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ACNP-67517

PATHFINDER ATOMIC POWER PLANT
TWO-PHASE LEVEL MEASUREMENTS *and*
(TEST 161)
STEAM DRYER EFFICIENCY MEASUREMENTS
(TEST 162)

Submitted to
U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
Bethesda, Maryland

Ref: AEC Contract No. AT(11-1)-589

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TWO-PHASE LEVEL MEASUREMENTS (TEST 161)

STEAM DRYER EFFICIENCY MEASUREMENTS (TEST 162)

by L. L. Kintner, T. M. Raby, J. P. Kelly, and A. M. Larson

Submitted to

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY

and

CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY

under

Agreement dated 2nd Day of May 1957, as Amended
between

Allis-Chalmers Manufacturing Company and Northern States Power Company
under

AEC Contract No. AT(11-1)-589

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PATHFINDER ATOMIC POWER PLANT

TWO-PHASE LEVEL MEASUREMENT TEST (161)
STEAM DRYER EFFICIENCY TEST (162)

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FOREWORD

One of a series of reports on research and development in connection with the design of the Pathfinder Atomic Power Plant, this particular report deals with the Two-Phase Level Measurement Test (161) and the Steam Dryer Efficiency Test (162). The measurements comprising these tests were performed at various power levels up to 85 percent of the full-power design objective. The Pathfinder Plant is located at a site near Sioux Falls, South Dakota and reached initial criticality early in 1964. Northern States Power Company is the owner and operator of the plant. Allis-Chalmers is performing the research, development and design; also, it is responsible for plant construction.

The U. S. Atomic Energy Commission, through Contract No. AT(11-1)-589 with Northern States Power Company and Central Utilities Atomic Power Associates (CUAPA) are sponsors of the research and development program. The plant's reactor is of the Controlled Recirculation Boiling Water type with nuclear superheater.

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1. INTRODUCTION

This report presents the results of the Two-Phase Level Measurements (designated as test procedure 161), and the results of the Steam Dryer Efficiency Measurements (designated as test procedure 162), performed during startup and rise to power of the Pathfinder Plant. The objectives of the two-phase level measurements (Test 161) were to correlate true water level in the reactor with indicated water level at various power levels in order to validate design predictions of operating water levels; to establish an upper level limit to prevent excessive moisture from getting into the superheater; and to establish a lower level limit to facilitate water recirculation after a scram.

In Test 162, steam quality measurements were performed in order to ascertain the effectiveness of the internal steam dryers in removing moisture from reactor steam at intermediate and higher power levels.

Tests were performed at power levels up to 85 percent of the 100 percent design power objective (190 Mwt). Operation in the 85 percent - 100 percent power range is not expected to materially affect the conclusions of this report.

2. TEST DESCRIPTION

2.1 TWO-PHASE LEVEL MEASUREMENTS (TEST 161)

During the initial rise to power, the two-phase level was measured with sampling tubes placed in the reactor. The results were then compared with the water level indicated on the water column. The sampling tubes withdraw fluid through a 0.040-in. dia. orifice at the tube inlet when the pressure is lowered at the exhaust end of the sampling tube. The sample flow is smallest with steam flow entering the orifice; the flow increases as the proportion of water in a steam-water mixture entering the orifice increases. To determine the two-phase level in the reactor, the water level is raised from an initial level below the orifice to a level above the orifice, while other reactor conditions are held at a constant. A relatively large increase in flow through the sample tube is an indication that the fluid entering the orifice has changed from essentially pure steam to a two-phase mixture of water and steam. The two-phase level is at the elevation of the orifice when a large change in flow occurs.

A detailed description of Test 161 procedures, as well as predicted design level and allowable operating limits, is presented in Appendix A of this report.

2.2 STEAM DRYER EFFICIENCY MEASUREMENTS (TEST 162)

Reactor steam samples were withdrawn from two points within the reactor vessel; one point located upstream of the steam dryer, and the other point located downstream of the dryer. Both samples were brought out of the reactor vessels in separate 0.5-in. tubes leading to one Ellison U-Path steam calorimeter. The difference in steam quality or moisture content of each sample then determined the effectiveness of the steam dryer. A detailed description of Test 162 is presented in Appendix B of this report.

3. TEST RESULTS, TWO-PHASE LEVEL MEASUREMENTS (TEST 161)

Two-phase level measurements were made at reactor power levels beginning at 6.5 Mwt up to and including 85 percent of the full design power level. In general, the results indicate good agreement with predicted design values and show that the two-phase level can be maintained within a desirable operating range. Initially established operating limits and scram settings based on the calculated two-phase level have, in most cases, proven to be conservative.

3.1 TWO-PHASE LEVEL MEASUREMENTS AT 6.5 Mwt

The first two-phase level measurement was made at reactor power level of 6.5 Mwt, steam flow of 25,000 lb/hr, and reactor water temperature was 420 F. The two-phase level was 15 in. above normal level (1297 ft - 5 in.) when the indicated level on LR-251 was 12.5 in. (See Fig. 161.9.1 in Appendix A.) The width of the S-shaped curve was about 2 in. (See Fig. 161.9.4 in Appendix A.) The flow of condensate from the probe varied from 0.05 gpm for steam entering the probe to 0.10 gpm for two-phase mixture entering the probe.

Based on previous calculations, the interface is expected to be within the range of 63 to 85 in. above indicated water level, where indicated is at 12.5 in. Exit steam voids for 6.5 Mwt reactor power and 300 psia are calculated to be 0.05. Assuming a linear relationship between two-phase level and core exit steam voids, the expected difference between two-phase measurement and indicated water level is between 9 and 12 in. In view of these results, high level scram settings which are based on the calculated two-phase level are conservative.

3.2 TWO-PHASE LEVEL MEASUREMENTS AT 40 Mwt

Two-phase level measurements were made at 40 Mwt for pressures of 325 psig and 540 psig. The two-phase level was measured on probe LL-3, which has an inlet 15 in. above normal water level. Comparison of measurements and expected values are given in Table 3-1.

TABLE 3-1

TWO-PHASE LEVEL MEASUREMENTS AT 40 Mwt

	Run No.	
	2	3
Reactor power, Mwt	40	40
Reactor pressure, psig	325	540
Recirculation flow, gpm x 10 ³	61	60
Indicated level, LR-251, in.	-0.3	+4.0
Two-phase level, inches above 1297 ft 5 in.	+15	+15
Difference between two-phase measurement and water column reading, in.	15.3	11
Exit void fraction	0.25	0.18
Expected difference between two-phase measurement and water column reading, in.	8 - 16.5	5.5 - 12

A comparison of the measured difference between two-phase level and indicated level with expected values shows that:

- (a) The variation with pressure is about as expected.
- (b) The measured values are near the upper limit of the expected values.

The expected values are based on a linear relationship between 0 and 100 percent power, whereas the true relationship will probably be concave upwards. The level difference is expected to be approximately proportional to exit core voids, which is slightly concave upwards. It is anticipated that, at higher power levels, the measured values will fall closer to the middle of the expected range. The data of the 40 Mwt tests show that the high water level scram point, which is based on the calculated upper limit of two-phase level, is still valid.

3.3 TWO-PHASE LEVEL MEASUREMENTS AT 20-40 PERCENT OF POWER

Two-phase level measurements were made at power levels of 55 Mwt and 80 Mwt during power escalation from 20 percent to 40 percent of full power. The reactor pressure was 540 psig. For the 80 Mwt power, measurements were made on both LL-3, which is 15 in. above normal level (1297 ft - 5 in.) and on LL-2, which is 33 in. above normal level. Comparison of measured and expected values are given in Table 3-2 below.

TABLE 3-2

TWO-PHASE LEVEL MEASUREMENTS AT 55 Mwt AND 80 Mwt

	Run No.		
	4	5	
Reactor power, Mwt	55	80	
Reactor pressure, psig	540	540	
Recirculation flow, gpm x 10 ³	61	58	
Reactor probe no.	LL-3	LL-3	LL-2
Indicated level, LR-251, in.	+1.0	-1.7	+14.0
Two-phase level, inches above 1297 ft			
5 in.	+15	+15	+33
Difference between two-phase measure-			
ment and water column, in.	14	16.7	19
Exit void fraction	0.19	0.25	0.25
Expected difference between two-phase			
measurement and water column, in.	10.8-15.6	13.2-21.0	17.8-25.6

A comparison of the measured difference between the two-phase and the indicated levels with the calculated difference, indicates the following:

- (a) At low power levels (~55 Mwt) the measured difference approaches the upper limit predicted by the calculations.

- (b) At high power levels (> 55 Mwt) the measured difference approaches the lower limit predicted by the calculations.

These results were expected.

The effect of raising the indicated water level about 1 ft at 80 Mwt is to increase the level difference between the two-phase level and the indicated 2.7 in. The expected effect was approximately 4.6 in., calculated by the relationship:

$$\Delta L \text{ (two-phase - indicated)} = \frac{\Delta L \text{ water column}}{1 - \bar{\alpha}_e}$$

where

ΔL is level difference, in., and
 $\bar{\alpha}_e$ is average core exit void fraction.

This relationship assumes a constant cross-sectional area, whereas the reactor internal area is larger between 25 in. and 33 in. above normal level. The top of the boiler core holddown is about 25 in. The larger area would result in a lesser actual effect than that calculated above.

The high water level scram at full power (+4 in. indicated) is based on the calculated upper limit of two-phase. The results of these tests show that this scram limit is still valid. If, as expected, the data at higher powers approaches closer to the lower limit, it may be possible to raise the high water level scram.

3.4 TWO-PHASE LEVEL MEASUREMENTS AT 40-60 PERCENT OF POWER

During power escalation to 60 percent of full power, two-phase level measurements were made at 63 Mwt with reduced recirculation flow and at 115 Mwt with full recirculation flow. A comparison between the data derived from these runs and the data derived from a previous run at 80 Mwt and at full recirculation flow is given in Table 3-3.

Comparison of the run at slightly reduced recirculation flow (Run 6) with the 80 Mwt run at full flow on LL-3 showed that the measured difference between the two-phase level and the indicated level is about the same. This agreement was expected, since core exit voids remained approximately the same for these two runs.

Comparison of the runs at 80 Mwt and 115 Mwt with full recirculation flow on LL-2 shows an increase of 9.5 in. in level difference between two-phase and indicated. The range of expected increase was from 4.6 in. to 9.2 in. The measured value, 28.5 in., is slightly above the middle of the expected range of 21.2 to 34.4 in. Since the full power scram limit of +4 in. is based upon the largest predicted value, the 60 percent power data indicates that this scram limit is still valid. Since the water area per unit vessel length is not constant in this region, the two-phase level is not expected to be linear with power.

TABLE 3-3

TWO-PHASE LEVEL MEASUREMENT AT 40-60 PERCENT OF POWER

	Run No.		
	5	6	7
Reactor power, Mwt	80	63	115.5
Reactor pressure, psig	540	540	541
Recirculation flow, gpm x 10 ³ . . .	58	57	58
Reactor probe no.	LL-3	LL-2	LL-3
Indicated level on LR-251, in. . . .	-1.7	+14.0	-3.0
Two-phase level, inches above 1297 ft 5 in.	+15	+33	+15
Difference between two-phase measurement and water column, in.	16.7	19	18
Exit void fraction	0.25	0.25	0.22
Expected difference between two- phase measurement and water column, in.	13.2-21.0	17.8-25.6	11.6-20.2
			21.2-34.4

3.5 TWO-PHASE LEVEL MEASUREMENTS AT 60-85 PERCENT OF POWER

Data for two-phase level measurements is tabulated in Table 3-4. Run 8 is for the same power level as Run 7, which is reported in Sec. 3.5 and which gives the same results. The power level for Runs 9 and 10 may be 6 percent lower than as shown in Table 3-4, based on feedwater flow measurements.

TABLE 3-4

TWO-PHASE LEVEL MEASUREMENTS AT 60-85 PERCENT OF POWER

	Run No.			
	8	9	10	11
Reactor power, Mwt	114	128	153	162
Reactor pressure, psig	552	568	570	590
Recirculation flow, gpm x 10 ³ . . .	58	57	55	57
Reactor probe no.	LL-2'	LL-2	LL-2	LL-2
Indicated level on LR-251, in. . . .	+4.5	+3.3	+1.7	+1.1
Two-phase level, inches above 1297 ft 5 in.	+33	+33	+33	+33
Difference between two-phase measurement and water column, in.	28.5	29.7	31.3	+31.9
Exit void fraction	0.31	0.33	0.36	0.37
Expected difference between two- phase measurement and water column, in.	21.2-34.4	23.2-37.6	26.8-44.2	27-46

The difference between two-phase and indicated levels at 128 and 153 Mwt reactor power is slightly below the middle of the expected range. If the power level is 6 percent less than tabulated values, the measured values are closer to the middle of the expected range. For 144 Mwt, the expected range is 25.6 to 41.8 compared with a measured value of 31.3 in. At 162 Mwt, the highest power level attained to date, measured values are closer to the lower limit of the range. The full power scram indicated limit of +4 in. is conservative, based upon operation at the 85 percent power run.

3.6 SUMMARY AND CONCLUSIONS

Data obtained at various power levels showed good agreement between expected and measured values. Differences between the two-phase measurements and the indicated level fall within the range expected, as indicated in Table 3-5 which summarizes results of 10 measurements made from initial power levels of 6.5 Mwt to final power of 162 Mwt (85 percent of design full power). The results also confirmed that established scram limits are conservative and may be changed to afford more operating flexibility. A plot of permissible indicated level, showing selective measured points at discrete power levels, is presented in Fig. 3.1. Based on data presented in Fig. 3.1, the scram level may be conservatively set at +5 in. for 100 percent full power. Once 100 percent measurements are made and if the trend at lower powers continues, the scram level may be set at +10 in. or higher.

During two-level phase measurements, an attempt was made to obtain a correlation between the oscillations of two-phase level and those indicated by the water column by measuring the amplitude of the level fluctuation associated with each. The results are summarized in Table 3-6. Data were obtained on the frequency of water flow oscillation in the reactor probes when the two-phase level was near the inlet orifice. The data were obtained by noting the time required for 10 swings. The frequency observed from the reactor probes ranged from $1/2$ to $1/4$ cycle per sec. The frequency of oscillation on the water level indication (as measured on the Offner recorder) was $1/5$ to $1/6$ cycle per sec. The accuracy of a visual count of the cycles was not too good because the oscillations are irregular. As far as the accuracy of the measurements permits one to judge, the frequency of flow oscillations from reactor probes is about the same as the frequency of oscillations from the water column indicator.

The amplitude from reactor probes is obtained by observing when the oscillations of flow start and cease as water level is raised or lowered. Again, the accuracy is not as good as that furnished by the level indicator recording. However, it appears that there is a correlation between amplitude of two-phase level fluctuations in the reactor and fluctuations indicated by the water column level indicator. The data showed no significant trend of increasing amplitude with increasing power.

Observations of the flow indications of the three reactor recirculation loops, and recordings made of the flow signals, indicate that there is a slight flow oscillation in each loop of 1000 to 3000 gpm per loop. The oscillations are not in phase, so the net flow oscillation through the core is expected to be less. The frequency of the individual loop flow oscillations is of the same order of magnitude as the reactor level oscillations. Because of the capacitance effect of the steam separators, this magnitude of change in flow could result in a level change of a few inches. The oscillations are significantly reduced by reducing recirculation flow. The oscillations have no measurable effect on reactor operation.

TABLE 3-5
SUMMARY OF TWO-PHASE LEVEL MEASUREMENTS

	Run No.					
	1	2	3	4	5	
Reactor power, Mwt	6.5	40	40	55	80	
Reactor pressure, psig	300	325	540	540	540	
Recirculation flow, gpm x 10 ³	65	61	60	61	58	
Average liquid level column temp., °F	--	382	437	385	390	
Reactor probe no.	LL-3	LL-3	LL-3	LL-3	LL-3	LL-2
Indicated level on LR-251, in.	+12.5	-0.3	+4.0	+1.0	-1.7	+14
Two-phase level, inches above 1297 ft 5 in.	+15	+15	+15	+15	+15	+33
Difference between two- phase measurement and water column, in.	2.5	15.3	11	14	16.7	19
Exit void fraction	0.05	0.25	0.18	0.19	0.25	0.25
Expected difference between two-phase measurement and water column, in.	9-12	8-16.5	5.5-12	10.8-15.6	13.2-21.0	17.8-25.6

	Run No.					
	6	7	8	9	10	11
Reactor power, Mwt	63	115.5	114	128	153	162
Reactor pressure, psig	540	541	552	568	570	590
Recirculation flow, gpm x 10 ³	57	58	58	57	55	57
Average liquid level column temp., °F	--	431	--	433	428	449
Reactor probe no.	LL-3	LL-2	LL-2	LL-2	LL-2	LL-2
Indicated level on LR-251, in.	-3.0	+4.5	+4.5	+3.3	+1.7	+1.1
Two-phase level, inches above 1297 ft 5 in.	+15	+33	+33	+33	+33	+33
Difference between two- phase measurement and water column, in.	18	28.5	28.5	29.7	31.3	31.9
Exit void fraction	0.22	0.31	0.31	0.33	0.36	0.37
Expected difference between two-phase measurement and water column, in.	11.6- 20.2	21.2- 34.4	21.2- 34.4	23.2- 37.6	26.8- 44.2	27-46

TABLE 3-6

AMPLITUDE OF LEVEL FLUCTUATIONS

	Run No.				
	1	2	3	4	5
Reactor power, Mwt	6.5	40	40	55	80
Recirculation flow, gpm x 10 ³	65	61	60	61	58
Amplitude of level fluctuation					
(a) Reactor probes	1.6	2.2	0.75	1.2	2.3
(b) Level indicator	1.75	3.0	2.75	1.0	2.0

	Run No.					
	6	7	8	9	10	11
Reactor power, Mwt	63	115	114	128	153	162
Recirculation flow, gpm x 10 ³	57	58	58	57	55	57
Amplitude of level fluctuation						
(a) Reactor probes	2.8	3.0	2.2	2.5	2.7	2.8
(b) Level indicator	2.5	3.5	2.5	2.5	3.0	3.5

Basis: Water column at reactor temperature
 Reactor pressure = 540 - 600 psig
 Two-phase levels are average of expected range

Measured values:

- - 21% power, 540 psig
- - 42% power, 540 psig
- △ - 60% power, 540-550 psig
- - 80% power, 570 psig

TWO-PHASE LEVELS FOR RANGE OF PERMISSIBLE INDICATED LEVELS

FIG. 3.1

4. STEAM DRYER EFFICIENCY MEASUREMENTS (TEST 162)

Attempts to measure steam quality in the reactor were first made at a power level of 40 Mwt. These initial attempts were unsuccessful because of instrumentation problems. Modifications to the instrumentation were made, and a new series of measurements were attempted at power levels ranging from 0-80 Mwt. These measurements indicated some moisture content both upstream and downstream of the dryers, even when the reactor was shut down. It was postulated that heat losses in the sample piping were causing erroneous readings. The sample piping was shortened to approximately 40 ft, insulated, and the steam sample flow was increased. These modifications resulted in low-power reading of 0.6-0.8 percent moisture. It was concluded that this was the best reading obtainable with the long lengths of sample tube dictated by the installation. Normal sample tubes for conventional applications are very short. Therefore, for this test all indicated readings are corrected by -0.6 percent, which represents the minimum measurable reading in order to obtain true moisture content.

4.1 INITIAL STEAM QUALITY MEASUREMENTS AT 0-80 Mwt OF POWER

Steam quality measurements were made at four power levels ranging from zero power to 80 Mwt. Zero and low power measurements were made to obtain a zero reference reading for future measurements. The results of measurements are summarized in Table 4-1. Examination of the data shows that the downstream moisture contents are less than the design level of 0.5 percent. The pressure gauge used at 56 Mwt was found to be out of calibration. This accounts for the fact that the downstream moisture content is higher than the upstream moisture content.

TABLE 4-1

STEAM QUALITY MEASUREMENTS AT 0-80 Mwt

Power Level, Mwt	Pressure, psig	Moisture, %			
		Upstream		Downstream	
		Measured	Corrected	Measured	Corrected
0	292	0.872	-	0.687	-
7	400	0.605	0	0.605	0
56	532	0.785	0.18	0.810	0.205
80	549	0.870	0.265	0.765	0.160

4.2 STEAM QUALITY MEASUREMENTS AT HIGHER POWER LEVELS

Additional steam quality measurements were made as part of the gradual power escalation program. Data were obtained for power levels of 115 Mwt, 128 Mwt and 154 Mwt. The results are summarized in Table 4-2.

TABLE 4-2

STEAM QUALITY AT HIGHER POWER LEVELS

Reactor power, Mwt	115	128	154
Reactor pressure, psig	552	570	570
Reactor steam flow, lb/hr	400,000	445,000	530,000
Moisture, %*			
Upstream	0.53	0.71	0.83
Downstream	0.35	0.47	0.55

*Measured values corrected by -0.605 percent, which is zero power reading.

4.3 SUMMARY AND CONCLUSIONS

The results of the Steam Dryer Efficiency tests are summarized in Table 4-3. Downstream moisture content remained close to the design level of 0.5 percent. Moisture content, upstream and downstream of the dryer, increased with increasing power. However, in general, dryer efficiency remained constant at about 34 percent for higher power runs. Dryer efficiency is defined as:

$$\text{Efficiency (\%)} = 100 \left(1 - \frac{\% \text{ moisture downstream}}{\% \text{ moisture upstream}} \right)$$

The magnitude and rate of increase of moisture content is about as expected.

One effect of moisture in steam entering the superheater is to decrease the steam outlet temperature. For the 154 Mwt run, the 0.55 percent moisture results in inlet steam enthalpy which is 4 Btu/lb lower than saturated steam enthalpy. The total enthalpy rise of the steam in the superheater for this run is 140 Btu/lb. (Steam outlet temperature = 660 F.) For saturated steam at the superheater inlet, the steam outlet temperature would be 7 F higher. The power fraction is also about 3 percent higher than that calculated using saturated steam at the inlet due to moisture in the inlet steam.

TABLE 4-3

SUMMARY OF STEAM QUALITY MEASUREMENTS

Reactor power, Mwt	7	56	80	115	128	154
Reactor pressure, psig	400	532	549	552	570	570
Reactor steam flow, lb/hr x 10 ³	~25	--	285	400	445	530
Moisture - Upstream, %	0	0.18	0.265	0.53	0.71	0.83
Downstream, %	0	0.205	0.160	0.35	0.47	0.55
Dryer efficiency, %	--	--	40	34	34	34

APPENDIX A

TEST PROCEDURE 161

TWO-PHASE LEVEL MEASUREMENT

PATHFINDER ATOMIC POWER PLANT

REVISION 1

Dated April 18, 1966

to

TEST PROCEDURE 161

Dated April 7, 1966

TITLE: Two-Phase Level Measurement

This procedure shall be revised as follows:

Delete old page No.:
Title Page, 3

Add revised page No.:
Title Page, 3

Approved for Allis-Chalmers: _____ Date: 4/20/66

PATHFINDER ATOMIC POWER PLANT

PROCEDURE FOR TEST 161

TWO-PHASE LEVEL MEASUREMENT

April 7, 1966

TEST PROCEDURE APPROVAL SHEET

TEST 161

ALLIS-CHALMERS

Prepared by _____
Cognizant Engineer

Approved by _____
Section Head

Reviewed by _____
Site Operations Engineer

Approved by _____
Site Operations Manager

Approved _____ 4/7/66
Assistant Project Manager

NORTHERN STATES POWER

Approved by _____
Operations Committee

Reviewed by _____
Safety Committee Chairman

Approved _____

LIST OF EFFECTIVE CHANGES

Date

Change No.

Applicable Pages

Originator

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- 161.1 Purpose
- 161.2 General Test Method
- 161.3 Applicable Theory
- 161.4 Prerequisites
- 161.5 Hazards and Precautions
- 161.6 Test Procedure
- 161.7 Report
- 161.8 Manpower Required
- 161.9 Illustrations

TEST 161 . TWO-PHASE LEVEL CHECK

161.1 Purpose

To correlate the true water level in the reactor at various power levels with the indicated water level. An upper limit on two-phase level is imposed to prevent excessive moisture from getting into the superheater. A lower limit on water level is imposed to facilitate water recirculation after a scram. The data from this test will be used to determine operating range of water level more accurately than is possible from design calculations.

161.2 General Test Method

During the initial rise to power (Tests 277 and 278) the two-phase level in the reactor will be measured with sampling tubes in the reactor and compared with the indicated water level on the water column (Fig. 161.9.1). The sampling tubes withdraw fluid through a 0.040-inch-diameter orifice at the tube inlet when the pressure is lowered at the exhaust end of the sampling tube. The sample flow rate is smallest with steam flow entering the orifice and increases with increasing water in a steam-water mixture entering the orifice. To determine the two-phase level in the reactor, the water level is raised from an initial level below the orifice to a level above the orifice while holding other reactor conditions constant. A relatively large increase in flow rate through the sample tube is an indication that the fluid entering the orifice has changed from steam to a two-phase mixture. The two-phase level is at the elevation of the orifice when the large change in flow rate occurs.

The maximum two-phase level is limited to an elevation four inches below the top of the steam separators by the high water level scram. Fig. 161.9.3 shows the expected two-phase levels and initial high level scram settings at various power ranges. During the initial rise to power, the measured two-phase levels will be compared with the range of expected levels (Fig. 161.9.2). If two-phase levels are higher than the maximum expected level, the high water level scram setting will be lowered.

161.3 Applicable Theory

The two-phase level is detected by the change in flow through a 0.040-inch diameter orifice. The exhaust pressure on the sampling probe is low enough that sonic (critical) flow is achieved at the orifice. Thus the mass flow through the orifice is dependent only on the thermodynamic state of the fluid entering the orifice. For a mixture of steam and water entering the orifice, the mass flow through the orifice is higher than for saturated steam. Fig. 161.9.4 shows typical mass flow rates as a function of two-phase levels obtained for the Pathfinder probes with steam rates approximating Pathfinder full power steam rates. For lower powers, the S-shaped curve is expected to occur over a smaller change in water level.

In the Pathfinder tests, curves will be plotted of indicated water level versus probe flow rate. The two-phase level will be assumed to be at the orifice location for the mean indicated level as shown in Fig. 161.9.4. The uncertainty in two-phase level will be taken as the width of the S-shaped curve.

161.4 Prerequisites

161.4.1 Special Equipment

1. Two-phase level detectors LL-1, LL-2, and LL-3 and associated instrumentation.
2. Thermocouples on water columns below expected range of water level in the columns.
3. Intercom between plant water level indicators and recorders, two-phase level flowmeters and control room.

161.4.2 Reactor Conditions

Water level measurements will be made during rise to power Tests 277 and 278. For water level tests, all reactor conditions except water level will be held as constant as possible. Reactor power, pressure and recirculation flow rate are the parameters which have the largest effect on two-phase level. Feedwater temperature, purification flow and seal water flow have a lesser effect.

The exact power levels at which water level is checked are at the discretion of the reactor operations supervisor. During the initial rise to power, it is recommended that water levels be checked at 3 power levels below 60% power and 4 power levels above 60% power. Water level is varied within the range shown on Figure 161.9.3. Initial levels are at the low end of the range as specified in 161.6 Step 3.

161.4.3 Instrumentation Check

All reactor water level instrumentation is calibrated prior to this test (Test 136). Indicators should be zeroed at normal water level elevation (1297'-5"). High level scrams will be set as shown in Fig. 161.9.2 for various power ranges.

161.5 Hazards and Precautions

1. Dependent upon the power level, care shall be taken that the level remains within the operating limits as described by the normal level protection system (refer to Figure 161.9.3).
2. No unusual radiation activity is expected in the vicinity of the equipment. However, the actual levels will be observed and working limits established, if necessary, prior to taking each measurement.
3. Care should be taken by personnel not to touch hot, exposed tubing.

Revised 4/18/66

161.6 Test Procedure

At each power level for which a two-phase level check is made, the following procedure applies:

Step 1 - Synchronize watches of data takers and mark time on data recorders.

Step 2 - Record the following data:

1. Reactor Pressure
2. Recirculation Flowrate
3. Reactor Water Inlet Temperature
4. Feedwater Temperature and Flowrate
5. Reactor Power
6. Water Column Temperature
7. Conditions of Auxiliary Coolant Systems

Step 3 - Open the manual valves in two-phase level detection lines LL-1, LL-2, and LL-3, and close manual valves in SS-1, SS-2, and D-1. (Dwg. 43-501-203)

Step 4 - Energize the solenoid valves in the two-phase detection lines. Item 21 of Dwg. 43-501-203.

Step 5 - Increase the indicated water level at a rate not to exceed 0.5 inches per minute over the ranges shown in the following table.

<u>Power (% of Rated)</u>	<u>Range of Indicated Level, inches*</u>	<u>Applicable Two-Phase Level Probe**</u>
0%	+10 to +19	LL-3
20%	0 to +19	LL-3
40%	-10 to +14	LL-3, LL-2
60%	-15 to +9	LL-3, LL-2
80%	-18 to +4	LL-3, LL-2
100%	-18 to -1	LL-3, LL-2

*Based on 60,000 gpm recirculation flow and 600 psig reactor pressure. Initial levels for other flows may be estimated from Fig. 161.9.2. Water column is assumed to be reactor temperature.

**Probe LL-1 is near the top of the separator chimney and is not used during power operation.

While the water level is rising, record the following data at least once a minute:

1. Flow Rate Through Applicable Two-Phase Level Probe
2. Indicated Water Level on Applicable Indicators and Recorders
3. Time of Reading
4. Flow Rate of Water Added to Primary System. (If constant can be read once.)

When the flowrate on the two-phase level flow meter increases sharply, the two-phase level is at the orifice. Continue increasing level another few inches until the change in flow rate is small or until the upper limit of the permissible water level range in the above table is reached.

NOTE: For steam entering the orifice, the flow may be expected to be about 0.1 gpm and for two-phase mixture about 0.3 gpm.

Step 6 - Decrease water level while observing the two-phase level probe flow meter and the indicated water levels. When the two-phase flow rate decreases sharply, signal the data takers at the water level indicators and recorders to record the indicated levels. Continue to decrease level until the indicated level is at the desired value for the next power level (Table in Step 5).

Step 7 - Record data specified in Step 2.

Step 8 - De-energize solenoid valve and close manual valves in Probes LL-1, LL-2, and LL-3.

Step 9 - Plot data obtained during Step 5 as shown on Fig. 161.9.4 to obtain correlation between two-phase level and indicated level. Compare with expected values in Fig. 161.9.2 and extrapolate data to next power level. Plot data and extrapolated value on Fig. 161.9.3 to see that two-phase level will be below the upper limit specified. Check high level scram setting for next power level.

161.7 Report

Final report will be prepared after completion of power escalation.

161.8 Manpower Required

Data will be taken in the Control Room and in the Containment Building simultaneously during the test. At least two data recorders are required for this test in addition to normal operating personnel.

161.9 Illustrations

161.9.1 Water Level Instrumentation

161.9.2 Expected Two-Phase Levels

161.9.3 Operating Range of Water Level

161.9.4 Typical Performance Curves for Two-Phase Level Indicator

FIG. 161.9.1

Basis: Water column at reactor temperature
 Reactor pressure = 600 psig
 Indicated level at normal elevation -
 1297 ft-5 in.

EXPECTED TWO-PHASE LEVELS

FIG. 161.9.2

Basis:

Water column at reactor temperature
 Reactor pressure = 600 psig
 Two-phase levels are average of expected range (Fig. 161.9.2)

TWO-PHASE LEVELS FOR RANGE OF PERMISSIBLE INDICATED LEVELS

FIG. 161.9.3

APPENDIX B

TEST PROCEDURE 162

STEAM DRYER EFFICIENCY

TEST 162

STEAM DRYER EFFICIENCY

October 1, 1965

TEST 162

STEAM DRYER EFFICIENCY

Table of Contents

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162.8.1	Data Sheet for Steam Moisture Content	4
162.8.2	Calculational Procedure	5

TEST 162

STEAM DRYER EFFICIENCY

162.1 Purpose

To check the effectiveness of the steam dryer in removing moisture from reactor steam.

162.2 General Test Method

The steam will be sampled at two points within the reactor vessel, upstream of the steam dryer and downstream of the dryer. The upstream sample of steam is brought out of the reactor vessel in a 1/2 inch tube into one throttling calorimeter, where its quality is determined. The downstream sample of steam is similarly brought out of the reactor vessel in a 1/2 inch tube into another throttling calorimeter. The effectiveness of the steam dryer will be checked from the amount of moisture removed by the steam dryer.

During initial startup tests 278, the reactor will be brought to several equilibrium power levels. Steam quality measurements will be made at approximately 20% power for reactor pressures of 300 psig and 535 psig and at least three power levels between 50 and 100% power, including the 100% power run.

162.3 Applicable Theory

For full power operation, the steam leaving the separators and steam separated by gravity is expected to have a steam quality greater than 95%. After passing

through the dryers, the steam quality is expected to be greater than 99.5. For lower power operation, the steam leaving the separators (upstream of the dryers) is expected to have a steam quality higher than at full power. At very low powers (less than 10%) the steam upstream of the dryers is expected to have about the same quality as steam downstream of the dryers.

162.4 Prerequisites

162.4.1 Special Equipment

1. Sampling tubes must be installed in the reactor as per Dwg. 43-501-106.
2. Calorimeters must be installed per Dwg. 43-002-056.

162.4.2 Reactor Conditions

This experiment will be performed during Phase III of the program for which plant conditions will be as given in Test 278. They will be normal operating conditions as defined in the Operations Manual.

162.5 Hazards and Precautions

1. No unusual radiation activity is expected in the vicinity of the equipment. Calculations show representative levels of approximately 2 mr/hr. However, the actual levels will be observed prior to taking each measurement.
2. Care should be taken by personnel not to touch hot, exposed tubing.

162.6 Test Procedure

Step 1 Open valves to both calorimeters and allow calorimeters to reach thermal equilibrium.

Step 2 Record the data indicated on data sheet 162.8.1.

Step 3 Compute the steam quality and steam dryer efficiency in accordance with Paragraph 162.8.2 and record on data sheet 162.8.1.

162.7 Report

Prepare report of results.

162.8 Data and Calculations

Attached

162.8.1 Data Sheet for Steam Moisture Content

Recorded by _____

Date _____

Time _____

Reactor Steam

Temperature, °F _____

Pressure, psig _____

Flow Rate, lb/hr _____

Upstream Calorimeter

Inlet Pressure, psig _____

Outlet Pressure, psig _____

Outlet Temperature, °F _____

Moisture Content (calculated), X_U % _____

Downstream Calorimeter

Inlet Pressure, psig _____

Outlet Pressure, psig _____

Outlet Temperature, °F _____

Moisture Content (calculated), X_D % _____

Dryer Efficiency (calculated), E, % _____

Comments

162.8.2 Calculational Procedure

Step 1 Calculate the moisture content of steam into each throttling calorimeter per the following formula:

$$X = 100 \left[\frac{h_{gi} - h_{go} - C_p (T_o - T_s)}{h_{fgi}} \right]$$

where X = percent of moisture

h_{gi} = enthalpy of saturated steam at inlet pressure (Btu/lb)

h_{go} = enthalpy of saturated steam at outlet pressure (Btu/lb)

h_{fgi} = latent heat of vaporization at inlet pressure (Btu/lb)

C_p = specific heat of superheated steam at outlet pressure (Btu/lb °F)

T_o = outlet temperature (°F)

T_s = saturation temperature at outlet pressure (°F)

Step 2 Calculate the steam dryer efficiency per the following formula:

$$E = 100 \left[1 - \frac{X_d}{X_u} \right]$$

where X_d = percent moisture downstream of dryer

X_u = percent moisture upstream of dryer