199
8/10/81
E.H.

①

B6267

D 2917

DOE/ET/34215-18
XN-NF-555
UC-78

MASTER

Fuel-Performance Improvement Program

Process Development and Fabrication for Sphere-Pac Fuel Rods

June 1981

EXXON NUCLEAR
COMPANY, Inc.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

Work on this program is performed for the
UNITED STATES DEPARTMENT OF ENERGY

by

CONSUMERS POWER COMPANY and EXXON NUCLEAR COMPANY, INC.

Under Contract DE-AC02-76ET34215

and by

PACIFIC NORTHWEST LABORATORY, *Operated by* BATTELLE MEMORIAL INSTITUTE;

Under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available from

National Technical Information Service

United States Department of Commerce

5282 Port Royal Road

Springfield, Virginia 22151

Price: Printed Copy \$____; Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-255	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

FUEL-PERFORMANCE IMPROVEMENT PROGRAM

Process Development and Fabrication for Sphere-Pac Fuel Rods

June 1981

**R. K. Welty
M. H. Campbell
Exxon Nuclear Company, Inc.
Richland, Washington 99352**

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report was prepared for the U.S. Department of Energy
by Exxon Nuclear Company, Inc. under Contract
DE-AC02-76ET34215.

ABSTRACT

The Fuel Performance Improvement Program (FPIP) is a U. S. Department of Energy (DOE) sponsored program involving Consumers Power Company, Exxon Nuclear Company, and Pacific Northwest Laboratory (PNL). The purpose of the program is to evaluate LWR fuel concepts such as sphere-pac that may be more resistant to failure from pellet-cladding interaction (PCI) during power increases than standard pellet fuel. A more PCI-resistant fuel would offer extended burnup potential and, hence, improved uranium utilization.

Uranium fuel rods containing sphere-pac fuel have been fabricated for in-reactor tests and demonstrations. A process for the development, qualification, and fabrication of acceptable sphere-pac fuel rods is described. Special equipment to control fuel contamination with moisture or air and the equipment layout needed for rod fabrication is described and tests for assuring the uniformity of the fuel column are discussed. Fuel retainers required for sphere-pac fuel column stability and instrumentation to measure fuel column smear density are described. Results of sphere-pac fuel rod fabrication campaigns are reviewed and recommended improvements for high throughput production are noted.

ACKNOWLEDGMENTS

This report summarized work conducted for the U. S. Department of Energy through the joint efforts of Consumers Power Company, Exxon Nuclear Company, Inc. (ENC), and Pacific Northwest laboratory (PNL).*

The authors acknowledge the guidance of the Program Manager, C. E. Crouthamel, ENC. The individual contributions of F. L. Lewis, K. Deery, and P. G. Sarafian of ENC during design, process development, and fabrication are gratefully acknowledged, and the assistance of M. D. Freshley and J. O. Barner, PNL, during preparation of this manuscript.

The authors also acknowledge the contributions of the Process Engineering, Inspection, Quality Control, Quality Assurance, and Shipping Departments at ENC, and the Chemical Analysis and Non-Destructive Analysis Departments at the Hanford Engineering Development Laboratory (HEDL).

* PNL is operated by Battelle Memorial Institute.

SUMMARY AND CONCLUSIONS

The Fuel Performance Improvement Program (FPIP) is a U. S. Department of Energy (DOE) sponsored program involving Consumers Power Company, Exxon Nuclear Company, and Pacific Northwest Laboratory (PNL). The purpose of the program is to evaluate LWR fuel concepts that may be more resistant to failure from pellet-cladding interaction (PCI) during power increases than standard pellet fuel. A more PCI-resistant fuel would offer extended burnup potential and, hence, improved uranium utilization.

The purpose of the activities described in this report was to fabricate sphere-pac fuel rods for in-reactor tests and demonstration irradiations in support of the FPIP. To accomplish this, the basic fuel loading technology developed at Oak Ridge National Laboratory was utilized. However, considerable process development and scale-up work were required to fabricate sphere-pac rods in accordance with commercial quality assurance standards and in quantities needed for the FPIP.

Some of the major considerations that were addressed during process development and fuel rod fabrication were 1) moisture or air contamination control inside the sphere-pac rods, 2) fuel column uniform packing density and stability during and after fabrication, and 3) special instrumentation to measure the smear density of the fuel column.

- 1) Special care was taken throughout processing to avoid moisture pickup by the spheres. There was a concern that the large surface

area of the UO_2 microspheres would result in a high moisture content in the fuel. Rigid moisture control was maintained throughout the process with the hydrogen content in the fabricated rods averaging 0.3 ppm hydrogen, well below the hydrogen limit of 1.5 ppm on a fuel weight basis. Temporary end cap seals protected the loaded sphere-pac rods from moisture adsorption before final end closure welding.

- 2) Sphere-pac rod fuel retainers were designed and tested. These retainers (thin zircaloy discs) located at each end of the sphere-pac fuel column were needed to prevent microspheres from intruding into the upper plenum area or under the bottom insulator disc.
- 3) A gamma densitometer (Densigage) was used to measure the smear density along the length of the sphere-pac fuel column. These measurements were used for process control, whereas neutron radiographs, made at the Hanford Engineering Laboratory (HEDL) in the TRIGA Reactor, served as a visual check of the loading of the fuel column.

The equipment, operating parameters, and optimized loading procedures that were developed and described in this report permitted fabrication of sphere-pac rods with an average fuel column density of $87 \pm 1\%$ TD which did not have any localized densities below 84% TD within any 5.0 mm axial length.

Five instrumented sphere-pac rods were fabricated for the Halden tests (HBWR Series H-2, H-3, H-4), and 42 full-length and 18 segmented fuel rods were fabricated for the demonstration irradiations in the Big Rock Point Reactor (BRPR Series S-2, S-3, and S-4). The average smear densities of

the HBWR fuel rods ranged from 87.6 to 88.5% TD with a standard deviation of 0.89 to 1.1% TD. The 42 full-length BRPR fuel rods averaged 86.8% TD with a standard deviation of 0.28% TD. The 18 segmented BRPR fuel rods averaged 86.7% TD; the standard deviation was 0.16% TD.

The activities described in this report were implemented to fabricate sphere-pac fuel rods for the FPIP. As such, the process was of a pilot plant scale. Commercial production of sphere-pac rods, especially rods longer than 2 meters, will require additional process and hardware development.

Specific recommendations to permit increased production rates are:

- 1) Improved microsphere feeders to provide more constant feed rates.
- 2) An improved feeder mechanism to assure equal mixing of the three microsphere size fractions per unit time during rod loading.
- 3) A modified mounting clamp for the rods during vibratory compaction to eliminate low density areas in the fuel rods.
- 4) An improved fuel retainer to prevent the small sized microspheres from intruding into the plenum area of the fuel rod.
- 5) An improved temporary end cap that is more economical to fabricate and easier to operate.

x

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	i
ACKNOWLEDGEMENTS	ii
SUMMARY AND CONCLUSIONS	iii
1.0 INTRODUCTION	1
2.0 PROCESS DEVELOPMENT	3
2.1 EQUIPMENT DESCRIPTION	3
2.1.1 Loading System	3
2.1.2 Microsphere Feeders	5
2.1.3 Fuel Rod Vibrator Assembly	9
2.1.4 Recirculating Gas System	9
2.1.5 Microsphere Aspiration System	9
2.2 LOADING PROCEDURE PROCESS DEVELOPMENT	13
2.3 LOADING SEQUENCE	15
2.4 SPHERE-PAC DENSITY MEASUREMENT	17
2.5 NEUTRON RADIOGRAPHY	20
2.6 ROD HANDLING TECHNIQUES BEFORE WELDING	21
2.7 SPECIAL ROD HARDWARE DESIGN AND TESTING	23
2.8 PRESSURIZED SPHERE-PAC ROD END CAP WELDING	29
2.9 QUALITY CONTROL STANDARDS FOR SPHERE-PAC FUEL RODS	30
3.0 FUEL ROD FABRICATION	33
3.1 HALDEN BOILING WATER REACTOR ROD FABRICATION	33
3.2 BIG ROCK POINT REACTOR ROD FABRICATION	37
4.0 RECOMMENDATIONS	44
5.0 REFERENCES	47

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2.1 Schematic Layout of Sphere-Pac Loading System	4
2.2 Overall View of the Sphere-Pac Loading System	6
2.3 Microsphere Feeder Arrangement	7
2.4 Microsphere Feeder Assembly (Fine Fraction)	8
2.5 Fuel Rod Vibratory Loading Assembly for Sphere-Pac Rods . .	10
2.6 Vibrator Assembly	11
2.7 Vacuum Filter for Aspirating Microspheres	12
2.8 Densigage	18
2.9 Neutron Radiographs of Two Typical BRPR Series S-2 Segmented Rods	22
2.10 Temporary End Cap Seal for Sphere-Pac Rods	24
2.11 Typical Assembly of Temporary End Cap Seal	25
2.12 Upper Fuel Retainer	27
3.1 Fabrication and Inspection Steps for Sphere-Pac Fuel Rod Fabrication	34
3.2 Measured Density of Sphere-Pac Rods H2UCS033, H3UCS034, H2SPS040, H2XXS041, H2XXS042 (Normalized)	38

LIST OF TABLES

<u>Table</u>	
2.1 Microsphere Size Distribution for HBWR and BRPR Sphere-Pac Rods	14
3.1 HBWR Series H-2, H-3, and H-4 Sphere-Pac Rod Fabrication Variables	36
3.2 Calculated and Measured Average Densities for BRPR Sphere-Pac Rods	40

1.0 INTRODUCTION

The Fuel Performance Improvement Program (FPIP) is a U. S. Department of Energy (DOE) sponsored program involving Consumers Power Company, Exxon Nuclear Company, and Pacific Northwest Laboratory (PNL). The purpose of the program is to evaluate LWR fuel concepts that may be more resistant to failure from pellet-cladding interaction (PCI) during power increases than standard pellet fuel. A more PCI-resistant fuel would offer extended burnup potential and, hence, improved uranium utilization. Early in the program, a state-of-the-technology report⁽¹⁾ identified several fuel design modifications with potential for improving PCI performance. One of these, packed-particle fuel, is of interest because localized cladding deformation is expected to be significantly reduced with this type of fuel.⁽²⁾

A subsequent report, assessment of fuel concepts,⁽³⁾ presented the potential advantages of packed-particle fuels and led to the inclusion of a small number of packed-particle fuel rods (vipac) in the HBWR Series H-1 and BRPR Series S-1 irradiations in the Halden Boiling Water Reactor (HBWR) and the Big Rock Point Reactor (BRPR), respectively.

Sphere-pac is another form of packed-particle fuel that is expected to exhibit better performance than vipac because of an anticipated decrease in localized fuel-cladding mechanical interaction and, hence, lower local stresses on the cladding during irradiation.

Oak Ridge National Laboratory produced the UO_2 microspheres that were needed to fabricate the sphere-pac rods for the FPIP irradiations.

Five sphere-pac fuel rods were produced for the irradiation tests in the Halden Boiling Water Reactor (HBWR) and 42 full-length and 18 segmented sphere-pac fuel rods were fabricated for the Big Rock Point reactor (BRPR) demonstration irradiations.

This report describes the process development activities (Section 2) and fuel fabrication procedures (Section 3) that were used to make these rods.

Finally, Section 4 recommends areas where future work would be most fruitful if program results favor commercialization of the sphere-pac concept for LWR application.

2.0 PROCESS DEVELOPMENT

This section describes the equipment, loading procedures, fuel column smear density measurements, special rod hardware and rod handling techniques before welding, pressurized end-cap welding and quality control standards developed to fabricate sphere-pac rods for the FPIP.

2.1 EQUIPMENT DESCRIPTION

The equipment used to load sphere-pac fuel rods was installed in the high bay area of Exxon Nuclear's Engineering Laboratory Operations Building. The major items of equipment were specifically purchased and assembled for this program. Certain specialized items, such as the microsphere feeders, were obtained from the Oak Ridge National Laboratory.

A description of the sphere-pac loading system and the equipment used is as follows:

2.1.1 Loading System

Figure 2.1 is a schematic drawing of the loading system showing the relationship between the various items of equipment. The loading equipment was enclosed in a stainless steel glovebox with a recirculating dry helium atmosphere. Glove portals were located directly in front of the feeders to facilitate the loading operation. The fuel rods were held in position by clamps on the vibrator assembly that was located outside of the glovebox and the rods penetrated the glovebox through a rubber sphincter seal. The details are shown in the expanded portion of Figure 2.1.

Vibratory feeders were used to meter the flow of the microspheres as they were loaded into the cladding tubes. Two feeders are required, one for the fines, and one for the coarse and medium fractions. The microspheres were fed into a stainless steel funnel inserted into the

Figure 2.1 Schematic Layout of Sphere-Pac Loading System

top of the tube where the metered spheres co-mingle as they enter the tube. A moisture probe was used to monitor the water content of the recirculating helium. Whenever the water moisture levels in the glovebox rose above a dewpoint of -46°C , operations were suspended until the helium drying system decreased the moisture level to a dewpoint of -50°C .

Lead bricks under the feeders were used to dampen vibrations from the feeders and fuel rod vibrators. This helped prevent changes in the microsphere feed rate calibrations due to vibration.

Figure 2.2 is a photograph of the general front view of the equipment and provides an overall spacial view of the equipment arrangement. Materials and equipment were passed into and out of the glovebox through the air lock located on the left. The photograph also shows the apparatus used to dry the helium, to the left, below the airlock.

2.1.2 Microsphere Feeders

Vibrating trough feeders (Figure 2.3) activated by magnetic vibrators (Syntron-Model F-TOC) were used to meter the microspheres into the fuel rods. The coarse and medium fractions were fed from separate troughs attached to a single vibrator while the fine fraction of microspheres was fed from an independently controlled feeder as shown in the typical equipment arrangement of Figure 2.4. The flow rate of the microspheres was controlled by an orifice opening below the feed hopper that metered the microspheres into the vibrating trough. Feeder calibration was accomplished by preweighing the amount of each fuel fraction required in the finished rod and recording the time required to completely empty the feed hoppers and troughs. Rod loading with the desired mix of particle sizes was assured by adjusting the orifice openings with the micrometer above the orifice until all three size fractions emptied from the feed troughs at the same time.

Figure 2.2 Overall View of the Sphere-Pac Loading System

Figure 2.3 Microsphere Feeder Arrangement

Figure 2.4 Microsphere Feeder Assembly (Fine Fraction)

2.1.3 Fuel Rod Vibrator Assembly

A sketch of the vibrator assembly used for loading and compacting the microspheres into the fuel rods is shown in Figure 2.5. Two air driven vibrators were attached at 60 degrees from the horizontal to the outer surface of the angle iron support; one at 1/3 height and the other at 2/3 height. These air vibrators (springless vibrators, 25.4 mm diameter piston, manufactured by the Cleveland Vibratory Company) create a low amplitude vibration. Small air vibrators (VIBCO Vibrator Company, Model BB190) were also attached to the angle iron support to assist compaction during filling of the rods. The equipment assembly is shown in Figure 2.6.

2.1.4 Recirculating Gas System

The protective dry helium atmosphere, in which the sphere-pac rods were loaded, was recirculated through a gas treatment apparatus (Dri-Train, Model HE-193-1, manufactured by the Vacuum Atmosphere Corporation). Moisture in the helium was controlled within a dewpoint range of -46°C to -50°C as monitored with a Parametrics Model 1000 hygrometer.

2.1.5 Microsphere Aspiration System

Excess microspheres could be removed from the fuel rods using a small aspiration-filter system. Figure 2.7 shows the vacuum filter system used during fabrication of the sphere-pac rods. The filter box, used to remove the microspheres picked up in the aspirator-filter system, was located inside the glovebox and the microspheres were simply recycled back to the feed stock for reuse.

Figure 2.5 Fuel Rod Vibratory Loading Assembly for Sphere-Pac Rods

Figure 2.6

Vibrator Assembly

Figure 2.7 Vacuum Filter for Aspirating Microspheres

2.2 LOADING PROCEDURE PROCESS DEVELOPMENT

Two techniques for loading a fuel rod with microspheres have been used in the past by ORNL, infiltration and simultaneous feeding.⁽⁴⁾

Infiltration is a technique where the full amount of coarse and medium size fractions are loaded simultaneously into the fuel rod. The fine spheres are then slowly fed into the top of the vibrating fuel column. Continued vibration causes the fine fraction to infiltrate and fill in the interstices left between the coarse and medium size spheres in the fuel column. This method was not considered suitable for fabrication of commercial reactor fuel rods because of the time required to load a fuel rod (approximately one hour for a 1.8 meter long rod).

For the simultaneous feeding technique, all three microsphere sizes are fed into the cladding tube at the same time using a metered rate of feed for control. The advantage of this technique is a reduction in the loading time required as compared to the infiltration method described above. This latter technique was selected for the FPIP sphere-pac loading development.

For the initial loading tests, the coarse fraction of the three component microsphere mixture was varied between 55 and 60 wt%, the medium fraction between 20 and 30 wt%, and the fine fraction between 15 and 25 wt% to determine the optimum size composition. No appreciable differences were observed in the average fuel column density over these size ranges, although it is possible that the limited range of operating parameters of the equipment did not permit delineation of small effects. The microsphere size distribution and mixture formulation selected for the HBWR and BRPR sphere-pac rods, as a result of these tests, is listed in Table 2.1. This three component mix is a slight modification of the original ORNL⁽⁴⁾ recommendation.

Table 2.1 Microsphere Size Distribution
for HBWR and BRPR Sphere-Pac Rods

<u>Fraction</u>	<u>Diameter, μm</u>	<u>Wt%</u>
Coarse	1150-1410	58
Medium	280-320	20
Fine	< 44	22

All of the process development tests conducted for the HBWR rods used the same general vibratory compaction technique. The microsphere feeders (Section 2.1.2) were calibrated such that all three of the required preweighed microsphere size fractions emptied into the fuel rod simultaneously. During filling, the small VIBCO vibrators (Section 2.1.3) attached to the fuel rod holder were activated to aid in the distribution of the microspheres within the rod. After the predetermined amount of fuel was loaded, a 1000 g weighted follower rod was placed on top of the fuel column and the rod was vibrated more vigorously with the Cleveland vibrators (Section 2.1.3) for a preset time period. After this compaction time, the vibration was stopped and the fuel column length was measured with a calibrated depth gauge. If the fuel column was too long, the follower rod was reinserted in the fuel rod and the vibration was continued until the desired fuel column length was attained (in no case was the fuel column too short, i.e., >89% TD). As long as the feed rates of the microspheres are held consistent, fuel rods can be loaded routinely to the desired smear density using this technique.

The results of these process development tests were analyzed to select operating parameters for fabricating the HBWR fuel rods (Table 3.1). Parameters were selected that permitted loading a fuel rod in the shortest

time period while achieving the fuel column density specification requirements, i.e., $87 \pm 1\%$ TD average with no localized densities below 84% TD within a 5 mm axial length.

The frequency, amplitude and acceleration of the vibrators were not measured during this program. The equipment was standardized, in that the same air pressure was used in the vibrators for all fuel rod loading.

2.3 LOADING SEQUENCE

The microsphere size distribution and loading procedure described in Section 2.2 gave consistent results in obtaining the required overall smear density of $87 \pm 1\%$ TD, but usually resulted in variable densities (70-80% TD) within the top 2.5 mm of the HBWR fuel rods. This density variation occurred because the three microsphere size fractions trailed off at different rates when the very last of the fuel emptied from the feeders. The low density regions were caused by either an excess or lack of fines.

To address this problem, an overfill loading technique was developed before fabrication of the sphere-pac fuel rods for BRPR. This was accomplished by loading an excess ($\sim 1.5\%$) of the fuel required to fill the rod to the desired fuel column length and removing the excess by aspiration after loading.

During rod loading, the coarse and medium size microspheres were fed into the fuel rod from separate troughs attached to a single vibrator. The fines were simultaneously fed into the tube from an independently controlled vibrator. The feed rates for the three size fractions were calibrated so that the loading rate of each size fraction was constant per unit of time and the microspheres emptied from the feeders. The time required to load the microspheres into the 1.8 m long BRPR rod was 90 seconds. The VIBCO vibrators attached to the fuel rod support channel

operated continuously at a low energy (20 psi) input during fuel loading. After the microspheres were loaded into the tube, these pneumatic vibrators were activated for an additional 30 seconds. A 1000 g follower rod was then inserted on top of the fuel column and the Cleveland pneumatic vibrators attached to the rod support channel were activated at a moderate energy (80 psi) input for 60 seconds to achieve the specified density of $87 \pm 1\%$ TD. A plenum depth gauge was then inserted into the fuel rod to check for the correct plenum length. The excess microspheres in the rod were aspirated from the rod using a small vacuum source attached to a filter box (Section 2.1.5). After adjusting the plenum length, the insulator disc and plenum spring were placed on top of the fuel column, the rod was sealed with a temporary end cap, and the fuel density within the rod was measured on the Densigage (Section 2.4). If there were no low density regions in the fuel column, the rod was returned to the loading glovebox, the plenum spring removed, and the fuel retainer was inserted on top of the insulator disc (Section 2.7). This could only be done after density measurement due to the interference fit between the retainer and the cladding. If there were any low density regions in the fuel column, the rod was revibrated for an additional 30-60 seconds at 80 psi and rechecked by the above procedure. (The lower fuel retainer disc was inserted from the bottom end, just prior to bottom end cap welding, and seated using a full rod-length depth gauge.)

All the FPIP fuel rods loaded in this manner had specified smear densities of 86.5-87.0% TD over the entire length of the sphere-pac fuel column. The microspheres that were removed from the rod by aspiration were easily separated by sieving and recycled back into the feed stock.

Aspiration can also be used to rework rods that have discontinuities in the fuel column, i.e., low density regions. The microspheres can be removed by aspiration to just below the variable density region detected by the Densigage and then the rod can be refilled as described above. Two developmental rods were tested by this method, wherein fuel regions that were approximately 71% TD were removed and the rods were refabricated to meet the acceptance density specification.

2.4 SPHERE-PAC DENSITY MEASUREMENT

The average smear density for a sphere-pac rod can be readily calculated from the total weight of microspheres contained and the measured fuel column height. Such averaged values, however, do not provide information on localized density variations. Earlier experience with particle fuel⁽⁵⁾ had shown that there can be discrete regions along the length of the fuel column where the density can be substantially lower than the average smear density. Density discontinuities in the fuel column are not acceptable because the local power distribution in the rod and adjacent fuel rods is affected, and the fuel thermal conductivity in the low density region is reduced.

A gamma densitometer method was used to evaluate axial density variations in the sphere-pac rods. A Densigage^(a) instrument had been developed earlier to sort UO₂ fuel pellets and this instrument was modified for scanning sphere-pac rods. For this application, the Densigage measured the sphere-pac column density by determining the gamma ray attenuation of a collimated monoenergetic Cs¹³⁷ gamma beam (0.667 Mev). A 50.8 mm diameter by 50.8 mm thick sodium iodide (NaI) crystal was used for the detector. The principal features of the Densigage are shown in Figure 2.8. The

(a) Developed by ENC.

Figure 2.8 Densigage

gamma source and detector were housed inside lead bricks (top center in the photograph). An adjustable fuel rod holding trough was positioned horizontally through the gamma source housing and at right angles to the gamma beam. A collimator window 4.95 mm long and 1.27 mm wide was orientated with the length dimension of the window parallel to and centered on the fuel rod axis. Density determinations were made by counting for 10 seconds at 12.7 mm intervals along the full length of each rod. The instruments in the bottom of the photograph (Figure 2.8) are the electronics system, printer, and calculator. The calculator was programmed to print out the instantaneous density at each measurement interval and the average density up to that point.

At the start of the program, the Densigage was calibrated to measure sphere-pac column densities directly. Two methods were used to obtain the calibration.

- 1) Sixteen full-length sphere-pac rods for which the average smear density had been calculated using mensural, mass, and volume data, were analyzed on the Densigage. Measurements were made at the rod centerline and attenuation data collected at 12.7 mm axial intervals. These readings were averaged to obtain an "average" fuel density. The Densigage average was found to be higher than the calculated mass/volume value. Because the mass/volume data was finite, a bias adjustment was made to the Densigage readings. The adjustment corrected for the average difference in densities between the Densigage and the mass/volume readings after a statistical

treatment was made to the Densigage measurements to eliminate discrepant observations. The resulting correction to the Densigage data readings was -1.97%.

- 2) Ten specially prepared fuel pellets with low porosity were characterized dimensionally and their geometric density calculated. These pellets were placed inside typical cladding used for BRPR sphere-pac fuel and their densities measured on the Densigage. The average difference between the Densigage measurements and the geometric pellet measurements resulted in a -1.84% TD difference between the Densigage and the measured pellet densities.

An average value of the correction factors, i.e., -1.97%, was used for correcting actual sphere-pac fuel densities measured with the Densigage.

Another factor to be considered when making Densigage type measurements is that the indicated value at any given point on the axis of the rod can vary by rotation. This can be caused by a slight misalignment of the center of the rod axis with the Densigage collimeter window or an azimuthal density variation in the sphere-pac column. If a low density region was identified from the Densigage reading, the rod was rotated and the density measurement was repeated to establish the lowest density value. If the localized density measurement still indicated a value below 84% TD, the fuel rod was reworked.

2.5 NEUTRON RADIOGRAPHY

Neutron radiography was also used to help evaluate the smear density of the loaded sphere-pac fuel rods. Each sphere-pac rod fabricated

for irradiation in the FPIP was radiographed using the 240KW TRIGA reactor located in the Neutron Radiographic Facility of the Hanford Engineering Development Laboratory. These examinations served to identify any variations in the apparent density of the sphere-pac fuel column by a method independent of the Densigage.

The radiographic facility used a beam tube 6.10 m long that was tapered from a 432 mm x 1016 mm exposure area to a 25.4 mm x 25.4 mm source aperture located near the core periphery. The fuel rods were positioned between the exposure area and an evacuated film cassette during a 60 minute exposure to thermal neutrons. The film cassette contained a gadolinium screen and Kodak Type SR film that were exposed simultaneously. Rods were radiographed in both the 0° and 90° orientations producing high quality radiographs.

Figure 2.9 is a print of a neutron radiograph showing a typical BRPR Series S-2 segmented sphere-pac rod with an enlarged section to better show the packing array of the microspheres. The radiograph readily shows the individual large microspheres. The small spheres could not be individually resolved. The radiographs did not show any significant discontinuities or low density regions. All of the neutron radiographic films have been retained for future inspection and analysis.

2.6 ROD HANDLING TECHNIQUES BEFORE WELDING

Whenever a loaded sphere-pac rod was transported outside of the glovebox enclosure before the plenum spring was inserted and the top end cap was welded in place, the open end of the rod was sealed by using a temporary end cap plug. These temporary end plugs prevented entry of

Figure 2.9 Neutron Radiograph of a Typical
BRPR Series-2 Segmented Rod

water vapor into the fuel rods whenever the rods were handled outside the glovebox. A typical plug is illustrated as a sequential sketch in Figure 2.10 and also shown in Figure 2.11. If the rods were to be handled horizontally, the upper insulator disc and plenum spring were placed in the rod in addition to the temporary end plug to prevent microspheres from intruding into the plenum area. The fuel retainer disc was not inserted into the rod until the Densigage and plenum depth measurements were deemed acceptable due to the interference fit between the disc and clad discussed in Section 2.3.

The effectiveness of the temporary end cap plugs were tested by storing loaded rods (with the temporary end plug placed in the top of the rod) in the room air (approximately 35% relative humidity) for 12 hours. Subsequent moisture analysis on microspheres in the test rod were compared with the analysis of microspheres retained in the helium atmosphere glovebox (2 ppm H_2O in the helium atmosphere). No increase in the water content was observed. The moisture content of microspheres in the test rods ranged from 4-6 ppm H_2O . The control test microspheres averaged 4 ppm H_2O . The use of this temporary end cap seal is not considered practical for the large scale production of sphere-pac rods (see Section 4.0). The absolute assurance of no moisture intrusion into the rod may require that rod loading, Densigage check, and end cap seal welding all be performed in a controlled atmosphere environment.

2.7 SPECIAL ROD HARDWARE DESIGN AND TESTING

Some problems arose during development of the HBWR and BRPR sphere-pac rods that are not normally experienced in pellet fuel rod fabrication.

ASSEMBLY

INSERTED

EXPANDED

Figure 2.10 Temporary End Cap Seal for Sphere-Pac Fuel Rods

Figure 2.11 Typical Assembly of Temporary End Cap Seal

During x-radiography inspection of the sphere-pac development rods, it was apparent that some microspheres had bypassed the upper alumina insulator disc during normal handling of the rod in the horizontal position after vibratory compaction and before x-ray analysis. In order to prevent this intrusion of microspheres into the plenum region, a thin (0.1 mm thick) zircaloy retainer disc was inserted between the plenum spring and the upper insulator disc (Figure 2.12).

The disc was designed with an interference fit with the cladding. An equally important consideration for the design of the disc is that it should not cause any undue strain in the cladding during creep down. Therefore, the disc is made to be very thin with a hole in the center that serves two purposes. First, the hole reduces the stiffness of the disc which in turn reduces the force exerted against the cladding. Second, it permits fission gas to communicate with the upper plenum. Microspheres do not pass through the hole into the plenum because the retainer disc is held against the insulator disc by the plenum spring.

Process verification tests were performed on the retainer disc by loading test rods with the disc and shaking the rods in the horizontal position. The rods were then examined using x-radiography and none had any microspheres in the plenum area. Process tests were also performed to determine the possibility of interaction between the disc and the inside surface of the cladding. In one test, a disc was seated between fuel pellets and an insulator disc inside a cladding tube and heated to 500°C for 72 hours. Results showed that normal internal cladding oxidation did not cause any galling or seizing between the retainer disc and the cladding.

General Notes · UNLESS OTHERWISE SPECIFIED

1. MATERIAL: Zr-2 OR 4
2. DIMENSIONING AND TOLERANCING IN ACCORDANCE WITH ANSI Y14.5, 1973.
3. BREAK SHARP EDGES AND REMOVE ALL BURRS
4. SURFACE TEXTURE 63/AA OR BETTER IN ACCORDANCE WITH ANSI B46.1, 1962.
5. NUMBERS SHOWN IN PARENTHESIS ARE MILLIMETERS

Figure 2.12 Upper Fuel Retainer

After the test, the retainer disc fell out of the cladding with no force being applied. Because the oxide film on the cladding was very thin in this test ($\sim 0.4 \mu\text{m}$), a second test was performed in which the retainer discs were subjected to more severe oxidation by autoclaving two discs in an open tube for 72 hours at 400°C to form an oxide film that was 1 to 1.5 microns thick. The initial force required to seat the two discs was measured by a Chatillon gage and found to be 6.1 and 4.9 kg. After autoclaving, the force required to unseat the retainer discs had decreased to 3.6 kg and 2.7 kg, respectively; it appeared that the autoclave film in these tests was acting as a lubricant and actually reduced the friction between the disc and cladding instead of locking the disc in place. Because the oxide film in an actual sphere-pac rod is approximately $0.4 \mu\text{m}$ thick, the retainer discs are not expected to cause any bonding or galling problems in the fuel rods.

Another problem that was resolved in a similar manner was the levitation of the lower insulator disc during vibratory compaction of the fuel column. The levitation permitted microspheres to relocate between the insulator disc and the lower end cap. The degree of levitation of the insulator disc produced a layer of spheres between the insulator and end cap that was 0.5 to 1.7 mm thick. A small amount of fuel under the insulator disc was considered to be inconsequential because the heat generation in the lower end of the rod is less than 6 kW/m and, therefore, would cause only a very small temperature increase in the lower end cap region. Nevertheless, a method to prevent levitation of the insulator disc was considered desirable.

A larger diameter for the alumina insulator disc was considered but rejected because of the potential swelling of the alumina during irradiation.

Since the zircaloy fuel retainer disc had worked well in the top of the rod, it was also used to prevent levitation of the bottom insulator disc. The same design and dimensions were used for both the top and bottom retainer discs to eliminate any potential for mix-up in placing the correct disc at the proper end of the rod. The use of the retainer disc in the sphere-pac fuel rods was relatively successful, with x-radiographic examination revealing that only a few of the small size fraction microspheres had bypassed the disc.

2.8 PRESSURIZED SPHERE-PAC FUEL ROD END CAP WELDING

In order to pressurize the sphere-pac rods, it was necessary to determine the time required in the weld chamber for the gas pressure to equalize within the fuel column. Previous experience with BRPR segmented vipac rods indicated that 20 minutes in the weld chamber was required for pressure equalization. Subsequent process development tests were performed using HBWR and BRPR sphere-pac rods. A calibrated pressure transducer was attached to the upper end of an HBWR or BRPR segmented fuel rod and the time required for the pressure to equalize was determined. Within two minutes, the pressure in the upper plenum of the HBWR and BRPR segmented test rods reached ~90% of the set pressure. Therefore, a period of five minutes was allowed to assure pressure equalization in these sphere-pac rods prior to welding during actual fabrication. Five minutes was required for pressure equalization in the full-length BRPR fuel rods. Therefore, a period of ten minutes was used during actual fabrication to assure pressure equalization within these rods.

In preparation for pressurizing and welding, the welding chamber was evacuated to 0.13 Pa and backfilled with helium having a purity greater than 99.9%. The evacuation and backfill procedure was repeated to ensure that the atmosphere in the rod was similar to the atmosphere in the chamber. The helium pressure was then increased to 425 KPa and held for the time periods discussed above. The end caps were then welded in place. The resultant moisture level in the gas was well below 100 ppm. Gas samples were taken from the supply bottles to assure that gas purity specifications were met.

2.9 QUALITY CONTROL PROCEDURES FOR SPHERE-PAC FUEL RODS

All standard Quality Control standards used for pellet fuel were applied to the sphere-pac fuel rod fabrication. The term sphere-pac was substituted where applicable for "pellet" in all Q. C. standards. The following procedures were applied to the fabrication of the HBWR and BRPR sphere-pac fuel rods. The procedures marked with asterisk were specifically written for sphere-pac rod fabrication.

Q. C. PROCEDURES FOR SPHERE-PAC FUEL RODS

1.0 QUALITY CONTROL MANAGER PROCEDURES

- Introduction and Authority Signatures
- Authorized Signatures and Application of Release Stickers

2.0 QUALITY CONTROL ENGINEERING PROCEDURES

- Conditional Release
- Error Control Procedures for Scales and Balances

3.0 PROCESS CONTROL ENGINEERING PROCEDURE

- Quality Control Production Audits
- Enrichment Control Audits
- Auditing Fuel Rod Fabrication Follower Record*

4.0 VENDOR QUALIFICATION AND AUDITING PROCEDURES

- Acceptance Criteria

5.0 PHYSICAL AND CHEMICAL TESTING PROCEDURES

- Metallographic Laboratory*
- Chemical Laboratory*

6.0 RECORDS AND STATISTICS PROCEDURES

- Traceability of Materials and Components
- Data Forms*
- Document Control Systems for Q. C.

7.0 QUALITY CONTROL INSPECTION PROCEDURES

- Certification of Ultrasonic Test Standards
- Enrichment Control
- Maintenance and Control of Inspection Tools and Equipment
- Liquid Penetrant Inspection Dip Tank Method

- Liquid Penetrant Inspection Spot Check Method
- Fuel Cladding Ultrasonic Flaw Test Stations
- Helium Leak Check
- Ultrasonic Test
- Radiographic Procedures*
- Fuel Rod Density Testing System (Densigage)*
- Final Rod Inspection
- Tubing Inspection
- Preparation of Ultrasonic Standard
- Autoclave Inspection
- Plenum Length Gage Calculations
- Rod Archives*

3.0 FUEL ROD FABRICATION

The purpose of the sphere-pac fuel rod fabrication process development tests was to qualify the loading technique and rod hardware to be used in fabricating sphere-pac fuel rods for testing in the Halden Boiling Water Reactor (HBWR) and for demonstration irradiations in the Big Rock Point Reactor (BRPR). The HBWR fuel rods were short (approximately 0.45 m), instrumented, and loaded with 11% enriched fuel.⁽⁶⁾ The BRPR sphere-pac fuel rods were of two types, i.e. full-length rods (1.83 m) and segmented (0.43 m) rods. Both BRPR rod types contained 2.5% enriched fuel.⁽⁷⁾

Figure 3.1 shows the process flow diagram for sphere-pac fuel rod fabrication.

3.1 HALDEN BOILING WATER REACTOR ROD FABRICATION

Five instrumented, pressurized sphere-pac rods were made for the HBWR Series H-2, H-3, and H-4 fuel loadings. The 11% enriched microspheres used in these rods were produced at ORNL. The technique for loading the three microsphere size fractions used for these rods was developed as discussed in Section 2.2 to produce rods that had an average density of $87 \pm 1\%$ TD. The sizes of the microspheres and corresponding density of each size used in the HBWR rods were:

<u>Fraction</u>	<u>Size, μm</u>	<u>Microsphere Density, %TD(a)</u>
Coarse	1150-1410	98.3
Med. Coarse	280-320	98.2
Fine	≤ 45	--

The mixture formulation for the three sphere sizes is listed in Table 2.1.

(a) The analytical procedure was not capable of assessing the %TD of fine fraction.

Figure 3.1 Fabrication and Inspection Steps for
Sphere-Pac Fuel Rod Fabrication

The HBWR test fuel rods were unique in that they had special instrumentation hardware incorporated in the end caps. A description of the instrumentation is as follows:

<u>No. Rods</u>	<u>Description</u>
3	Sphere-pac with elongation sensors (lower end cap)
1	Sphere-pac with thermocouple (upper end cap) and elongation sensor (lower end cap)
1	Sphere-pac with thermocouple (upper end cap) and pressure transducer (lower end cap)

Two of the sphere-pac rods had a W/Re thermocouple inserted into the sphere-pac fuel column through the upper end cap to measure center fuel temperatures during irradiation. The thermocouples were located inside tungsten-rhenium (22%) thermocouple wells to permit sphere-pac loading and to keep the thermocouples centered in the fuel column. Care had to be taken to prevent damage to the thermocouple wells during vibratory compaction of the microspheres. The method used to successfully fill these special rods was to load a preweighed amount of microspheres into the fuel rod until a level just below the lower end of the thermocouple well was reached. The fuel length was checked with a plenum gage and the thermocouple well was inserted. The well was centered in the rod at the bottom by three radially attached wire spacers and at the top by a pin inserted into the well and centered through the microsphere feed hopper. The rod was then topped off with microspheres and vibrated for a short time to compact the microspheres around the thermocouple well. The double compaction times used for the rods with thermocouples, i.e., Rods 41 and 42, are indicated in Table 3.1.

Table 3.1 HBWR Series H-2, H-3 and H-4
Sphere-Pac Rod Fabrication Variables

Rod No.	Smear Density, %TD(a)	Standard Deviation, %TD	Loading Time, sec.	Loading Vibrator Air Pressure, KPa	Final Compaction Time, sec.	Final Compaction Air Pressure, KPa
33	87.6	1.1	30	138	270	276
34	88.0	0.9	32	138	270	276
40	87.9	0.95	30	138	330	276
41	87.7 ^(b)	0.91	30	138	210-bottom ^(c) 17-top	276
42	88.5 ^(b)	0.89	30	138	195-bottom ^(c) 15-top	276

(a) 100% TD = 10.96 g/cm³.

(b) In the region below the thermocouple well.

(c) Rods 41 and 42 have thermocouples in the top end of the fuel column. The two times listed are the compaction times to (1) bring the microspheres to the level before the thermocouple well was inserted, and (2) the time to compact the microspheres around the thermocouple well.

Figure 3.2 is a plot of the Densigage measurements made over the active fuel length of each HBWR rod. All of the data show a decrease in density near the top (25-50 mm) of the fuel column. However, none of the localized density values are below 84% TD. There are also some low density regions at the bottom of the rods. This is caused by an excess of fines infiltrating into this area due to the long vibratory compaction times (Table 3.1) required before development of the overfill technique. Rods 41 and 42, which contained thermocouples in the fuel, do not have density readings in the region of the thermocouple because the thermocouple well interferes with the densigage measurements.

The microspheres used in the HBWR fuel rods were outgassed to remove moisture by placing the spheres in stainless steel trays inside a vacuum outgassing furnace. The furnace was evacuated to 0.013 Pa and the temperature was held at 450°C for 3.5 hours. The furnace was cooled under vacuum and the microspheres transferred into the pellet handling glovebox, where the microspheres were stored in a helium atmosphere container.

The average hydrogen content^(a) for the sphere-pac fuel used in the HBWR fuel rods was 1.42 ppm, or 0.92 ppm when adjusted for adsorption of atmospheric hydrogen during sample processing. Analysis of the hydrogen content in the fuel was determined by the inert gas fusion method (at 2000°C) using an LECO hydrogen analyzer. A chromatograph was used to determine the hydrogen concentration.

3.2 BIG ROCK POINT REACTOR ROD FABRICATION

Forty-two full-length and eighteen segmented sphere-pac rods were fabricated for the BRPR Series S-2, S-3, and S-4 fuel loadings. The 2.52%

(a) Average of 5 analytical samples per lot.

Figure 3.2

Measured Density of Sphere-Pac Rods
H2UCS033 , H3UCS034, H2SPS040, H2XXS041,
and H2XXS042 (Normalized to Overall Bulk
Smear Density)

enriched microspheres used in these rods were produced at ORNL. The size of each fraction and the percent of each fraction used in the rods were the same as for the HBWR rods (Table 2.1). The particle density for the 2.52% enriched microspheres was:

<u>Fraction</u>	<u>Size, μm</u>	<u>Microsphere Density, %TD</u>
Coarse	1150-1410	98.9
Medium	280-320	97.9
Fines	< 45	97.6

At the outset of the BRPR sphere-pac rod fabrication, considerable difficulty was encountered in achieving uniform densities over the full-length (1.8 m) of the rods as compared to the shorter (0.45 m) HBWR rods or the test loadings using depleted microspheres. Several production rods were down-loaded due to variable density. However, after repeated attempts to revibrate some rods, it was found that repositioning the rods in the clamping mechanism that holds the rods during vibration resulted in an increase in overall rod density of approximately 0.5% TD. As a result, the standard production practice used was to vibrate one-half of the allotted time in one position and rotate the rod 90° in the clamps and complete the vibration period. All of the rods loaded in this manner were between 86.5% TD and 87.0% TD (Specification = $87 \pm 1\%$ TD).

The vibration times and procedures listed in Section 2.3 were used for all the rods.

Table 3.2 lists the calculated average densities (geometric) and measured average densities (Densigage) for the 42 full-length rods and 18

TABLE 3.2

Calculated and Measured Average
Densities for BRPR Sphere-Pac Rods

Rod No. (Series S-2 Full-Length Rods)	Calculated Avg. Density, wt% TD(a)	Measured Avg. Density, wt% TD(b)
LS300001	86.5	86.6
LS300002	86.7	86.5
LS300003	86.8	--
LS300004	86.9	--
LS300005	86.8	--
LS300006	86.6	86.6
LS300007	86.5	86.3
LS300008	87.0	--
LS300009	86.3	86.4
LS300010	86.7	86.8
LS300011	86.9	87.1
LS300012	86.4	86.9
LS300013	86.6	86.7
LS300014	87.2	86.8
LS300015	86.8	86.8
LS300016	86.5	87.2
Average	86.7	86.7
Standard Deviation	0.2	0.3

Rod No. (Series S-2 Middle Segments)	Calculated Avg. Density, wt% TD(a)	Measured Avg. Density, wt% TD(b)
LS320001	86.3	--
LS320002	86.1	--
LS320003	86.1	86.6
LS320004	86.6	86.8
LS320005	86.8	86.7
LS320006	86.6	86.8
LS320007	86.3	86.4
LS320008	86.8	86.5
LS320009	86.6	86.8
LS320010	86.5	86.8
Average	86.5	86.7
Standard Deviation	0.3	0.2

Table 3.2 (continued)

Rod No. (Series S-3 Full-Length Rods)	Calculated Avg. Density, wt% TD (a)	Measured Avg. Density, wt% TD (b)
MS300001	87.0	86.8
MS300002	87.0	86.8
MS300003	86.7	86.7
MS300004	86.9	87.2
MS300005	87.1	87.2
MS300006	86.5	86.4
MS300007	87.3	87.3
MS300008	86.8	86.9
MS300009	86.8	--
MS300010	86.8	--
MS300011	87.3	87.3
MS300012	86.9	87.0
MS300013	87.0	87.1
MS300014	87.2	87.3
MS300015	87.2	86.7
MS300016	86.7	86.9
MS300017	87.3	87.3
MS300018	87.1	87.1
MS300019	86.4	86.8
MS300020	87.1	87.1
MS300021	86.8	86.6
MS300022	86.7	--
MS300023	87.0	86.9
MS300024	86.6	86.3
MS300025	87.1	87.0
MS300026	87.0	86.6
Average	86.9	86.9
Standard Deviation	0.2	0.3

Rod No. (Series S-4 Middle Segments)	Calculated Avg. Density, wt% TD (a)	Measured Avg. Density, wt% TD (b)
LU320015	86.6	86.3
LU320016	86.7	86.6
LU320017	86.7	86.7
LU320018	86.6	86.5
LU320019	87.0	86.7
LU320020	86.7	86.5
LU320025	86.9	86.7
LU320026	87.0	86.7
Average	86.8	86.6
Standard Deviation	0.2	0.1

Table 3.2 (continued)

Rod No. (Series S-4 Lower Segments)	Calculated Avg. Density, wt% TD(a)	Measured Avg. Density, wt% TD(b)
LU330015	86.4	86.3
LU330016	86.6	86.8
LU330017	86.4	86.3
LU330018	86.5	86.7
LU330019	87.6	87.6
LU330020	86.7	86.9
LU330025	86.4	86.9
LU330026	86.6	86.6
Average	86.7	86.9
Standard Deviation	0.4	0.5

(a) Calculated from weight/volume rod data.

(b) Measured with a gamma Densigage Cs-137 source; bias correction of -1.9 wt% TD has been made.

segmented rods. The calculated and measured average rod densities agreed closely, especially on the full-length rods. The shorter segmented rods showed a slightly larger variation in point-to-point density measurements. In all of the rods, no localized density regions below the specification limit of 84% TD were measured.

Density variations at the top of the BRPR fuel column were eliminated by the over-fill and aspiration technique discussed in Section 3.1. BRPR rods loaded in this manner had a fuel density of 86.5 to 87.0% TD up to the very top of the fuel column. This technique was also used to rework some BRPR rods that had density discontinuities in the fuel column, i.e. densities <84% TD.

The microspheres used in the BRPR fuel rods were outgassed and analyzed for hydrogen using the same procedures described for the HBWR fuel (Section 3.1). In addition to the hydrogen analysis, the BRPR fuel was analyzed for water content during heating at 800°C by coulometry. All analyses were made in a controlled atmosphere glovebox. The samples were weighed after analysis to detect any sorption of atmospheric moisture. The moisture and hydrogen results for the BRPR sphere-pac fuel were:

<u>Fuel Series</u>	<u>H₂O^(a), ppm</u>	<u>H₂^(a), ppm</u>
S-2, S-3	4.0	1.054
S-4	4.0	0.3

(a) Average of 5 analyses per lot.

4.0 RECOMMENDATIONS

The sphere-pac fuel rod processing equipment was designed for the fabrication of a relatively small number of sphere-pac fuel rods to meet the needs of the FPIP, and the equipment performed well for this purpose. However, for scaled-up production requirements and more positive performance of the processing equipment, the following improvements are suggested.

- 1) The calibration of the microsphere feeders is checked by determining the feed rate of a predetermined amount of microspheres. The feed rate is controlled by adjusting the orifice gate between the feed hopper and feed trough; the height of the gate is set by a micrometer mounted to a "Vee" slide. Uncontrolled variations in the amplitude of the Syntron vibrator affects the feed rate of the microspheres. In order to maintain a constant feed rate, it is necessary to recalibrate the feeders frequently. This would be inconvenient and time consuming for processing a large number of rods. ORNL has suggested two methods for improving the feeder mechanisms.

A) Weight Control Method

Weight feed-rate control of the amplitude of vibration in the microsphere feeders. With this technique, a signal from a sensitive load attached to the feed hoppers would be used to control the vibrator amplitude and thus control the rate at which the microspheres emptied from the feeders.

B) Variable Window Shade Feeder Method

The three size fractions of microspheres would be distributed in an annulus around a cone and fed into the cladding tube by unwinding or opening the annulus (window shade feeder) at a constant speed, thereby permitting a constant mix of microspheres to fall into the cladding tube per unit time.

The weight control feeder method mentioned in (A) above is judged to be the most promising. There are a variety of components available commercially that could be adapted for this use, or a modification thereof which would permit distributing the microspheres inside the fuel rod with the desired size-weight ratios.

- 2) The mounting clamps that hold the cladding tube in the angle iron support during loading and compaction cause low density regions in the sphere-pac fuel column. To prevent this from occurring, the fuel rod is rotated 90° mid-way during the vibratory compaction period. This practice necessitates stopping the vibratory process to rotate the fuel rod. An improved clamping arrangement clamp would be one that holds the rod by the lower end cap and permits the fuel rod to vibrate naturally. This concept has not been tried because tests would have to be performed to evaluate the effect of the stress on the lower end cap and the weld. However, sphere-pac vibratory loading requires very low vibrational amplitudes, and it may prove feasible to develop a lower end cap clamping method.

- 3) The fuel retainer disc design used in the FPIP rods was effective in preventing microsphere intrusion into the plenum region. For scaled-up sphere-pac fuel rod fabrication, this design is not considered sufficiently reliable as the dimensional tolerances on the retainer disc were extremely sensitive between acceptable and unacceptable performance limits. Further process development is needed using possibly either a ceramic fiber or woven metallic (Zr) mat to replace the current solid metal disc. By deforming the mat slightly when it is positioned inside the cladding tube, a positive seal would be made with the inside surface of the cladding. These porous materials would still permit free communication of fission gas from the fuel region to the plenum region.
- 4) The temporary end caps worked satisfactorily to prevent moisture from entering the fuel rod during the fabrication process. This was verified during process development and actual fuel rod fabrication. However, these temporary caps are expensive to fabricate (approximately \$10 per cap) and are cumbersome to use because it is sometimes difficult to remove them from the tube. A simple, snug-fitting slip-on cap may provide the necessary protection. Moisture control could also be achieved by performing the entire sphere-pac loading and welding operations in a controlled atmosphere. Because the sphere-pac fabrication is amenable to remote handling, automated production work stations could be designed to operate within a controlled atmosphere enclosure.

5.0 REFERENCES

1. W. J. Bailey, C. L. Wilson, L. J. MacGowan and P. J. Pankaskie, "State-of-the-Technology Review of Fuel-Cladding Interaction," C00-4406-2 (PNL-2488), Chicago Operations Office, Chicago, Illinois, December 1977.
2. J. P. Hoffman, M. F. Lyons and B. Weidenbaum, "Dimensional Changes in High Performance Powder and Pellet Fuel Rods - Profilometer Studies," GEAP-5100-8, September 1966.
3. W. J. Bailey and J. O. Barner, "Assessment of Fuel Concepts," C00-4066-3, January 1978.
4. R. R. Suchomel, "The Rediscovery of Sphere-Pac As an Attractive Process for Loading Fuel Pins," Paper 77-N-78, American Ceramic Society, 80th Annual Meeting, May 10, 1978.
5. J. E. Ayer, "The Packing of Fueled Spheres," Symposium on Sol-Gel Processes and Reactor Fuel Cycles," CONF-700502, pp. 310-322, Gatlinburg, Tennessee, May 4-7, 1970.
6. R. J. Guenther, J. O. Barner and R. J. Welty, "Description and Characterization of HBWR Series H-2, H-3 and H-4 Test Rods," DOE/ET/34215-14, March 1980.
7. R. K. Welty, "Description and Characterization of BRPR Series S-0, S-1, S-2, S-3 and S-4 Demonstration Fuel Rods," DOE/ET/34215-20, March 1981.
8. M. D. Freshley, "Mixed-Oxide Irradiations in the Plutonium Recycle Test Reactor," Nuclear Technology 15 (1972): 125-126.

DISTRIBUTION

<u>No. of Copies</u>		<u>No. of Copies</u>
	<u>OFFSITE</u>	H. Sobel American Electric Power Service Corporation 2 Broadway New York, NY 10004
2	A. A. Churm DOE Patent Division 9800 S. Cass Avenue Argonne, IL 60439	Tony Mansell Arkansas Power and Light Company P. O. Box 551 Little Rock, AR 72203
6	Martin Langsam DOE Contracting Officer 9800 S. Cass Avenue Argonne, IL 60439	J. S. Tulenko Babcock and Wilcox Company Nuclear Power Generation Division P. O. Box 120 Lynchburg, VA 24505
197	U.S. DOE Distribution Category UC-78	W. A. Weinreich Bettis Atomic Power Laboratory Box 79 West Mifflin, PA 12512
	D. L. Ziemann (Docket No. 50-55, License DPR-6, Big Rock Point Plant) U.S. Nuclear Regulatory Commission Division, Operating Reactors Mail Stop 542 Washington, DC 20555	B. A. Pasternak Booz-Allen Applied Research 4330 East-West Highway Bethesda, MD 20014
	Dr. W. V. Johnston Chief, Fuel Behavior Research Branch U.S. Nuclear Regulatory Commission Division Reactor Safety Research Washington, DC 20555	R. N. Duncan Combustion Engineering, Inc. 1000 Prospect Hill Road Windsor, CT 06095
	Ralph Meyer ATTN: M. Tokar Reactor Fuels Section Division of Systems Safety U.S. Nuclear Regulatory Commission Washington, DC 20555	W. M. Kiefer Commonwealth Edison Company P. O. Box 767 Chicago, IL 60690
		D. R. O'Boyle Commonwealth Edison Company P. O. Box 767 Chicago, IL 60690

No. of
Copies

M. L. Lee
Consolidated Edison Company
of New York
4 Irving Place
New York, NY 10003

D. B. Wehmeyer
Detroit Edison Company
2000 Second Avenue
Detroit, MI 48226

J. Korthever
Duke Power Company
P. O. Box 2178
Charlotte, NC 28342

T. Sneed
Duke Power Company
P. O. Box 2178
Charlotte, NC 28342

F. E. Gelhaus
Electric Power Research
Institute
P. O. Box 10412
Palo Alto, CA 94303

J. T. A. Roberts
Electric Power Research
Institute
P. O. Box 10412
Palo Alto, CA 94303

J. R. Tomonto
Florida Power and Light Company
P. O. Box 013100
Miami, FL 33101

S. Armijo
General Electric Company
175 Curtner Avenue
San Jose, CA 95125

H. W. Schadler
Manager, Metallurgy Laboratory
General Electric Company
P. O. Box 8
Schenectady, NY 12301

No. of
Copies

G. Bond
General Public Utilities
Service Corporation (GPU)
260 Cherry Hill Road
Parsippany, NJ 07054

D. J. Grotch
Knolls Atomic Power Laboratory
Box 1072
Schenectady, NY 12301

W. J. Tunney
Long Island Lighting Company
175 E. Old Country Road
Hicksville, NY 11801

S. W. Wilczek, Jr.
Niagara Mohawk Power Corporation
300 Erie Blvd. West
Syracuse, NY 13202

J. P. Cagnetta
Northeast Utilities Service
P. O. Box 270
Hartford, CT 06101

J. Hallam
Quadrex
1700 Dell Avenue
Campbell, CA 95008

T. Row
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37830

I. Spiewak
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37830

No. of
Copies

G. F. Deabeler
Philadelphia Electric Company
2301 Market Street
P. O. Box 8699
Philadelphia, PA 19101

K. Mahna
Public Service Electric and Gas
Company
80 Park Place
Newark, NJ 07101

R. R. O'Laughlin
Public Service Indiana
1000 East Main Street
Plainfield, IN 46168

W. R. Harris
Rand Corporation
1799 Main Street
Santa Monica, CA 90406

E. Straker
Science Applications, Inc.
8400 Westpark Drive
McLean, VA 22101

R. J. Mullin
Tennessee Valley Authority
1300 Commerce Union Bank Bldg.
Chattanooga, TN 37401

R. S. Miller
Westinghouse Electric Corp.
P. O. Box 355
Pittsburgh, PA 15230

R. M. Grube
Yankee Atomic Electric Company
20 Turnpike Road
Westboro, MA 01581

No. of
Copies

ONSITE

DOE Richland Operations Office

H. E. Ransom

Hanford Engineering Development
Laboratory

R. Omberg

Washington Public Power Supply
System

D. L. Larkin

27 Pacific Northwest Laboratory

W. J. Bailey
J. O. Barner
C. E. Beyer
L. R. Bunnell
M. E. Cunningham
M. D. Freshley (5)
R. J. Guenther
C. R. Hann
P. E. Hart
D. D. Lanning
C. L. Mohr
F. E. Panisko
R. E. Schreiber
M. S. Smith
R. E. Williford
R. D. Widrig
Publishing Coordination File (2)
Technical Information Files (5)

INTERNAL

8 Consumers Power Company

W. J. Beckius
D. P. Blanchard
F. W. Buckman
R. B. Dewitt
G. F. Pratt (3)
Library

No. of
Copies

No. of
Copies

34 Exxon Nuclear Company, Inc.

M. J. Ades
E. R. Astley
S. J. Beard
G. J. BusseIman
M. H. Campbell
C. E. Crouthamel (10)
P. L. Farnsworth
J. W. Fredericks
W. L. Hampson
O. L. Kruger
A. J. Martenson
K. R. Merckx

J. N. Morgan
W. S. Nechodom
R. Nilson
J. F. Patterson
N. Kjaer-Pedersen
G. A. Sofer
L. Van Swam
R. K. Welty
H. E. Williamson
K. E. Willis
K. N. Woods
Records File
Library