TECHNICAL PROGRESS REPORT
SHIPPINGPORT ATOMIC POWER STATION (PWR)
for the period
JULY 26, 1979 to JANUARY 25, 1980

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OPERATED FOR THE U. S. DEPARTMENT OF ENERGY

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FOREWORD

The Shippingport Atomic Power Station located in Shippingport, Pennsylvania, was the first large-scale, central-station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power. This program was started in 1953 to confirm the practical application of nuclear power for large-scale electric power generation. It has provided much of the technology being used for design and operation of the commercial, central-station nuclear power plants now in use.

Subsequent to development and successful operation of the Pressurized Water Reactor in the Atomic Energy Commission (now Department of Energy, DOE) owned reactor plant at the Shippingport Atomic Power Station, the Atomic Energy Commission in 1965 undertook a research and development program to design and build a Light Water Breeder Reactor core for operation in the Shippingport Station.

The objective of the Light Water Breeder Reactor (LWBR) program has been to develop a technology that would significantly improve the utilization of the nation's nuclear fuel resources employing the well-established water reactor technology. To achieve this objective, work has been directed toward analysis, design, component tests, and fabrication of a water-cooled, thorium oxide-uranium oxide fuel cycle breeder reactor for installation and operation at the Shippingport Station. The LWBR core started operation in the Shippingport Station in the Fall of 1977 and is expected to be operated for about a total of 4 to 5 years. At the end of this period, the core will be removed and the spent fuel shipped to the Naval Reactors Expanded Core Facility for a detailed examination to verify core performance including an evaluation of breeding characteristics.

In 1976, with fabrication of the Shippingport LWBR core nearing completion, the Energy Research and Development Administration, now DOE, established the Advanced Water Breeder Applications (AWBA) program to develop and disseminate technical information which would assist U. S. industry in evaluating the LWBR concept for commercial-scale applications. The program is exploring some of the problems that would be faced by industry in adapting technology confirmed in the LWBR program. Information being developed includes concepts for commercial-scale prebreeder cores which would produce uranium-233 for light water breeder cores while producing electric power, improvements for breeder cores based on the technology developed to fabricate and operate the Shippingport LWBR core and other information and technology to aid in evaluating commercial-scale application of the LWBR concept.

All three development programs (Pressurized Water Reactor, Light Water Breeder Reactor, and Advanced Water Breeder Applications) are under the technical direction of the Naval Reactors Program of DOE. They have the goal of developing practical improvements in the utilization of nuclear fuel resources for generation of electrical energy using water-cooled nuclear reactors.

Technical information developed under the Shippingport, LWBR, and AWBA programs has been and will continue to be published.

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HIGHLIGHT SUMMARY

The Shippingport Atomic Power Station was operated with the Light Water Breeder Reactor core at high power levels (base load) throughout this report period except for reductions in power or brief shutdowns to perform planned testing. Evaluation of core test data taken during this period continues to show that the core is operating in accordance with design predictions,

Periodic flow coefficient of reactivity measurements are reported which all meet the criteria on which the revised core protection setpoints and station operating procedures (see WAPD-MRP-152) were based.

The core achieved 14,343 EFPH* at the end of the period after exceeding one billion kilowatt hours total gross electrical output on December 11, 1979.

* EFPH = Equivalent Full Power Hours (where full power is defined as 236.6 MW(t))

A. Shippingport Station Operations

1. Plant Evolutions

At the beginning of the report period, the LWBR core had accumulated 10,834 EFPH. The Station operated at near full power except for periods of lower power operation, maintenance discussed below or brief shutdowns to perform planned testing, achieving 14,343 EFPH on January 25, 1980. Station operation with the LWBR core achieved one billion kilowatt hours total gross electrical output on December 11, 1979. A small leak was detected in a valve vent line on one of the coolant loops on September 25, 1979. This loop was isolated and operations continued with 3 loops in service while preparations were made to repair the leak. After a Station shutdown on October 2, 1979, the leak was repaired and satisfactorily retested and the plant was returned to full power operation on October 17, 1979.

2. Evaluation of Core Test Data

a. Nuclear Data

(1) Periodic Physics Testing

During this period, periodic measurements of the flow coefficient of reactivity were performed. These tests were designed to monitor the magnitude of the flow coefficient which was previously reported as being higher than determined in previous testing. Following operation at power, the reactor was shutdown to a power level low in the intermediate range. The critical position with 4-FAST speed pumps operating was measured followed by a bank worth measurement. The flow coefficient (dynamic) was measured by turning off a reactor coolant pump while near critical and observing the resulting reactivity change using the Inverse Kinetics Simulator. The critical position was measured with 3-FAST speed pumps operating. Comparison of the 4-FAST and 3-FAST speed pump critical positions gives another determination of the flow coefficient (static).

Results of periodic flow coefficient measurements are presented in Table 1. These results all meet the criteria on which the revised core protection setpoints and station operating procedures (see WAPD-MRP-152) were based. The criteria require continued periodic testing to monitor any changes in the flow coefficient of reactivity as the core is depleted.

Table 1Summary of Periodic Flow Coefficient Measurements

<u>Measurement Type</u>	<u>Date</u>	<u>4-FAST to 3-FAST Δ Height (inches)</u>	<u>Bank Worth (10⁻⁴ Δρ/inch)</u>	<u>Flow Coefficient (10⁻⁴ Δρ/fast speed pump)</u>
Initial - Static	7/22/79	0.21	28.73	6.03
First Periodic - Static	7/31/79	0.23	23.53	5.41
First Periodic - Static	7/31/79	0.16	25.32	4.05
Second Periodic - Static	8/14/79	0.20	21.67	4.33
Second Periodic - Dynamic	8/14/79	--	--	4.28
Third Periodic - Static	9/14/79	0.16	22.68	3.62
Third Periodic - Dynamic	9/14/79	--	--	4.77
Fourth Periodic - Static	11/2/79	0.16	23.35	3.74
Fourth Periodic - Dynamic	11/2/79	--	--	4.02
Fifth Periodic - Static	12/12/79	0.14	21.94	3.07
Fifth Periodic - Dynamic	12/12/79	--	--	3.57
Sixth Periodic - Static	1/9/80	0.12	20.92	2.51
Sixth Periodic - Dynamic	1/9/80	--	--	2.90

A.2.a. (2) Monitoring Core Performance

Figure 1 presents a plot of Movable Fuel Assembly Bank positions versus lifetime. The upper curve is the as-built calculated fuel position as a function of EFPH, which is based on assumed continuous full power operation. The series of circles are inferred positions obtained by adjusting the measured fuel positions to account for differences in observed conditions from conditions appropriate to the full power PDQ depletion calculation. The data indicate that the core at full power is over-reactive by 0.36% $\Delta\rho$ relative to the 3-D PDQ calculations which have been corrected for time step depletion effects. The indicated value is well within the core design range of reactivity ($\pm 1\% \Delta\rho$).

The lower curve is the calculated hot, zero power critical position with xenon decayed out. The boxed data points are the measured critical positions following shutdown of at least 90 hours adjusted for differences in Pa-233 and Sm-149 between the detailed power history depletion and a base case depletion. These data indicate that the core, at zero power and xenon free, was overreactive by 0.25% $\Delta\rho$ relative to design calculations at 12,301 EFPH with 41% of full power equilibrium Pa-233. The indicated value is well within the core design range of reactivity uncertainty ($\pm 1\% \Delta\rho$).

Figure 1 shows a discontinuity at about 11,000 EFPH in the trend of the circles representing fuel positions. This discontinuity is thought to be caused by reactivity changes ascribed to the radial motion of the fuel modules in their clearances (discussed in WAPD-MRP-152, Section A.2.a.1.) and the noted change in the flow coefficient of reactivity.

b. Thermal and Hydraulic Evaluation

(1) Core Flow

The LWBR core flow distribution and core and balance piston pressure differentials are monitored on a continuous basis. Flows are measured in seven seed modules and six blanket modules. Pressure differentials are measured across the core. The measured data remain within the predicted range as shown in Table 2. On the average, flow values are about 1 to 2-1/2% less than the initial startup data and core pressure drop is about 4-5% higher, as expected due to deposition of crud in the core. Core hydraulic performance has been satisfactory during the current operating period.

FIGURE 3. LWBR CORE MOVABLE FUEL POSITION VERSUS LIFETIME

Figure 1

Table 2Comparison of Measured Core Flows
and Pressure Drops with Allowable Ranges

(Operation at Full Flow and Power)

	<u>Measured Range</u>	<u>Predicted Range</u>
Seed Flow (lb./sec.)	184.2 - 200.7	164.0 - 212.6
Blanket Type I Flow (lb./sec.)	261.5 - 275.9	247.0 - 290.0
Blanket Type II Flow (lb./sec.)	453.2 - 472.1	404.0 - 491.0
Blanket Type III Flow (lb./sec.)	547.4 - 585.0	505.5 - 585.0
Core Pressure Drop (psi)	48.0 - 52.0	38.8 - 58.0
Balance Piston Pressure Drop (psi)	44.7 - 47.5	41.8 - 47.9

(2) Movable Fuel Scram Characteristics

Scram characteristics for each of the 12 movable fuel assemblies were measured during September. The terminal scram velocities ranged from 11.0 to 12.6 inches per second (ips). These data are in good agreement with the expected range of 9 to 16 ips and the precritical measured data range of 11.4 to 13.0 ips. Similarly, the bottom-stop contact velocities ranged from 1.3 to 1.9 ips which are also in good agreement with the expected range of .5 to 4 ips and the precritical measured data range of .8 to 1.7 ips. Monitoring of movable fuel assembly motion as shown by the above data confirms that scram performance remains satisfactory.

c. Control Drive Mechanism Testing

The periodic testing of the Control Drive Mechanisms was performed in September 1979. All operating characteristics measured in accordance with the test procedure were within the expected ranges and consistent with previous measurements. It is therefore concluded that the mechanisms are operating properly.

A. 3. Support of Operations

The reactor plant was operated on base load throughout this six-month period. Therefore, the number of swingload cycles used to demonstrate load follow capability remains at 154 cycles as reported in WAPD-MRP-152. Fuel rod integrity has been maintained as indicated by the continuing low level of radioactivity measured in the reactor coolant.

Control of plant operations to avoid high cladding stresses in the fuel rods which could lead to stress corrosion cracking or mechanical rupture of the cladding is provided by a comparison of the Lifetime Equivalency Parameter (LEP) to the minimum allowable level (DLEP). The method used by the reactor operator to calculate LEP and its use in comparison with the DLEP curves are described in the earlier reports in this series (WAPD-MRP-149, 150 and 151). The set of LEP plots and DLEP curves used by the operator are shown in Figure 2.

The operator-calculated LEP is used by station operating personnel to compare with the DLEP and thus to determine the need for restricted operations to protect fuel rod clad integrity. As long as the reactor power history permits the LEP to remain above the operating DLEP, routine operations to full power are permitted. If the power history were to cause the LEP to fall to the curve labeled Setpoint DLEP, core protection setpoints would have to be changed to protect the cladding from postulated accidents during any power operations. The broken line in Figure 2 shows the LEP calculated monthly through December 1979 on the basis of maximum cladding stresses. The stress-based LEP is independently calculated by Bettis to verify the operator-calculated LEP.

The LEP comparisons to the DLEP curves indicate satisfactory margins for power maneuvering to full rated power and for postulated power transients to peak module overpower levels.

B. Plant Modification

No significant plant modifications were made in this report period.

C. Plant Maintenance

Investigation of a spurious alarm for a redundant emergency power system identified a malfunctioning overcurrent relay. Preventive maintenance was performed on December 18, 1979 on all similar relays of the Emergency Power System using vendor instructions and equipment. Thirty percent of the overcurrent relays failed the acceptance test due to excessive forward leakage current of the output circuit silicon controlled rectifiers. The questionable rectifiers were replaced and all overcurrent relays were satisfactorily tested.

LEP VS LIFETIME

FIGURE 2

D. Training

The continuous retraining of DOE certified operations personnel and the precertification training of replacement personnel has continued in accordance with the overall plan for such training during the LWBR operating and defueling period.

E. Shipment of PWR Core 2 Components from the Shippingport Atomic Power Station

The PWR Core 2 upper and lower core barrels were separated in preparation for shipping the upper core barrel for burial. (The lower core barrel will be shipped separately.) Fabrication of the upper core barrel shipping container was initiated. Shipment of the upper barrel is scheduled to begin in the next report period.

F. Primary Plant Water Chemistry

1. Monthly Operational Data

Figures 3 through 17 present reactor plant primary coolant chemistry data for the six month period from July through December 1979. The pH, conductivity, total gas and hydrogen levels measured throughout this period are depicted in Figures 3 through 8. After NH_4OH additions, pH and conductivity levels immediately increase, then decrease, as expected, with operations. Ammonium hydroxide additions are required to maintain coolant pH between 10.10 and 10.30. During this period there was one instance of an out-of-specification pH level of 10.05* on August 7, 1979. The pH was quickly brought back within specification by the addition of NH_4OH (see Figure 4). Conductivity levels were consistent with the pH measurements.

Total gas and hydrogen levels immediately decrease after degasification then increase with operations. Plant degasification is required to maintain the total gas below 125 cc/kg and the hydrogen between 10 and 60 cc/kg. All total gas levels were within specification during the entire period. However, there were several instances of high hydrogen concentrations. No corrective action was required. If coolant hydrogen gas concentrations exceed 60 cc/kg, degasification need not be employed to reduce the hydrogen unless the total gas exceeds 125 cc/kg.

Degassed gross beta activity levels, extrapolated to full power, and visual crud concentrations in the reactor primary coolant are presented in Figures 9 through 14. The degassed gross beta

*The out-of-specification condition was of short duration and is not expected to have had a detrimental effect on plant materials.

F.1 measurements are made during all periods of reactor power operations. These data are consistent with normal operating ranges, do not exhibit any unusual levels or trends, and continue to confirm low LWBR reactor coolant activity levels. There were a few isolated instances of above normal (but ≤ 25 ppb) effluent visual crud concentrations measured during this period. Effluent visual crud concentrations must exceed 12 ppb for a period of three weeks before action is required. No consistently high effluent trends were in evidence and no corrective action was required.

During this six month period, 37 sets of fission product iodine measurements were made, see Figures 15, 16 and 17. These weekly gross iodine, iodine-131, and iodine-133 measurements, normalized to 100% power, are consistent with previous results. In addition, revisions to the computer program input, used to predict fission product buildup over core life, were made. As a result, a best fit of the measured fission product data through 13,000 EFPH is obtained with a 2.0 ppm ^{NU} contamination level in the core zircaloy cladding vice 1.3 ppm inferred from initial startup data. This 2.0 ppm value is considered acceptable agreement with uranium contamination levels measured in core tubing and is within the range of fission product measurements made at LWBR startup.

2. Primary Coolant Chemistry Test Data

Periodic primary coolant chemistry tests are conducted at Shippingport after startup according to the following sequence: (a) radiochemical analysis of primary coolant is performed semi-annually after a startup, and (b) fission product monitoring is performed after each startup.

a. Periodic Radiochemical Analysis of Reactor Coolant

The fourth performance of the periodic radiochemical analysis of reactor coolant was performed from August to December 1979. These data have been received and an evaluation will be completed during the next six-month period.

b. Reactor Coolant Fission Product Monitoring During Reactor Startup

This test is performed during all startups to confirm no defects exist in LWBR core fuel rod cladding. The test was performed eight times during this period. Results of all test evaluations completed to date provide no indication of defective fuel rods in the LWBR core.

LWBR REACTOR COOLANT CHEMISTRY FOR JULY, 1979

Figure 3

LWBR REACTOR COOLANT CHEMISTRY FOR AUGUST, 1979

Figure 4

LWBR REACTOR COOLANT CHEMISTRY FOR SEPTEMBER, 1979

Figure 5

LWBR REACTOR COOLANT CHEMISTRY FOR OCTOBER 1979

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Figure 6

LWBR REACTOR COOLANT CHEMISTRY FOR NOVEMBER, 1979

Figure 7

LWBR REACTOR COOLANT CHEMISTRY FOR DECEMBER, 1979

Figure 8

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LWBR REACTOR COOLANT DEGASSED GROSS BETA ACTIVITY AND CRUD LEVELS FOR JULY, 1979

Figure 9

LWBR REACTOR COOLANT DEGASSED GROSS BETA ACTIVITY AND CRUD LEVELS FOR AUGUST, 1979

Figure 10

LWBR REACTOR COOLANT DEGASSED GROSS BETA ACTIVITY AND CRUD LEVELS FOR SEPTEMBER, 1979

Figure 11

LWBR REACTOR COOLANT DEGASSED GROSS BETA ACTIVITY AND CRUD LEVELS FOR OCTOBER, 1979

Figure 12

LWBR REACTOR COOLANT DEGASSED GROSS BETA ACTIVITY AND CRUD LEVELS FOR NOVEMBER, 1979

Figure 13

LWBR REACTOR COOLANT DEGASSED GROSS BETA ACTIVITY AND CRUD LEVELS FOR DECEMBER, 1979

Figure 14

LWBR ONE-HOUR GROSS IODINE ACTIVITY AS A FUNCTION OF CORE DEPLETION

Figure 15

LWBR IODINE-131 ACTIVITY AS A FUNCTION OF CORE DEPLETION

Figure 16

LWBR IODINE-133 ACTIVITY AS A FUNCTION OF CORE DEPLETION

Figure 17

G. LWBR Core Defueling and Shipping Program

The objective of the LWBR Core Defueling and Shipping Program is to remove the LWBR core fuel modules from the reactor and transport them to the Expanded Core Facility (ECF) in Idaho to verify LWBR core performance, including an evaluation of breeding performance.

In this report period, fabrication of the following major equipment was completed: the disassembly stand for removing structural components, the refueling seal adapter, a transfer/shipping container for the holddown barrel, and the major tools and lifting adapters for module disassembly and handling. Fabrication continued on the internal structures to support blanket and reflector modules within the shipping containers, and orders were placed for internal structures to support seed modules during shipping, temporary module racks, and shipping equipment including a container servicing system, an underwater containment device, and lifting gear. The design of a cutting machine to sever bolts attaching the lower blanket module structures was completed after successful testing with a prototype machine. The third standardized M-130 shipping container was transferred for preparation to ship LWBR modules and work on the first two is in progress.

Preparations were initiated for an operational checkout of defueling equipment and procedures using components retained from the LWBR reactor development tests. The first phase of the checkout will begin in the next report period. Thirty-one detailed defueling and module disassembly procedures were prepared.

H. LWBR Core Evaluation at ECF

The objective of the LWBR Core Evaluation Program to be conducted at the Expanded Core Facility is to determine actual LWBR core breeding performance and performance of key core components. The scope and planning for this evaluation program has been described in previous reports (see WAPD-MRP-152).

In this report period, orders were placed for the support structures upon which the large underwater Module Disassembly Apparatus and Cut-Off Systems will sit. The mechanical design was finalized for the Module Disassembly Apparatus and fabrication of the base and table structures for both the machines was started. Detailed designs were completed for fuel storage racks and module stabilization clamps and procurement actions initiated. Most of the detailed designs were completed for hardware required to handle as-received modules and detailed design was initiated on fixtures which will be used to position the modules on the large cutting machines.

A prototype rod removal system was procured and assembled at Bettis. All systems are being checked out and operational testing experience

- H. is being factored into the final design of the production unit. Similarly, a mockup of the ECF hot cell and operating gallery has been constructed at Bettis, and preparations are in progress to install the Production Irradiated Fuel Assay Gage into the mockup for functional and operational checkout of the assay system. The design of the gage itself has been completed and most components including the major structures have been placed on order. An Electric Discharge Machining power supply has been delivered for use in testing at Bettis, and the detailed designs of components for a prototype Cut-Off System have been partially completed.

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APPENDIX ALWBR CORE PARAMETERS (cont'd)

	<u>UNIT</u>	<u>QUANTITY</u>
2. <u>Reactor Core</u>		
a. <u>General</u>		
Type		Pressurized light water moderated and cooled seed and blanket.
Core height	ft	8.7
Mean Core Diameter	ft	7.5
Fuel Material		
Movable Seed		$U^{233}O_2$ - ThO_2 ; with ThO_2 end reflectors
Stationary Blanket		$U^{233}O_2$ - ThO_2 ; with ThO_2 end reflectors
Reflector Blanket		ThO_2
Fuel loading (Thorium and Uranium Metric Tons)		About 42
Fuel cladding material		
Seed, blanket, and Reflector		Zircaloy-4, low Hafnium
Coolant Flow Passes		1
Lifetime	EFPH	At least 15,000
Fissile Inventory Ratio (expected end of life)		At least 1.012
b. <u>Seed Region</u>		
Type of assembly		Rods
Full fuel length	in.	104
Active fuel length	in.	84

APPENDIX ALWBR CORE PARAMETERS (cont'd)

	<u>UNIT</u>	<u>QUANTITY</u>
Number of fuel modules		12
Number of fuel rods/module		619
Total number of fuel rods		7428
Rod diameter (68°F)	in.	0.306
Rod pitch (68°F)	in.	0.369
(531°F)	in.	0.370
Heat transfer area	ft ²	5,184
<u>c. Regular and Power Flattening Blanket Regions</u>		
Type of assembly		Rods
Full fuel length	in.	104
Active fuel length	in.	84
	<u>Regular Blanket</u>	<u>Power Flattening Blanket</u>
Type	I II III	II III
Number	3 3 6	3 6
Number of fuel rods/module*	444 261 187	303 446
Total number of fuel rods**	3234	3581
Rod diameter (68°F), in.	0.5715	0.5275
Rod pitch (68°F), in.	0.630	0.630
(531°F), in.	0.6317	0.6317
Heat Transfer Area, ft ²		
	<u>Regular Blanket</u>	<u>Power Flattening Blanket</u>
Type I modules	1733	--
Type II modules	1022	1091
Type III modules	1464	3216

* Includes flux thimble locations

**Excludes flux thimble locations

APPENDIX ALWBR CORE PARAMETERS (cont'd)

	<u>UNIT</u>	<u>QUANTITY</u>
d. <u>Reflector Blanket Regions</u>		
Type of assembly		Rods
Fuel length	in.	102
Fuel module types	IV	V
Number of each type	9	6
Number of fuel rods/module	228	166
Total number of fuel rods	3047	
Rod diameter (68°F)	in.	0.832
Rod pitch (68°F)	in.	0.900
(531°F)	in.	0.9024
Heat transfer area, ft ²	3814	1853
3. <u>Reactor Control and Protection</u>		
Type		Negative fuel temperature coefficient, negative moderator temperature coefficient, and movable fuel control elements
Number of control elements		12
Control element speed range	in/min.	0.5 to 4.2
Design maximum reactivity insertion rate	ΔK/sec.	1.1 x 10 ⁻⁴

LWBR CORE PARAMETERS (cont'd)

	<u>UNIT</u>	<u>QUANTITY</u>
4. <u>Core Thermal/Hydraulic Design</u>		
Total coolant flow	lb/hr	30.90×10^6
Total seed flow	lb/hr	7.74×10^6
Total blanket flow	lb/hr	15.66×10^6
Total reflector blanket flow	lb/hr	2.90×10^6
BIF system and leakage flow	lb/hr	4.60×10^6
Coolant inlet temperature	°F	520
Coolant exit temperature	°F	542
Average coolant temperature	°F	531
Coolant temperature rise	°F	22
Coolant pressure	psia	1815