GEL-ADDITION PROCESS CHEMICAL STUDIES

— Quarterly Progress Report No. 16 —

May - July 1970

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Gel-Addition Process Chemical Studies
— Quarterly Progress Report No. 16 —
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ABSTRACT

The development of a sol-gel process and related processes for preparing (U,Pu)O₂ fast reactor fuels has continued at the Babcock & Wilcox Nuclear Development Center. Progress for the 16th quarter, ending July 31, 1970, is reported. The program is sponsored by the U.S. Atomic Energy Commission under Contract No. AT(30-1)-3714.

Seven pellet, seven vipac, and seven sphere-pac pins containing ²³⁵UO₂-20% PuO₂ have been prepared for the unencapsulated bundle to be irradiated in the EBR-II. These are sufficient for the initial loading. All the pins have been Xe-tagged and welded, and the final inspection is in progress.

The final five capsules scheduled in the "time-for-restructuring" series were irradiated in the BAWTR. Four capsules were irradiated simultaneously for 30 days, one each at 6, 10, 15, and 20 kW/ft. Another capsule was irradiated for 8 hours at 20 kW/ft.

Nine of the BAWTR capsules have been disassembled in the B&W hot cell facility. No abnormalities were observed in the visual examination or gamma scans of the 27 pins contained in the nine capsules.

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1. INTRODUCTION

This is the 16th progress report on a continuing program of experimental work on sol-gel and related methods for preparing mixed uranium-plutonium oxide fuels for fast reactor application. The program is sponsored by the U.S. Atomic Energy Commission under Contract No. AT(30-1)-3714. This report covers the period from May 1 to July 31, 1970.

The work program for the contract establishes several technical tasks, including fuel preparation and fabrication, reactor testing in both thermal and fast neutron fields, and analytical support. For FY-1970 the prime objectives were to (1) prepare 18 unencapsulated fuel pins with a smeared density of $82 \pm 2\%$ theoretical for irradiation in the EBR-II as part of a 37-pin subassembly to be shared with ORNL, (2) irradiate eight capsules in the BAWTR for from 1 to 81 days at linear heat ratings of 6 to 20 kW/ft, and (3) examine five of the irradiated BAWTR capsules in the B&W hot cell facility.

Twenty-one EBR-II pins—seven pellet, seven vipac, and seven sphere-pac—containing fully enriched UO_2 -20% PuO_2 have been fabricated. Difficulty was encountered in obtaining the specified smeared density with the vipac and sphere-pac pins. After consulting with ORNL and USAEC-RDT personnel, the specification was changed to a smeared density of $78 \pm 2\%$ theoretical. This change will have very little effect on the objectives of the experiment and will enable timely delivery of the finished pins.

All eight capsules scheduled for irradiation in the BAWTR during FY-1970 were completed. The exposure of an 81-day capsule at 6 kW/ft was terminated after 55 days because abnormal operating temperatures were indicated. The exposure of a 1-day capsule at 20 kW/ft was terminated after 8 hours when operation of the reactor was interrupted. Fifteen of 17 capsules in the series designed to show the differences in

restructuring kinetics of pellets and vibratory compacted spheres and shards had been irradiated by the end of the fiscal year.

Instead of completely examining five of the irradiated BAWTR capsules, 10 capsules were placed in the B&W hot cell facility to allow more efficient operation. Nine of these were disassembled during FY-1970, and no abnormalities were observed from visual examination and gamma scans of the 27 pins.

The primary objectives for FY-1971 are to prepare 13 additional EBR-II pins and to continue the post-irradiation examination of the BAWTR capsules consistent with the funds available. No additional BAWTR irradiations are scheduled. Progress in all technical areas of the program is reviewed in the following sections.

2. RESULTS AND CONCLUSIONS

2.1. Fuel Preparation

Two 100-gram batches of PuO_2 sol were prepared by a precipitation-peptization technique. Sufficient PuO_2 sol is now available for preparing the sol-gel microspheres required in FY-1971.

2.2. Fuel Fabrication

Seven pellet, seven vipac, and seven sphere-pac pins were prepared for the unencapsulated EBR-II bundle. The smeared densities were well within the revised specification of $82 \pm 2\%$ theoretical for the pellet pins and $78 \pm 2\%$ theoretical for the vipac and sphere-pac pins. The density specification was revised after the physical characteristics of the shards and microspheres were found to limit the achievable smeared densities. This revision will result in timely delivery of the finished pins without significantly changing the objectives of the irradiation experiment.

2.3. Irradiation Testing

Five additional capsules in the "time-for-restructuring" series were irradiated in the BAWTR. Four capsules were irradiated simultaneously for 30 days, one each at 6, 10, 15, and 20 kW/ft. The exposure of one capsule scheduled for a 1-day irradiation at 20 kW/ft was terminated after 8 hours when the BAWTR was unexpectedly shut down.

The 21 EBR-II fuel pins were Xe-tagged and welded. Detailed nondestructive testing of these pins is now in progress.

Nine of the capsules irradiated in the BAWTR have been disassembled in the B&W hot cell facility. Visual examinations and gamma scans of the 27 pins revealed no failures or detectable swelling. Metallographic examination will be made during the next quarter.

2.4. Analytical Support

A sample of refired coarse microspheres was characterized. The results showed that the fuel is within most specifications for fast reactor fuel.

3. FUEL PREPARATION (R. V. Carlson)

The FY-1971 fuel order includes about 1200 grams of coprecipitated powder and 600 grams of sol-gel microspheres containing 20% PuO_2 in UO_2 enriched to 93% ^{235}U for the EBR-II irradiation tests. This fuel will be used to fabricate 13 pins. Most of these pins will be loaded in the EBR-II bundle during scheduled outages, and the remainder will serve as archive samples or replacements for rejected pins.

3. 1. Preparation of PuO_2 Sol

Two 100-gram batches of PuO_2 sol were prepared by a precipitation-peptization technique.¹ The data are summarized in Table 3-1. No difficulties were encountered with either batch. Sufficient PuO_2 sol is now available for preparing the sol-gel microspheres required for the FY-1971 fuel order.

3. 2. Preparation of UO_2 Sol

The UO_2 sol prepared for the FY-1970 microsphere forming effort was of lower quality than desired.² Therefore, a short series of scouting experiments has been designed in an effort to find conditions to improve the quality of the UO_2 sol. The principal parameters to be varied are the urea and uranium concentrations during reduction. The equipment has been set up, and the experiments will be performed during the next quarter.

Table 3-1. Data for PuO_2 Sol Preparation

Batch No.	Stock solution		Pu input, g	4 M NH_4OH , l	No. washes	Final filtrate pH	NO_3^-/Pu mole ratio to peptize	Peptizing time, h	Baking time, h	Final NO_3^-/Pu mole ratio	Yield of denitrated powder, g	Pu recovered as sol, % ^(a)
	Pu, g/l	H^+ , M										
41	25.30	1.0	108.3	3.28	5	7.6	1.32	0.5	7.0	0.15	121.3	95.2
42	25.32	1.0	119.0	3.40	5	7.8	1.21	0.5	5.0	0.15	132.5	94.6

^(a) Assuming denitrated powder is 85 wt % Pu.

4. FUEL FABRICATION (A. H. Bremser)

Seven pellet, seven vipac, and seven sphere-pac pins have been prepared for the unencapsulated EBR-II bundle. During FY-1971, 13 additional pins will be prepared—three pellet, four vipac, and six sphere-pac.

4. 1. Fabrication of EBR-II Pellet Pins (L. J. Ferrell)

The EBR-II pellet pins were fabricated previously.³ The data for these pins are shown in Table 4-1.

4. 2. Fabrication of EBR-II Vipac Pins (D. L. Fowler)

Difficulty was encountered in fabricating EBR-II vipac pins to a fuel smeared density of $82 \pm 2\%$ theoretical. The packing efficiency for the 13.5-inch fuel length required in the EBR-II pins was less than observed for the 4.5-inch fuel lengths in the BAWTR pins. Several attempts were made to increase the packing efficiency by varying both the particle size distribution of the shards and the packing technique. However, it appeared that the packing efficiency was limited by the ratio of the fuel length to the pin diameter. Another factor that reduced the attainable fuel smeared density was the relatively low density of the particles themselves.

The fuel in six of the seven vipac pins was loaded sequentially in three 4.5-inch segments to a smeared density of $78 \pm 2\%$ theoretical (see section 1). The sequential loading technique resulted in shorter loading times at lower energy and therefore reduced the possibility of pin damage during fabrication. The data for these pins are shown in Table 4-2, and the smeared density of each segment is given in Table 4-3.

Table 4-1. EBR-II Pellet Pin Data

		Pin						
		D-12	D-14	D-9	D-17	D-16	D-6	D-4
UO ₂ blanket pellets	Length, in.	6.060	6.060	6.059	6.060	6.058	6.057	6.059
	Weight, g	37.08	37.14	37.05	37.16	37.16	37.17	37.06
Fiberfrax	Length, in.	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Bottom insulators	Length, in.	0.490	0.501	0.501	0.499	0.487	0.505	0.507
	Weight, g	2.982	3.113	3.116	3.086	3.018	3.078	3.096
Fuel	Length, in.	13.483	13.458	13.494	13.457	13.440	13.543	13.458
	Weight, g	75.00	74.74	75.01	74.76	74.46	75.41	74.82
	Smear dens.	82.73	82.92	82.78	82.79	82.70	82.83	82.50
Top insulators	Length, in.	0.506	0.502	0.500	0.496	0.498	0.502	0.501
	Weight, g	3.104	3.100	3.078	3.076	3.083	3.102	3.095
Fiberfrax	Length, in.	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Nickel reflector	Ident No.	D-7	D-4	D-3	D-6	D-17	D-1	D-21
Spring	Ident No.	D-7	D-4	D-3	D-6	D-17	D-1	D-21
Plenum sleeve	Ident No.	D-12	D-14	D-9	D-17	D-16	D-6	D-4

- Note:**
1. Diameters of the fuel pellets range from 0.2045 to 0.2050 inch.
 2. Diameters of the insulator and the blanket pellets are 0.214 ± 0.002 inch.

Table 4-2. EBR-II Vipac Pin Data

		Pin						
		D-22	D-20	D-24	D-25	D-21	D-5	D-18
UO ₂ blanket pellets	Length, in.	6.044	6.049	6.041	6.056	6.058	5.965	6.058
	Weight, g	36.93	37.23	37.01	37.10	37.03	36.99	37.15
Fiberfrax	Length, in.	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Bottom insulators	Length, in.	0.499	0.505	0.482	0.483	0.496	0.507	0.500
	Weight, g	3.096	3.074	2.980	3.002	3.058	3.046	3.079
Fuel	Length, in.	13.55	13.49	13.45	13.50	13.48	13.52	13.54
	Weight, g	71.00	70.58	70.50	68.96	70.66	70.98	71.07
	Smear dens.	78.06	77.93	78.08	76.09	78.09	78.21	78.19
Top insulators	Length, in.	0.509	0.494	0.480	0.496	0.500	0.494	0.504
	Weight, g	3.074	3.054	2.963	3.084	3.114	3.043	3.063
Fiberfrax	Length, in.	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Nickel reflector	Ident No.	D-22	D-20	D-24	D-25	D-8	D-5	D-18
Spring	Ident No.	D-22	D-20	D-24	D-25	D-8	D-5	D-18
Plenum sleeve	Ident No.	D-22	D-20	D-24	D-25	D-21	D-5	D-18

- Note: 1. Pin D-22 was loaded in one segment. All other pins were loaded in three segments.
2. Diameters of the insulator and the blanket pellets are 0.214 ± 0.002 inch.

Table 4-3. Smeared Density of Each Segment of Vipac Pins

Pin	Smeared density, % theoretical		
	Bottom segment	Middle segment	Top segment
D-20	78.03	78.29	77.39
D-24	78.42	77.48	78.31
D-25	75.40	76.03	76.44
D-21	77.35	77.33	79.72
D-5	79.28	77.83	77.44
D-18	78.04	77.70	78.70

4.3. Fabrication of EBR-II Sphere-Pac Pins (A. H. Bremser)

Difficulty was also encountered in fabricating EBR-II sphere-pac pins to a fuel smeared density of $82 \pm 2\%$ theoretical. The problem was apparently due to the physical characteristics of the microspheres—the particles had a wider size distribution than normal, and the density of the coarse microspheres was lower than normal.

Seven sphere-pac pins were loaded to a smeared density of $78 \pm 2\%$ theoretical (see section 1). To obtain this smeared density, the coarse microspheres had to be refired to 1550C for 3 hours in $N_2-6\% H_2$. The smeared density of the coarse bed increased from about 56% theoretical to about 60% theoretical after the refiring. In addition, the coarse spheres were separated into three size ranges—+60-40 mesh,* +40-30 mesh,* and +30 mesh*—to overcome the effects of the broad size distribution. The smallest spheres were loaded first and the largest were loaded last. The data for these pins are shown in Table 4-4.

*U.S. Standard sieve size.

Table 4-4. EBR-II Sphere-Pac Pin Data

		Pin						
		D-2	D-19	D-27	D-30	D-10	D-31	D-29
UO ₂ blanket pellets	Length, in.	6.104	6.047	6.053	6.056	6.058	6.043	6.058
	Weight, g	36.96	36.97	37.17	37.16	37.18	37.15	37.07
Fiberfrax	Length, in.	0.25	0.25	0.25	0.25	0.25	0.25	0.25
UO ₂ insulators	Length, in.	0.508	0.500	0.500	0.499	0.486	0.501	0.514
	Weight, g	3.056	3.100	3.084	3.112	3.000	3.109	3.040
Fuel	Length, in.	13.55	13.55	13.49	13.55	13.51	13.53	13.48
	Weight, g	71.19	71.14	71.19	71.20	71.10	71.17	70.87
	Sméared dens.	78.26	78.21	78.61	78.28	78.40	78.36	78.32
UO ₂ insulators	Length, in.	0.495	0.500	0.509	0.510	0.508	0.499	0.507
	Weight, g	3.017	3.106	3.063	3.130	3.068	3.084	3.088
Fiberfrax	Length, in.	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Nickel reflector	Ident No.	D-16	D-15	D-19	D-11	D-9	D-14	D-10
Spring	Ident No.	D-16	D-15	D-19	D-11	D-9	D-14	D-10
Plenum sleeve	Ident No.	D-2	D-19	D-27	D-30	D-10	D-31	D-29

5. IRRADIATION TESTING (E. N. Harbinson, C. J. Baroch)

The original gel-addition irradiation task⁴ was divided into three subtasks: (1) time required for inpile restructuring, (2) sorbed gas behavior, and (3) EBR-II irradiation. However, the second subtask has been eliminated from our current work program in order to direct the limited funds to the other two subtasks.

5.1. Time Required for Inpile Restructuring (E. N. Harbinson, R. E. Womack)

The effects of heat rate and time on the restructuring characteristics of sol-gel $\text{UO}_2\text{-PuO}_2$ spheres and of angular particles and pellets prepared from coprecipitated $\text{UO}_2\text{-PuO}_2$ powder are being evaluated under this subtask. Seventeen capsules containing three pins each—one vipac, one sphere-pac, and one pellet—were scheduled to be irradiated in the BAWTR. However, the scheduled exposures at 10 and 15 kW/ft for 81 days have been deferred indefinitely because of funding limitations. Sixteen capsules have been irradiated for from 8 hours to 55 days at linear heat ratings of 6 to 20 kW/ft. The exposure of one capsule (GA-9) was terminated after 5 days because of indicated abnormal temperatures, and another capsule (GA-12) was irradiated in its place. Two capsules contained spherical sol-gel particles prepared by ORNL and B&W in order to compare their irradiation behavior. The operating conditions for the 16 capsules are shown in Table 5-1.

Five capsules (GA-5, GA-7, GA-16, GA-18, and GA-19) were irradiated during this quarter. Capsule GA-16, containing ORNL spheres, B&W spheres, and pellets, was scheduled for a 1-day irradiation at 20 kW/ft. However, after 8 hours of full-power operation, the BAWTR was shut down unexpectedly. The capsule was removed at that time to avoid exposure at the lower heat ratings that would occur as the BAWTR was returned to full power. The primary purpose of this irradiation—comparison of the irradiation behavior of ORNL and B&W microspheres—

was met. In addition, since the behavior of B&W spheres and pellets during a 1-day exposure at 20 kW/ft was compared in a previous capsule (GA-4), the early termination of the exposure of capsule GA-16 will provide additional data.

Table 5-1. Operating Conditions for BAWTR Capsules

Capsule No.	Exposure time, days	Linear heat rate, kW/ft		NaK temperature, F	
		Design	Actual	Design	Actual
GA-2	9	15	15.3-16.7	1100	1080
GA-4	1	20	17.2-19.6	1150	965-1045
GA-5 ^(a)	30	20	17.5-19.0	1150	1065-1080
GA-6	9	20	17.0-20.0	1150	1060-1120
GA-7 ^(a)	30	15	13.5-16.5	1100	975-1180
GA-8 ^(b)	3	20	17.0-19.8	1150	1050-1140
GA-9 ^(c)	5	6	6.2-7.3	1040	1140-1225
GA-10	3	20	20.0-22.0	1150	1120-1160
GA-11	1	15	15.5-17.0	1100	1040-1060
GA-12 ^(d)	55	6	4.8-6.0	1040	1015-1025
GA-13 ^(b)	3	15	15.2-16.1	1100	1140-1170
GA-14 ^(b)	3	10	7.5-10.3	1080	950-1110
GA-15 ^(b)	3	6	5.0-6.5	1040	1140
GA-16 ^(e)	0.33	20	17.5-22.2	1150	1090-1200
GA-18 ^(a)	30	10	8.2-9.8	1080	975-1035
GA-19 ^(a)	30	6	7.0	1040	1190

(a) Capsules GA-5, -7, -18, and -19 were irradiated simultaneously.

(b) Capsules GA-8, -13, -14, and -15 were irradiated simultaneously.

(c) Capsule GA-9 was to be irradiated for 81 days, but was removed after 5 days of operation because of indicated abnormal temperatures.

(d) Irradiation suspended after 55 days of operation because of indicated abnormal temperatures.

(e) Irradiation suspended after 8 hours because of unexpected reactor shutdown.

Capsules GA-5, -7, -18, and -19 were irradiated simultaneously for 30 days, one each at 6, 10, 15, and 20 kW/ft. This was the second series of four capsules that were irradiated simultaneously.

The post-irradiation examination of 10 BAWTR capsules is under way in the B&W hot cell facilities. Nine of these have been disassembled. Visual examinations and gamma scans of the 27 pins revealed no failures, swelling, or other abnormalities. Detailed metallographic examinations will be initiated during the next quarter.

5.2. EBR-II Irradiations (E. N. Harbinson, J. W. Ewing)

The primary objective of the EBR-II irradiations is to obtain data on the operational characteristics of particulate fuels irradiated in a fast reactor. The effect of heat rate and burnup on the overall performance of sol-gel spherical particles and of angular particles and pellets prepared from coprecipitated UO_2 -20% PuO_2 powder will be compared and evaluated. This subtask included the irradiation of 30 fuel pins in a 19-pin encapsulated subassembly in row 7 of the EBR-II, and the irradiation of 28 unencapsulated pins in a 37-pin subassembly to be shared with ORNL. However, irradiation of the encapsulated subassembly has been postponed indefinitely. The heat rating for the unencapsulated fuel pins will be approximately 14 to 16 kW/ft.

The 21 fabricated fuel pins (see section 4) were Xe-tagged and welded. The welding chamber available for this work is designed so that only one fuel pin can be evacuated, tagged, and welded during a run. Therefore, it was decided to form the xenon transfer system and the welding chamber into an integral system. A diagram of the Xe-tagging and welding apparatus is shown in Figure 5-1, and a photograph of the xenon transfer system is shown in Figure 5-2. The gas handling system permits the removal of metered amounts of the Xe-tagging gas from its container and the insertion of the gas into the fuel pin with a small probability of waste or contamination. The main feature of the system is a small chamber that is sealed on opposite sides by rubber septa. A gas syringe fitted with a 30-inch needle is used to remove the desired quantity of xenon from the double-septum chamber. Subsequently, the second septum is pierced and the delivery end of the needle is directed into the loaded fuel pin held in the welding chamber. This integral system

allows the placement of the end cap and the onset of welding within about 10 seconds after the xenon has been discharged into the fuel pin.

The results of tagging and welding eight simulated EBR-II pins showed that each pin contained an average of 0.97 cc of xenon. The range of values was from 0.90 to 1.01 cc of xenon. These values compare favorably with the target value of 1.00 cc xenon per pin.

Each of the 21 fuel pins is described briefly in Table 5-2. Detailed nondestructive testing and inspection of these pins is in progress and will be completed early next quarter.

Table 5-2. Description of EBR-II Fuel Pins

<u>Pin No.</u>	<u>Fuel type</u>	<u>Smear density, % theoretical</u>	<u>Target peak burnup, MWD/t $\times 10^{-3}$</u>
D-2	Sphere-pac	78.26	75
D-4	Pellet	82.50	50
D-5	Vipac	78.18	100
D-6	Pellet	82.83	NA ^(a)
D-9	Pellet	82.78	75
D-10	Sphere-pac	78.40	50
D-12	Pellet	82.73	100
D-14	Pellet	82.92	100
D-16	Pellet	82.70	NA ^(a)
D-17	Pellet	82.79	75
D-18	Vipac	78.15	50
D-19	Sphere-pac	78.21	75
D-20	Vipac	77.90	100
D-21	Vipac	78.03	75
D-22	Vipac	77.99	75
D-24	Vipac	78.07	NA ^(a)
D-25	Vipac	76.05	100
D-27	Sphere-pac	78.61	75
D-29	Sphere-pac	78.32	100
D-30	Sphere-pac	78.28	100
D-31	Sphere-pac	78.36	100

^(a)NA = not assigned.

Figure 5-1. Diagram of Xenon Tagging and Welding Apparatus

Figure 5-2. Photograph of Xenon Tagging System

6. ANALYTICAL SUPPORT (D. H. Schmitt)

6.1. Characterization of EBR-II Fuel (R. H. Dodd, R. J. Boden)

The characterization data for the EBR-II fuel and insulators were presented previously.⁵ However, the coarse microspheres have been refired since the previous data were obtained (see section 4.3). The characterization results for the refired microspheres are summarized in Tables 6-1 and 6-2. The results show that the impurity levels are within most specifications for fast reactor fuel.

Table 6-1. EBR-II Coarse Microsphere Characterization^(a)

Analysis	Result
Pu/(Pu+U), wt %	20.22 ± 0.08
²³⁵ U content, wt %	92.68 ^(b)
O/M, atom ratio	1.989 ± 0.007
Moisture, ppm oxide	14.9 ± 1.9
Sorbed gas, cc/g	0.033 ^(c)
Density, % theor	95
Nitrogen, ppm metal	10.5 ± 5.8
Carbon, ppm metal	11 ± 5
Chloride, ppm metal	6.5 ± 2.2
Fluoride, ppm metal	2.2 ± 0.2

(a) Errors are for 95% confidence limits on the mean.

(b) ²³⁵U content determined by AVCO.

(c) Sorbed gas analysis performed on a mixture of 73 wt % coarse and 27 wt % fine microspheres in order to simulate the fuel composition in a pin.

Table 6-2. Trace Metallic Impurities in EBR-II
Coarse Microspheres (a)

Element	Concentration, ppm metal	Element	Concentration, ppm metal
Aluminum	625	Magnesium	16
Beryllium	<0.5	Manganese	6
Bismuth	<0.5	Nickel	<50
Boron	<0.5	Silicon	100
Cadmium	<0.5	Silver	<0.5
Calcium	50	Sodium	<10
Chromium	130	Tin	20
Copper	<5	Titanium	25
Iron	180	Vanadium	<5
Lithium	<1	Zinc	<50

(a) Values given are the mean of three determinations.

6.2. In-Process Control for EBR-II Fuel Preparation (R. H. Dodd)

A sample from the shipment of fully enriched uranyl nitrate to be used in preparing the FY-1971 EBR-II fuel order was analyzed and accepted. Other samples will be analyzed as they are received.

REFERENCES

- ¹ Carlson, R. V., Preparation of Plutonia-Urania Fuels by a Sol-Gel Process, Babcock & Wilcox, BAW-3714-10, pp 22 - 34, Lynchburg, Virginia, November 1969.
- ² Gel-Addition Process Chemical Studies, Quarterly Progress Report No. 15, February - April 1970, Babcock & Wilcox, BAW-3714-17, pp 3-2 to 3-5, Lynchburg, Virginia, June 1970.
- ³ BAW-3714-17, pp 4-1 to 4-2.
- ⁴ Gel-Addition Process Chemical Studies, Quarterly Progress Report No. 7, February - April 1968, Babcock & Wilcox, BAW-3714-7 p 35, Lynchburg, Virginia, July 1968.
- ⁵ BAW-3714-17, pp 6-8 to 6-11.

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