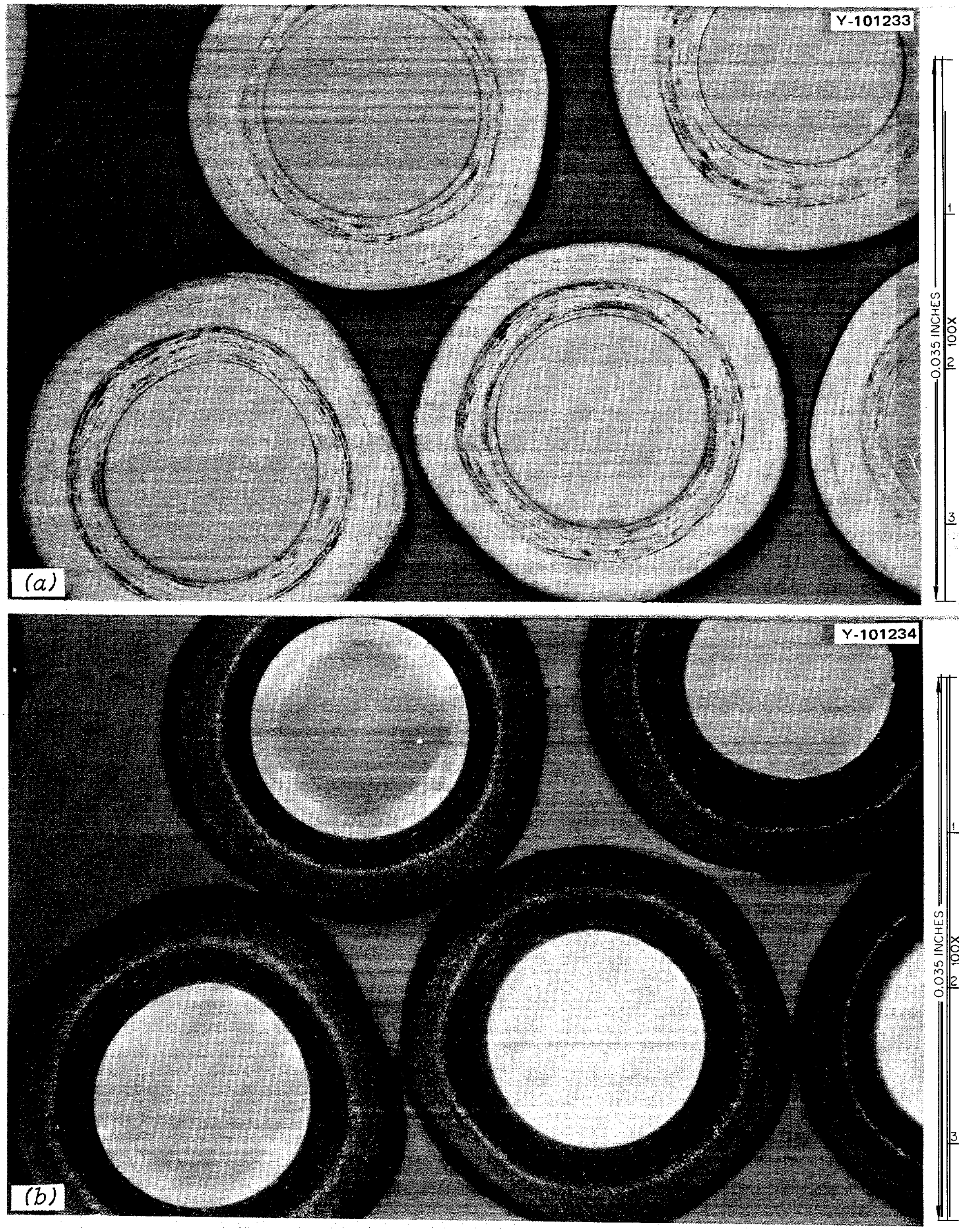


Fig. G6. Loose Biso-coated ThO_2 kernels used in types c and g RTE fuel (PR-48). 100×. (*a*) Bright field. (*b*) Polariz ed light.

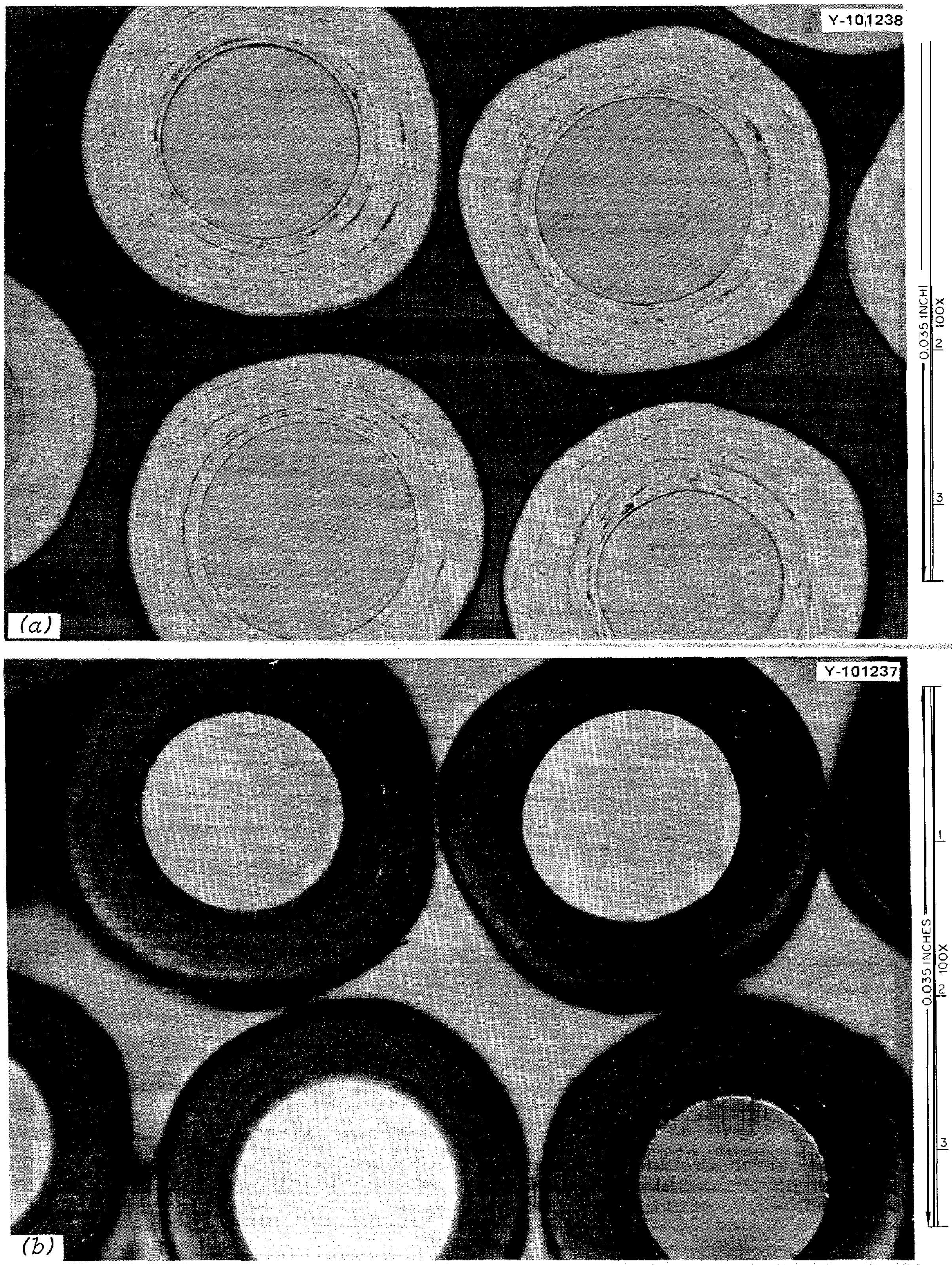
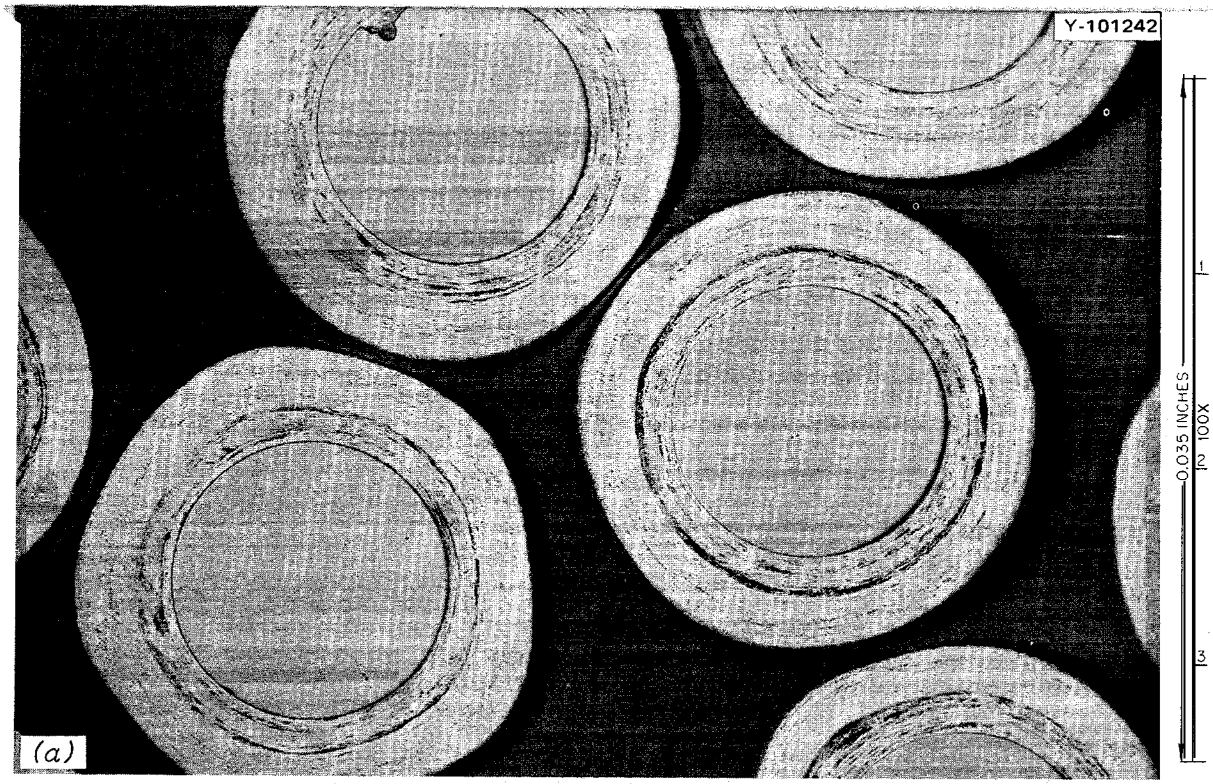


Fig. G7. Loose Biso-coated ThO_2 kernels used in types c and g RTE fuel (PR-50). 100×. (*a*) Bright field. (*b*) Polarized light.



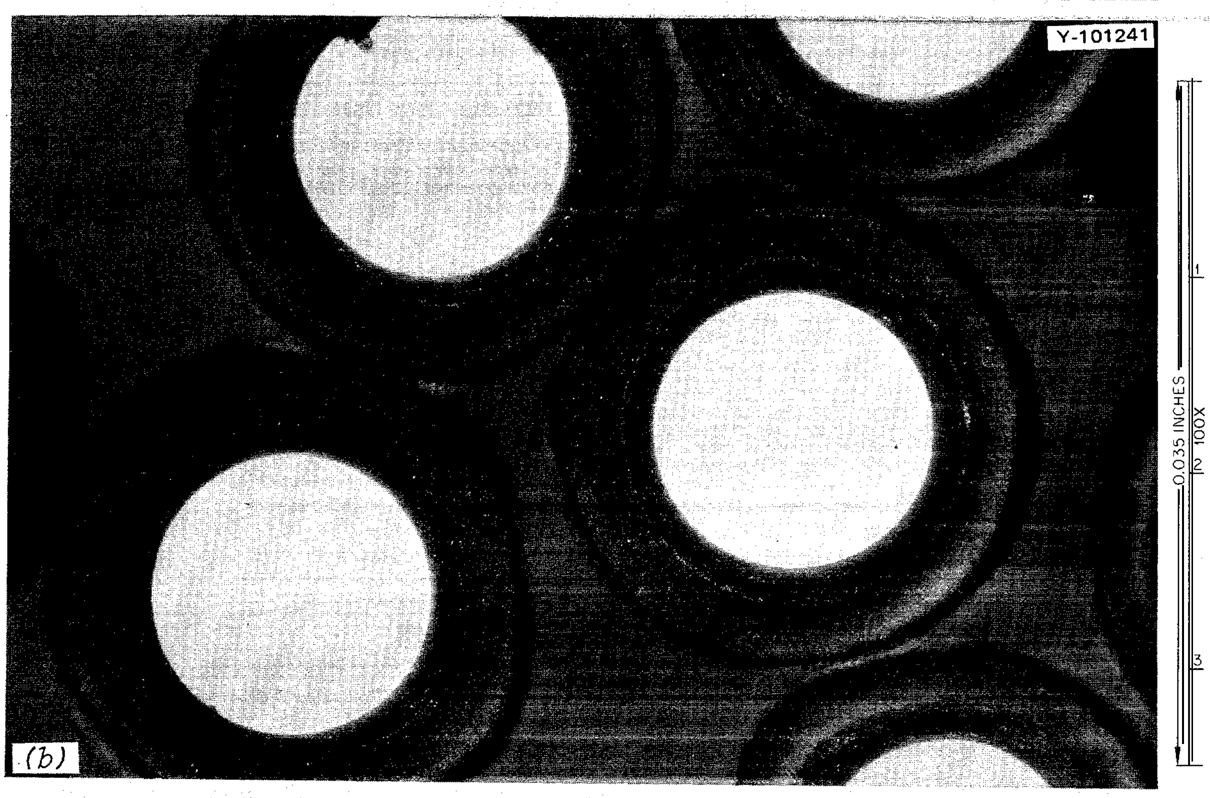


Fig. G8. Loose Biso-coated ThO_2 kernels used in types c and g RTE fuel (PR-51). 100X. (a) Bright field. (b) Polarized light.

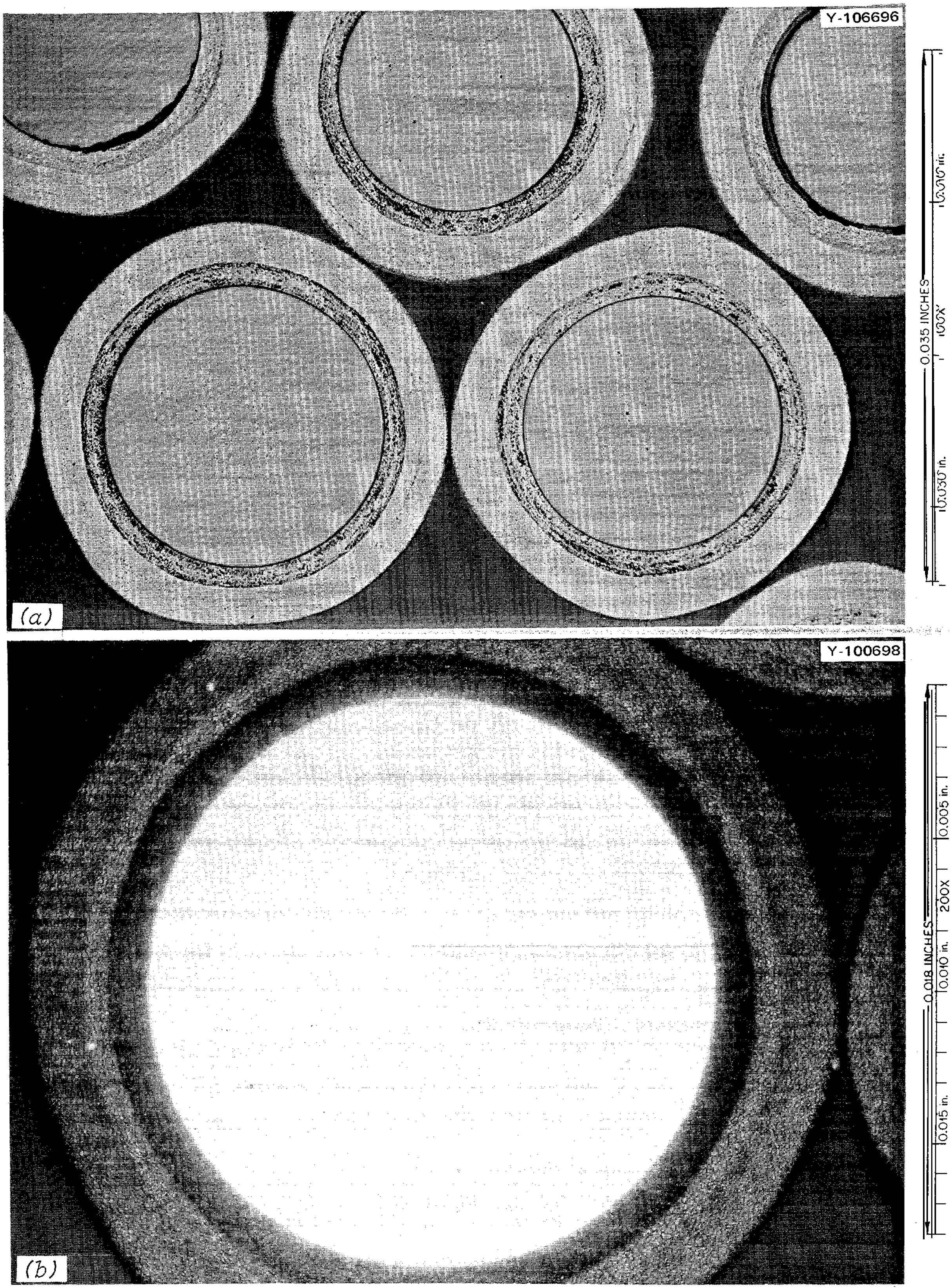


Fig. **G9.** Loose Biso-coated **ThO_2 kernels used in types c and g RTE fuel (mixed batch A).** (a) Bright field. (*b*) Polarized light.

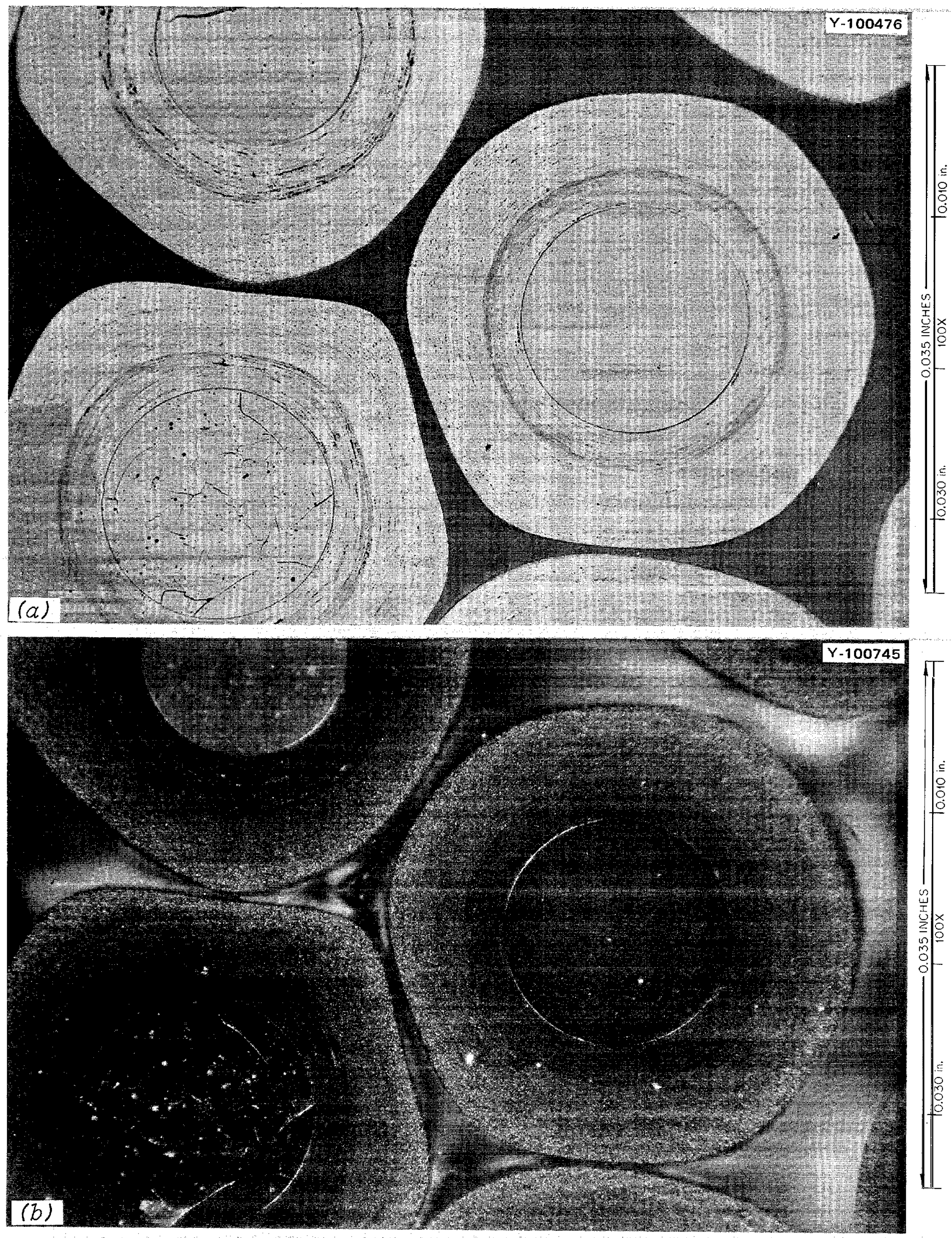


Fig. G10. Loose Biso-coated (2Th,U)O_2 kernels used in types c and d RTE fuel (PR-60). 100X. (a) Bright field. (b) Polarized light.

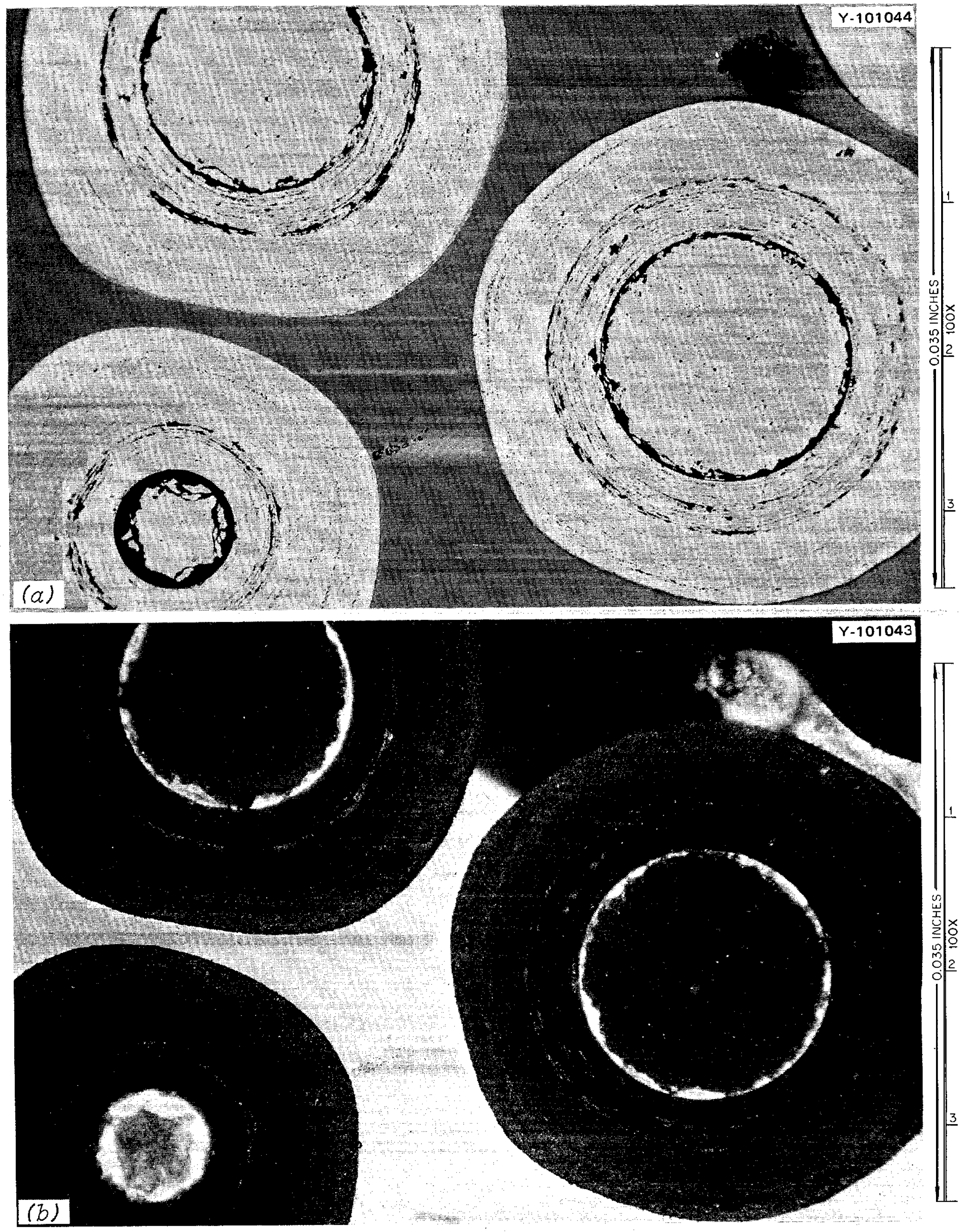


Fig. G11. Loose Biso-coated (2Th,U)O_2 kernels used in types c and d RTE fuel (PR-61). 100X. (a) Bright field. (*b*) Polarized light.

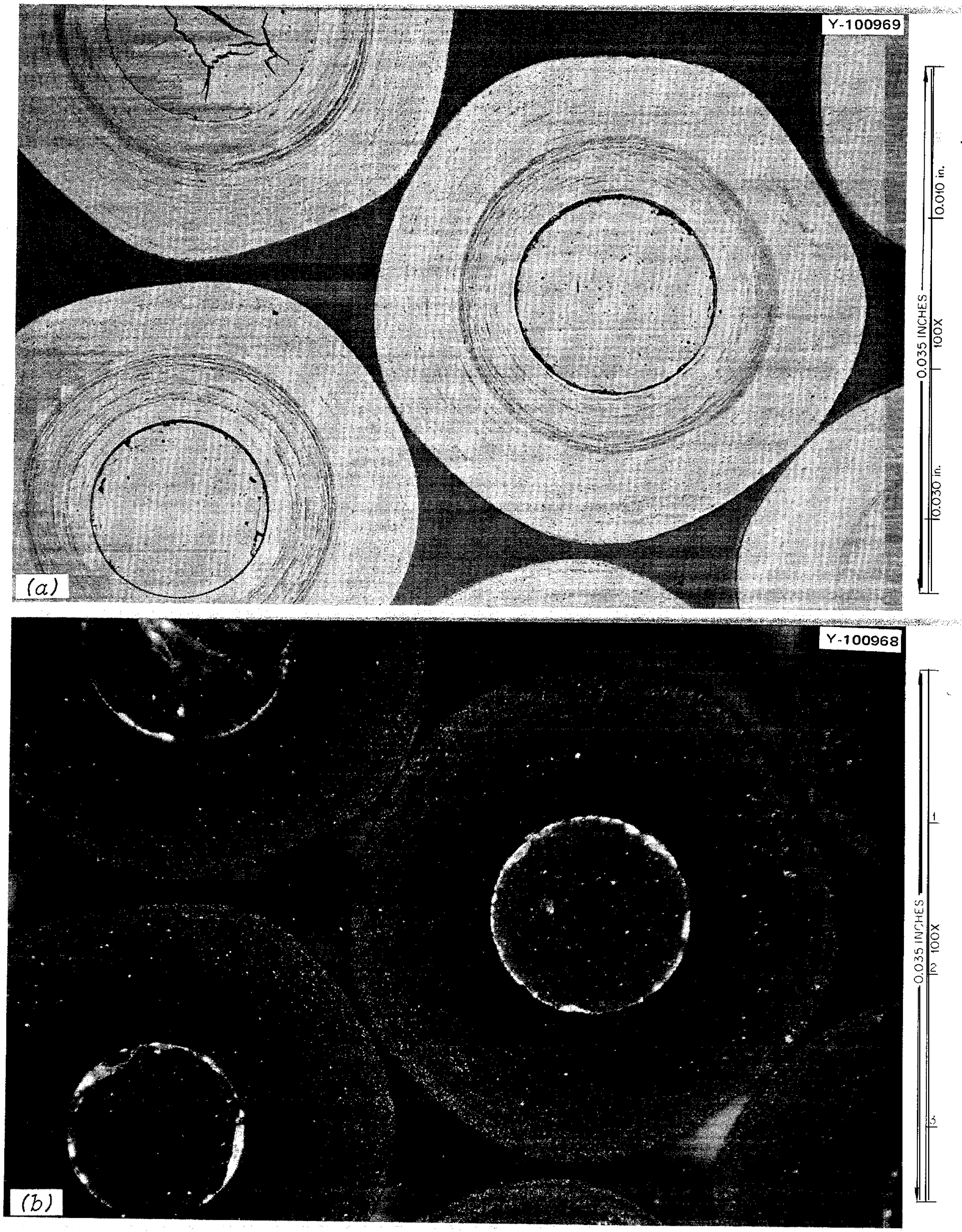


Fig. G12. Loose Biso-coated $(2Th,U)O_2$ kernels **used in types c and d RTE fuel** (PR-66). 100X. (a) Bright field. (b) Polarized light.

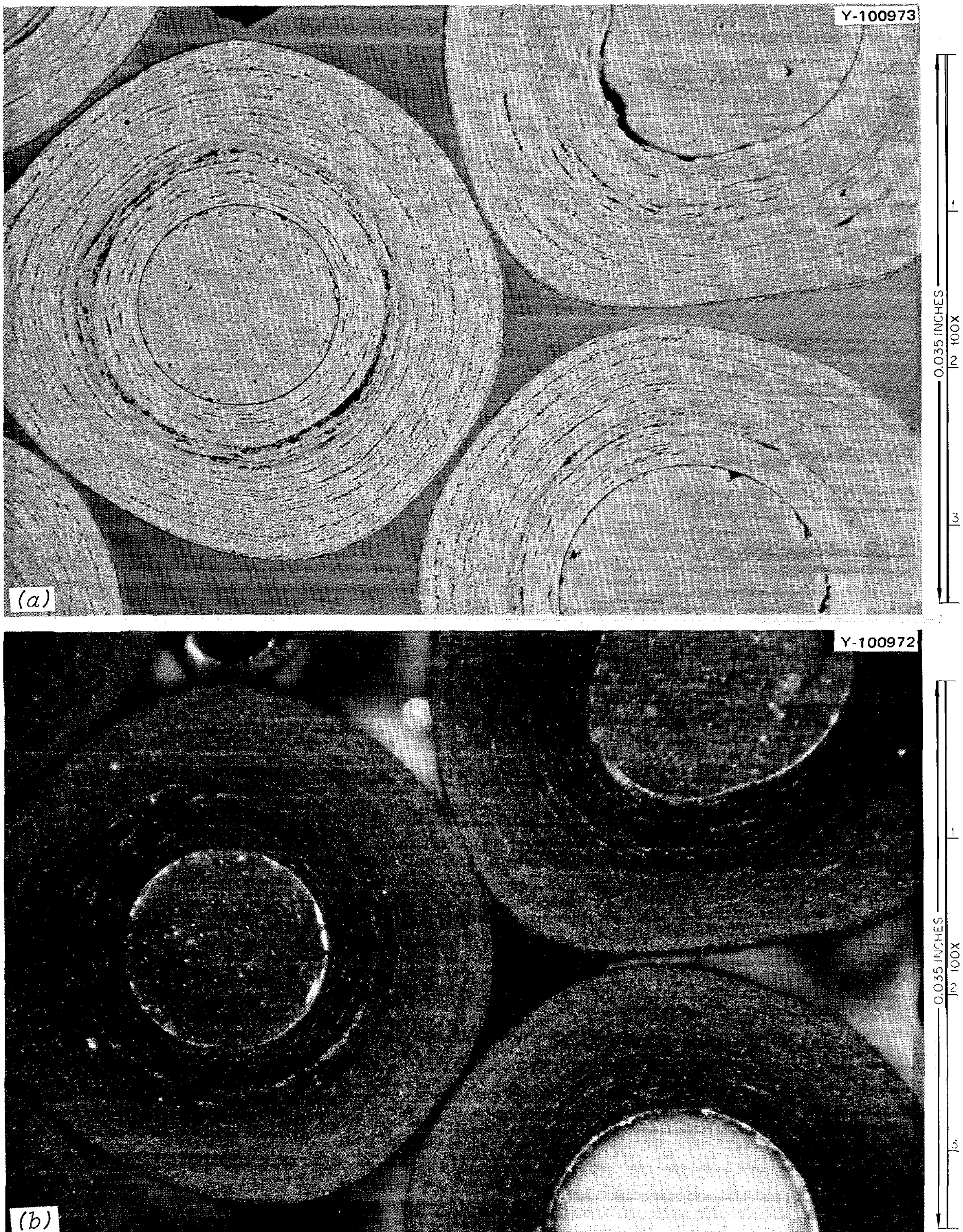


Fig. G13. Loose Biso-coated $(2Th,U)O_2$ kernels used in types c and d RTE fuel (PR-67). 100×. (a) Bright field. (*b*) Polarized light.

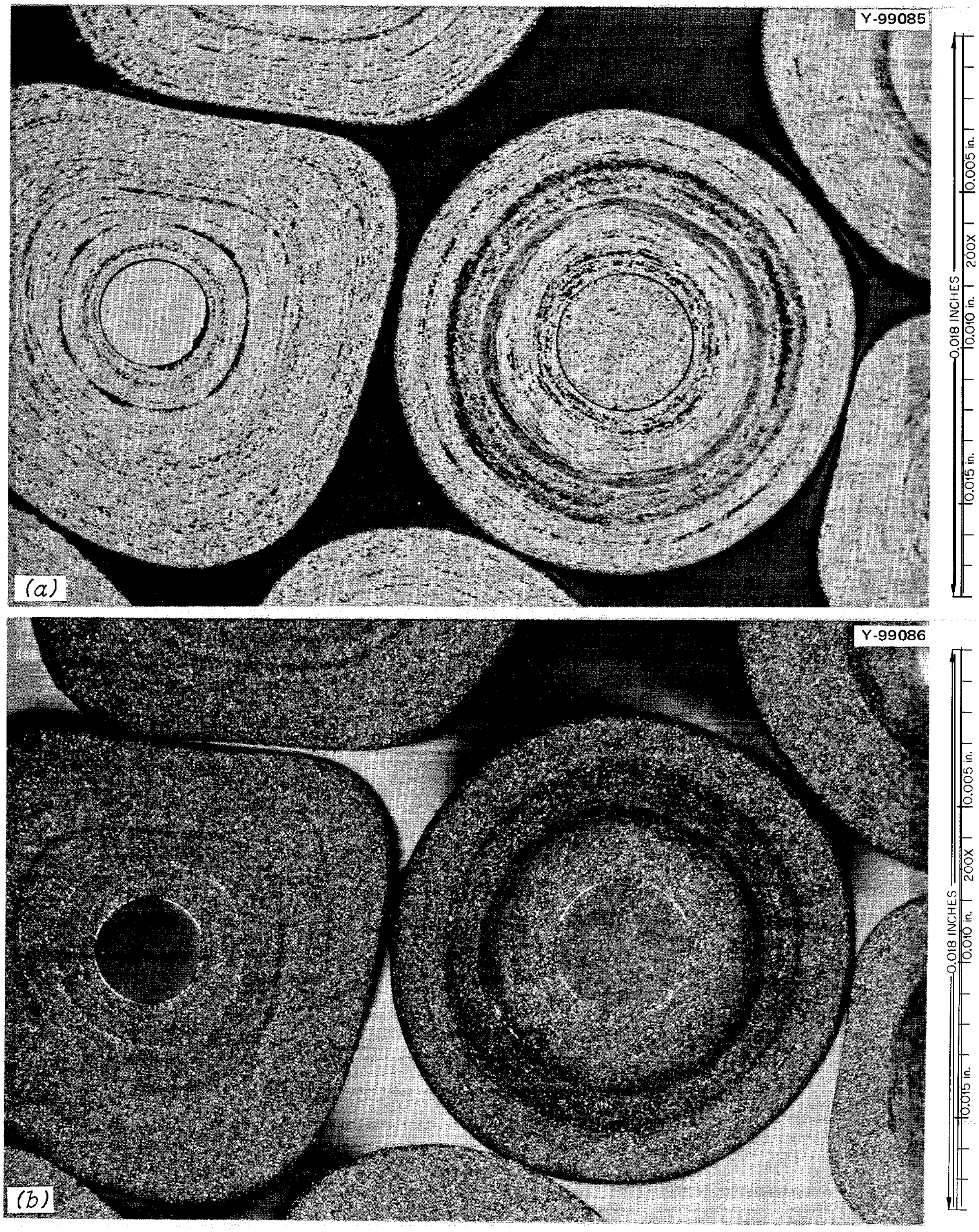


Fig. G14. Loose Biso-coated UO_2 kernels used in type g RTE fuel (mixed batches 1 and 2). 200X. (a) Bright field. (b) Polarized light.

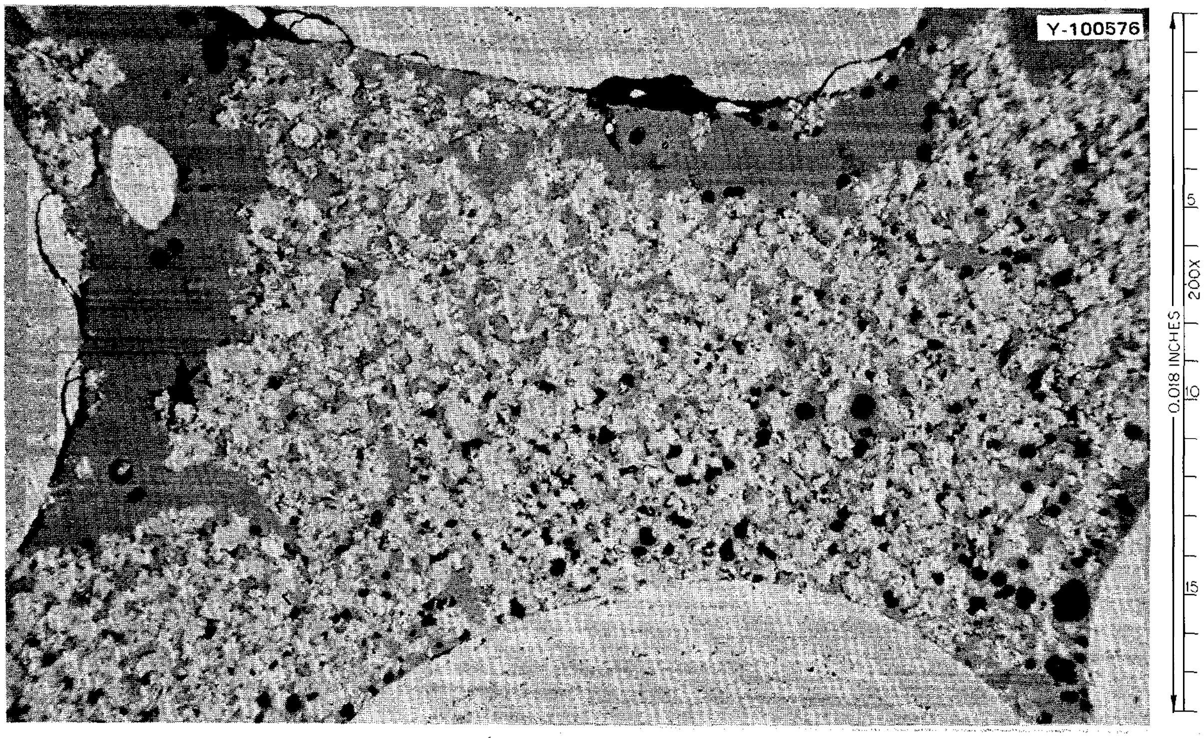


Fig. G15. Typical appearance of matrix in type a RTE fuel rods. Bonded with 15V pitch and 35 wt % <40-μm Poco AXZ graphite. Carbonized in natural flake graphite.

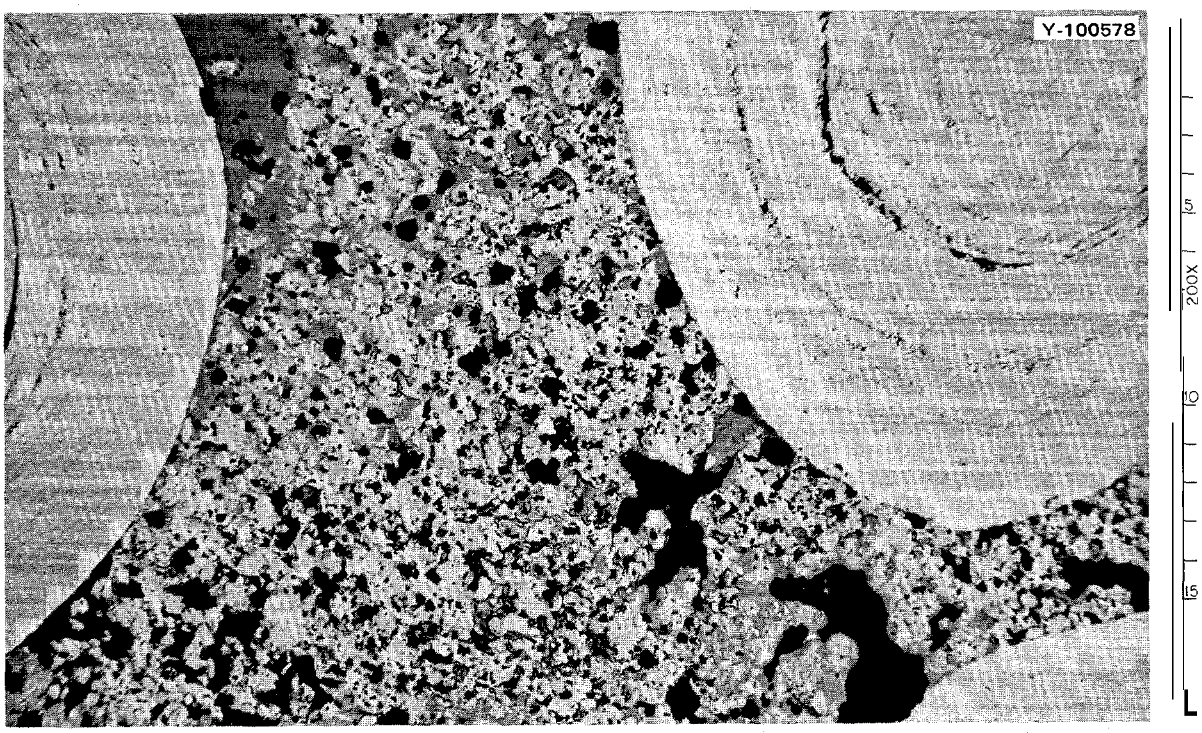


Fig. G16. Typical appearance of matrix in types c and d RTE fuel rods. Bonded with 15V pitch and 35 wt % <40-μm Poco AXZ graphite. Carbonized in natural flake graphite.

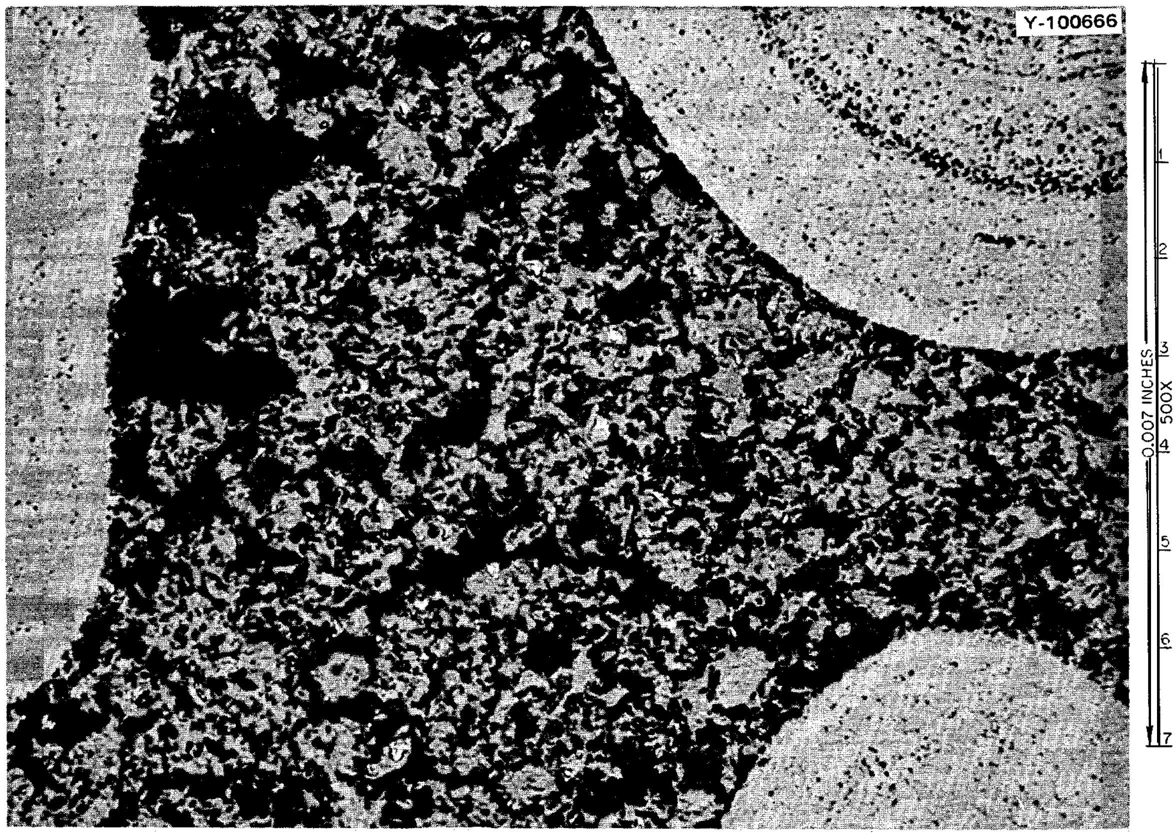


Fig. G17. Typical appearance of matrix in type g RTE fuel rods. Bonded with 15V pitch and 35 wt % <27-μm Poco AXM graphite. Carbonized in natural flake graphite.

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