ATTACHMENT 6

RCS Flow Measurement Using Elbow Tap Methodology Licensing Submittal

July 1997

NON-PROPRIETARY

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1.0 BACKGROUND

Current Technical Specifications for South Texas Project Units 1 and 2 have a surveillance requirement to determine the Reactor Coolant System (RCS) total flow rate by a precision heat balance measurement at least once per 18 months. The RCS total flow limit is the value assumed in the transient and accident analysis (plus measurement uncertainties) required to maintain minimum Departure from Nucleate Boiling Ratio (DNBR). The current surveillance method calculates RCS total flow based on steam generator thermal output from a precision calorimetric measurement, divided by the enthalpy difference across the reactor vessel as indicated by the hot and cold leg Resistance Temperature Detectors (RTDs). In recent cycles, measurements for both Unit 1 and Unit 2 have indicated apparent decreases in RCS total flow rates. However, these decreases are not substantiated by the changes that have occurred in the system hydraulics, and are not confirmed by other indications of loop flow. Changes in core reload designs have resulted in core exit temperature distributions that, when combined with incomplete flow mixing and asymmetric flow patterns in the reactor vessel upper plenum, produce varying hot leg temperature indications. The net effect of these phenomena has resulted in what has been referred to as hot leg streaming. Hot leg streaming effects directly impact the hot leg temperatures used in the calorimetric based RCS flow measurement, resulting in calculated RCS total flow rates that are lower than actual values. The apparent RCS total flow reductions caused by hot leg streaming have resulted in the measured RCS flow limit closely approaching the Technical Specification minimum, with a minimum RCS total flow margin as low as 0.37% having occurred in Unit 2.

2.0 PROPOSED CHANGE

The current Technical Specification Table 2.2-1 (page 2-4), "Reactor Trip System Instrumentation Trip Setpoints," provides the Trip Setpoint and Allowable Value for the RCS Flow-Low trip. The Allowable Value is to be changed to reflect the increased uncertainty associated with the correlation of the elbow taps to a previous baseline calorimetric. In addition, Technical Specification 3.2.5 (page 3/4.2-11), "Power Distribution Limits, DNB Parameters," is to be changed to allow the RCS total flow to be measured by the elbow tap Δp method. These changes will include modification of surveillance requirement 4.2.5.3, which currently requires performance of a precision heat balance every 18 months, to not specify the method for RCS flow measurement to be used at the beginning of each fuel cycle. Appropriate Technical Specification Bases sections will also be revised to reflect use of the elbow tap Δp method for flow measurement and to provide clarification. The revised Technical Specifications are in Appendix C.

3.0 SAFETY EVALUATION

3.1 INTRODUCTION

Reactor Coolant System (RCS) secondary calorimetric-based flow measurements at many pressurized water reactor plants, including South Texas Project Units 1 & 2, have been affected by increases in hot leg temperature streaming. The increases are related to changes in the reactor core radial power distribution resulting from implementation of low leakage core loading patterns. In some cases, measured flow appears to have decreased to, or below, the minimum measured flow required by the Technical Specifications. Such occurrences require licensee actions to either account for the apparent flow reduction in the plant safety analyses or to confirm by other means that RCS flow has not decreased below the specified limit. In many cases, plants have relied on the repeatability of RCS elbow tap flow meters to demonstrate that RCS flow has not decreased. This alternate approach confirms RCS flow by a normalization process using both calorimetric and elbow tap flow measurements.

Currently, the Technical Specifications require that RCS flow be measured once per fuel cycle to demonstrate that the actual flow is greater than the minimum flow assumed for the safety analysis. This Safety Evaluation justifies use of an alternate method to measure total RCS flow at South Texas Project Units 1 & 2.

The current RCS calorimetric flow measurement method based on RCS temperature and secondary calorimetric power measurements has inherent limitations imposed by changes in the core radial power distribution. The proposed alternate method using elbow tap flow measurements normalized to a measured baseline calorimetric flow minimizes these limitations.

3.2 SUMMARY

The procedure described in this safety evaluation for verifying RCS total flow with elbow tap flow measurements normalized to calorimetric flow measurements has been approved by the Nuclear Regulatory Commission for application at other nuclear power plants. Applicability of the procedure has been confirmed by comparing measured RCS elbow tap flow trends with best estimate flow trends based on analysis and application of RCS hydraulic test data (Section 3.6)

Evaluation of plant operating data from South Texas Project Units 1 & 2 has defined sufficiently accurate baseline parameters for both the elbow tap and calorimetric flow measurements. Flow changes measured by elbow taps obtained over several fuel cycles are consistent with the predicted flow changes due to changes in RCS hydraulics, as shown on Figures 3.6-1 and 3.6-2. Application of the procedure using normalized elbow tap measurements will result in the recovery of the apparent decrease in flow attributed to changes in hot leg temperature streaming.

While modifications to the South Texas Project Technical Specifications will be needed to allow use of the alternate RCS flow measurement procedure, no unreviewed safety questions have been identified.

3.3 RCS HOT LEG TEMPERATURE STREAMING

3.3.1 Phenomenon

The RCS hot leg temperature measurements are used in control and protection systems to ensure temperature is within design limits, and in a surveillance procedure with secondary plant calorimetric power measurements to determine the RCS flow. Uncertainty in the hot leg temperature measurement can have a significant impact on PWR performance. A precise measurement of hot leg temperature is difficult due to the phenomenon known as hot leg temperature streaming, i.e., large temperature gradients within the hot leg pipe resulting from incomplete mixing of the coolant leaving fuel assemblies at different temperatures. The magnitude of these hot leg temperature gradients where the temperatures are measured is a function of the core radial power distribution, mixing in the reactor vessel upper plenum, and mixing in the hot leg pipe.

Prior to application of low leakage core loading patterns, the largest difference in fuel assembly exit temperatures at full power was typically no more than 30°F. The lowest temperatures were measured at the exit of fuel assemblies on the outer row of the core. Flow from a fuel assembly in the center of the core mixes with coolant from nearby fuel assemblies as it flows around control rod guide tubes and support columns toward the hot leg nozzles. Flow from a fuel assembly on the outer row of the core, separated from the center region flows by the outer row of guide tubes, has little opportunity to mix with hotter flows before reaching the nozzles, so a significant temperature gradient can exist at the nozzle.

Since hot leg flow is highly turbulent, additional mixing occurs in the hot leg pipe, and the maximum gradient where temperature is measured, 7 to 17 feet downstream from the reactor vessel nozzle, is less than at the nozzle. In 1968, gradients measured on the circumference of the pipe were as high as 7 to 10°F, so turbulent mixing in the pipe did not eliminate the gradient introduced at the core exit.

The 1968 tests and subsequent tests showed that the highest temperatures are in the top half of the pipe, while the lowest temperatures are in the bottom half, as expected, since the colder water from the outer row of fuel assemblies is closest to the bottom half of the hot leg nozzle.

Figure 3.3-1 illustrates a postulated flow pattern in the reactor vessel upper plenum between the core exit and the hot leg nozzle. Figure 3.3-2 illustrates typical temperature gradients at the core exit and on the hot leg circumference at the point where the temperatures are measured. Typically, the core exit and hot leg gradients remain relatively stable, changing only slightly as the radial power distribution changes during a fuel cycle.

3.3.2 History

Prior to 1968, there were no multiple temperature measurements on hot leg pipes, so temperature streaming gradients were undetected and resistance temperature detector (RTD) locations were based on other criteria.

During startup of a Westinghouse-designed 3-loop plant in 1968, RTDs on opposite sides of the hot leg pipes measured different temperatures. Recalibrations and special tests confirmed that the measurements were valid, so Westinghouse concluded that the hot leg temperature differences resulted from incomplete mixing of flows leaving fuel assemblies at different temperatures. To confirm this conclusion, thermocouples were strapped to the outside of two hot leg pipes, and gradients were detected that increased as core power increased. The maximum full power gradient was 10°F in one loop and 7°F in the other loop. Since only one RTD was used to define hot leg temperature for control and protection systems, the hot leg temperature measurement was not as accurate as intended.

With additional analyses and development, Westinghouse designed and installed new instrumentation systems at other plants after 1968 to compensate for hot leg temperature streaming gradients. The new system, called the RTD Bypass System, employed scoops in the hot leg piping at three uniformly spaced locations on the circumference of the pipe. Holes on the upstream side of the scoop collected small sample flows. The three sample flows, which were at different temperatures, were combined and directed through an RTD manifold where the average hot leg temperature was measured.

To eliminate personnel radiation exposure to RTD Bypass System piping during plant shutdowns, Westinghouse replaced many systems after 1988 with a system having three thermowell RTDs in each hot leg. The RTDs were installed at uniformly spaced locations, like the RTD bypass scoops, to retain the three measurements on the hot leg. In many cases the thermowell RTDs were installed inside the bypass scoops, so the average thermowell RTD measurement was the same as the temperature by the RTD Bypass System.

Subsequent to 1968, additional hot leg streaming measurements were performed at 2-loop, 3-loop and 4-loop plants. The results of these measurements were used in several analyses to define hot leg temperature streaming uncertainties used in safety analyses and protection system setpoint calculations. Gradients measured in these tests varied from 7 to 9°F. After 1988, the thermowell RTD systems provided hot leg streaming data from the three RTDs in each hot leg. The gradients measured prior to 1991 varied from 2 to 9°F with most of the gradients measured at 5 to 7°F.

3.3.3 Hot Leg Streaming Impact on RCS Flow Measurements

Before 1988, reports of hot leg temperature measurement problems were unusual, and no significant changes in streaming gradients were identified. In 1988, the first significant indication of a streaming change occurred at a 4-loop plant, followed by similar occurrences in 1989 and 1990 at three more 4-loop plants. In all four cases, the measured coolant temperature rise across the core ($\Delta T = T_{hot} - T_{cold}$) had increased from that measured in previous fuel cycles by as much as 3%. Since coolant ΔT is a major input in determining the measured RCS calorimetric flow, a ΔT increase of 3% implied that RCS flow had apparently decreased by 3%. Many other plants, including South Texas Project Units 1 & 2 and several 3-loop and 4-loop plants, have also reported apparent flow reductions. In some cases, the apparent flow was just at or above the minimum flow requirement specified in the Technical Specifications, raising a concern that measured flows could be lower in future cycles. In all cases, however, RCS elbow tap flows indicated that the actual flow had not significantly changed.

Both units at one plant site in 1990 reported that calorimetric flows appeared to be below Technical Specification requirement. After additional data had been evaluated, data from elbow taps confirmed that RCS flow was adequate. The Nuclear Regulatory Commission was advised of the apparent low calorimetric flow indication and the elbow tap flow data. The Nuclear Regulatory Commission concurred with the licensee's conclusion that RCS flow was adequate for safe operation at full power for the remainder of the cycle.

3.3.4 Correlation of Changes in Power Distribution and RCS Flow

At the plants where apparent flow reductions were measured, Westinghouse noted that in all cases the core exit thermocouples measured much larger temperature gradients, approaching 60°F, as shown on Figure 3.3-3, due to much lower exit temperatures at the edge of the core. A review of core radial power distributions indicated that the power generated in outer row fuel assemblies decreased significantly from power levels measured in earlier cycles, confirming the large core exit temperature gradients.

Westinghouse compared radial power distributions and calorimetric flow measurements obtained from several cycles at several 3-loop and 4-loop plants, and concluded that the apparent changes in flow correlate with the radial power distribution gradient at the edge of the core. Figure 3.3-4 plots apparent low leakage loading pattern induced flow decreases measured at a group of 3-loop plants versus the difference between the average power generated in second row and outer row assemblies. The apparent flow decreases appear to occur when power differences exceed 50%, a condition consistent with low leakage loading patterns. The correlation of power difference versus flow can be represented by a straight line, as shown on Figure 3.3-4. According to this data, the measured RCS flow appears to decrease by 3% as the difference between power in second row and outer row assemblies increases from 49% to 78%.

FIGURE 3.3-1

UPPER PLENUM and RCS HOT LEG FLOW PATTERNS

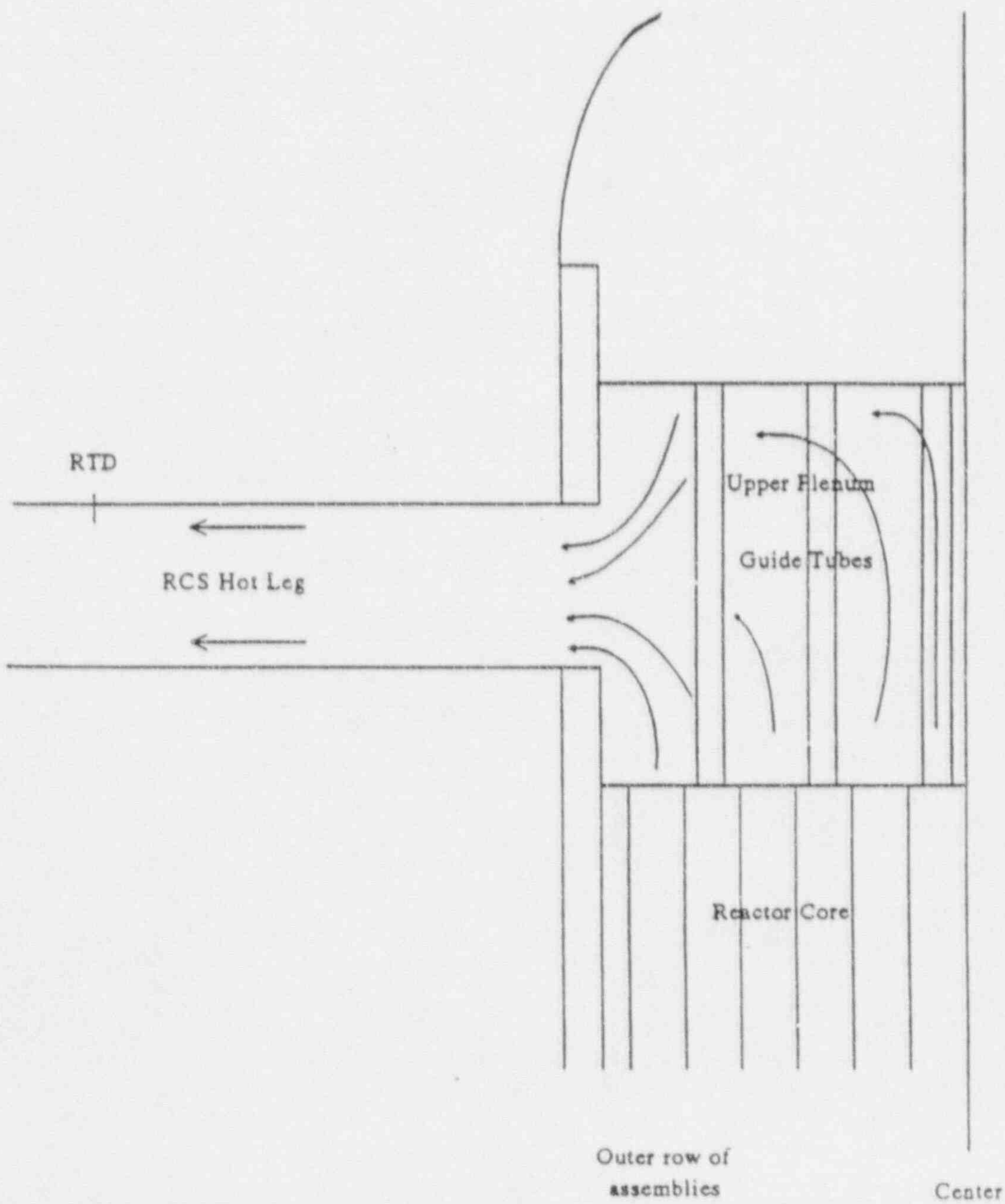


FIGURE 3.3-2

TYPICAL CORE EXIT TEMPERATURE GRADIENT and
RCS HOT LEG CIRCUMFERENTIAL TEMPERATURE GRADIENT

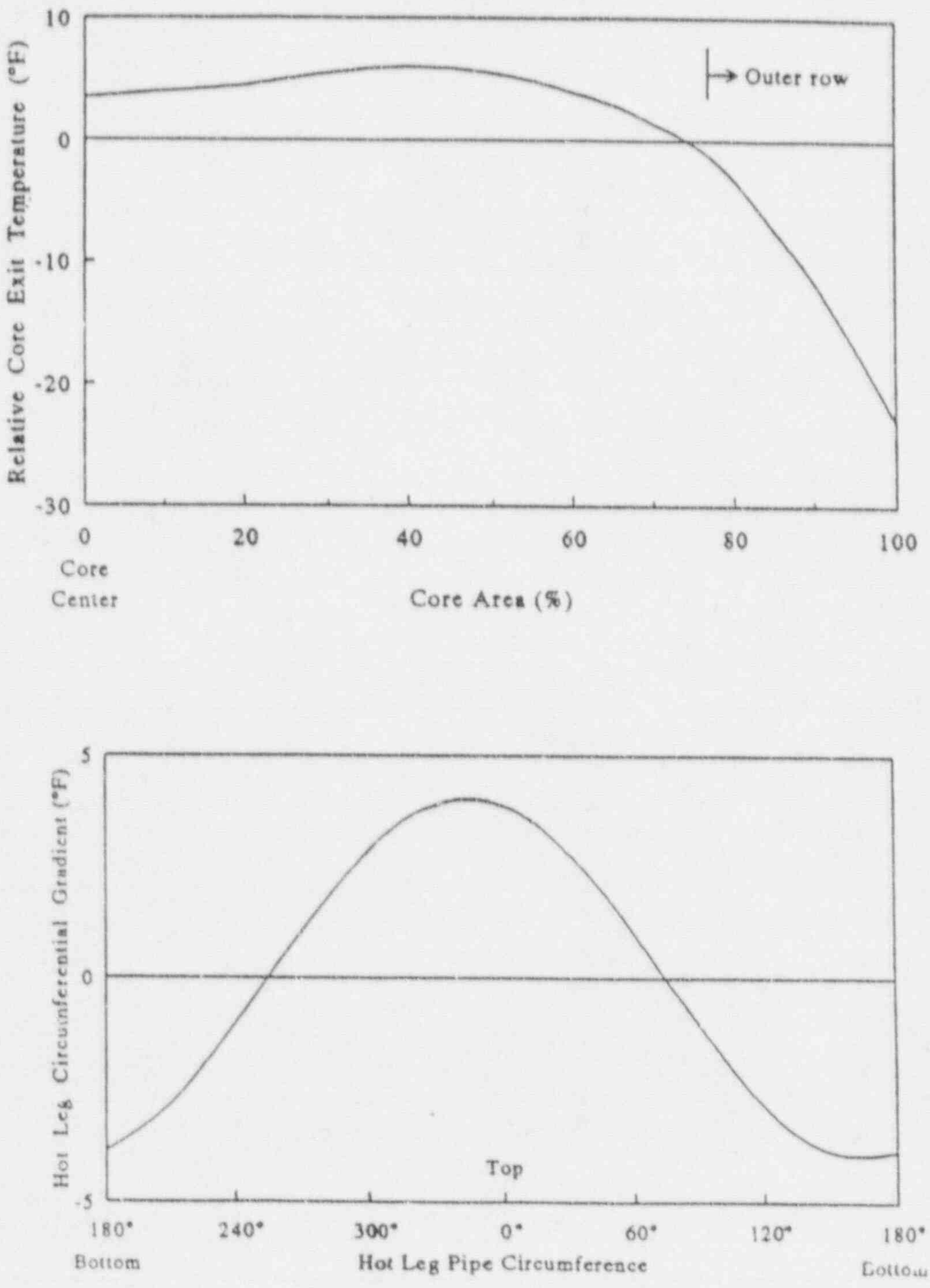


FIGURE 3.3-3

TYPICAL CORE EXIT TEMPERATURE CHANGE

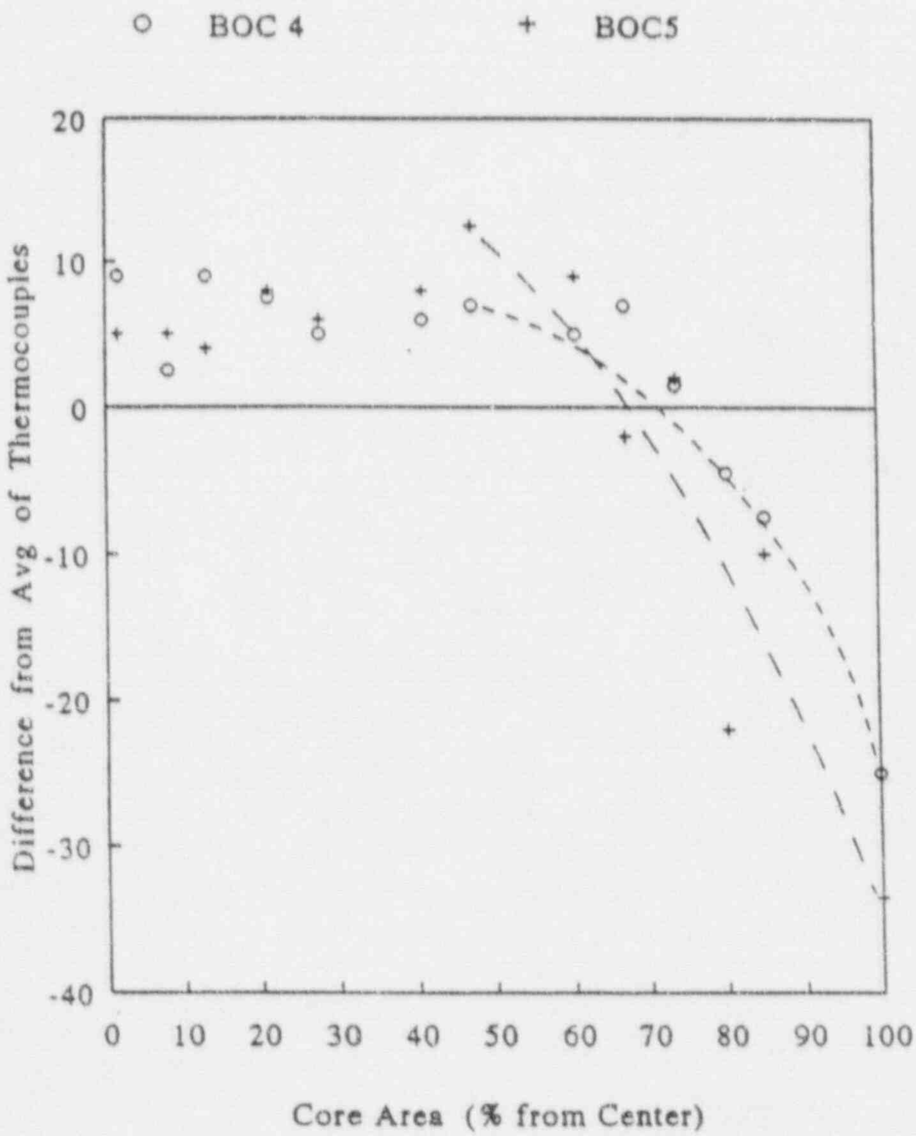
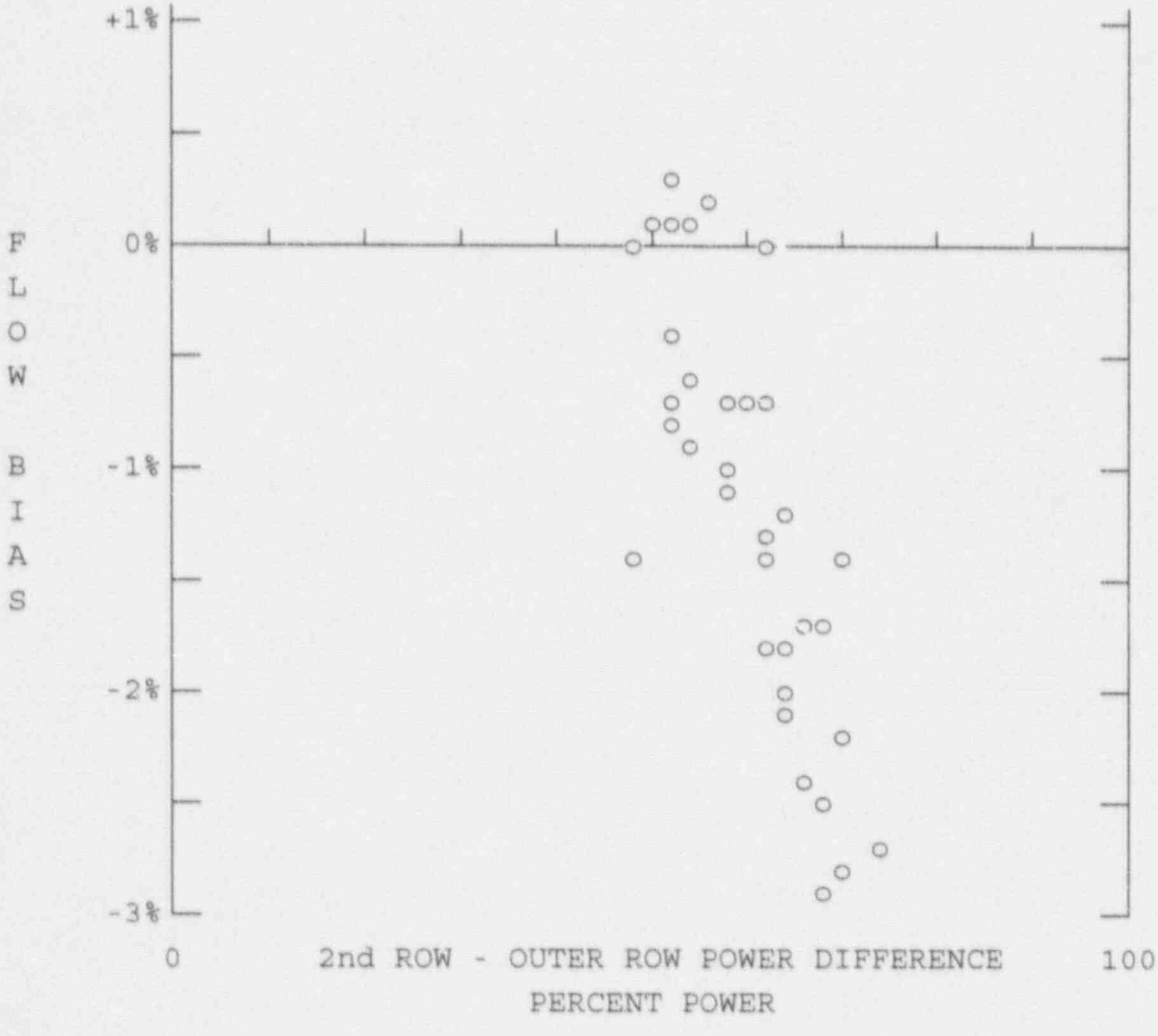


FIGURE 3.3-4

CALORIMETRIC FLOW MEASUREMENT BIAS
VERSUS DIFFERENCE BETWEEN AVERAGE
SECOND ROW AND OUTER ROW ASSEMBLY POWERS



3.4 ELBOW TAP FLOW MEASUREMENT APPLICATION

3.4.1 Elbow Tap Flow Measurements

Elbow tap differential pressure (Δp) measurements are being used more frequently in the industry to determine if, or by how much, RCS flow has changed from one fuel cycle to the next. Elbow tap flow meters are installed in all Westinghouse PWRs on the RCS pump suction piping on each loop, as shown for Prairie Island on Figure 3.4-1. The Δp taps are located on a plane 22.5° around the first 90° elbow. Each elbow has one high pressure and three low pressure taps connected to three redundant Δp transmitters. Elbow taps in this arrangement are used to define relative rather than absolute flows, due to the lack of straight piping lengths upstream from the elbow. The Δp measurements are repeatable and thus provide accurate indications of flow changes during a cycle or from cycle to cycle.

The RCS elbow tap flow meters[1] are a form of centrifugal meter, measuring momentum forces developed by the change in direction around the 90° elbow. The principal parameters defining the Δp for a specified flow are the radius of curvature of the elbow and the diameter of the flow channel through the elbow. Tests[1] have demonstrated that elbow tap flow measurements have a high degree of repeatability and that the flow measurements are not affected by changes in roughness of the elbow surface.

Specific phenomena that have affected other types of flow meters or that might affect the elbow tap flow meters in the RCS piping application have been evaluated to determine if these phenomena would affect repeatability of the flow measurement. In addition, measurements at Prairie Island Unit 2, where the highly accurate ultrasonic Leading Edge Flow Meter (LEFM) is installed, were compared with elbow tap measurements to confirm elbow tap flow measurement repeatability. The results of these evaluations and comparisons are summarized in the following paragraphs.

Venturi Fouling

Venturi flow meters in feedwater systems are affected by crud deposits (i.e., fouling) that affect surface roughness, local pressures, and flow area through the venturi throat. Fouling is apparently caused by an electro-chemical ionization plating of copper and magnetite particles in the feedwater on the venturi surfaces. The fouling process is directly related to the velocity increase as flow approaches the smaller venturi flow area. This condition is not present in an elbow since there is no change in cross section to produce a velocity increase and ionization. In addition, surface roughness changes as experienced in venturi flow meters do not affect the elbow tap flow measurement.

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1 "Fluid Meters, Their Theory and Application", 6th Edition, Howard S. Bean, ASME, New York, 1971.

Meter Dimensional Changes

The elbow tap flow meter is part of the RCS pressure boundary, so there are only minimal dimensional changes associated with pipe stresses, and pressure and temperature are the same (near full power conditions) whenever flow measurements are made. Erosion of the stainless steel elbow surface is unlikely, and velocities are not large (42 fps) relative to erosion. The effects of a dimensional change or erosion could only affect flow by changing elbow radius or pipe diameter, and these dimensions are very large relative to a possible dimensional change. Therefore, elbow tap flow meters are considered to be a highly stable flow measurement element.

Upstream Velocity Distribution Effects

The velocity distribution entering the steam generator outlet nozzle may be skewed by its off-center location relative to the tube sheet. The velocity distribution entering the 90° elbow where the flow meter taps are located may also be skewed by the out-of-plane upstream 40° elbow on the steam generator outlet nozzle. However, these velocity distributions, including the distribution in the elbow tap flow meter, remain constant so the elbow tap flow meter Δp/flow relationship does not change.

Another upstream effect that was considered was steam generator tube plugging. Tube plugging is typically distributed randomly across the tube sheet, so the velocity distribution approaching the outlet nozzle does not change as additional tubes are plugged. The velocity distribution could change if a large number of tubes were plugged in one area of the tube sheet. However, the plenum velocity head approaching the outlet nozzle is small compared to the pipe velocity head (0.6 ft versus 27 ft), and the large change in flow area greatly reduces or flattens an upstream velocity gradient. Therefore, any tube plugging, even if asymmetrically distributed, does not impact elbow tap flow measurement repeatability.

Also considered was the effect of steam generator replacement on the elbow tap flow measurements. The replacement steam generators will have the same outlet nozzle off center location and the same nozzle diameter and taper. Since the configuration is the same and the same difference in plenum and nozzle velocity heads will exist, steam generator replacement will have no impact on the elbow tap flow coefficient. The RCS flow will increase since there will be no plugged tubes and the steam generator flow resistance will be reduced; the elbow taps will correctly measure the increase in flow.

Flow Measurement Comparisons

The LEFMs installed at Prairie Island Unit 2 provided data to confirm repeatability of elbow tap flow meters. The comparisons, listed in Table 3.4-1, covered 11 years of plant operation, during which a significant change in system hydraulics was made. A reactor coolant pump impeller was replaced, and the replacement impeller produced additional flow. The LEFM data after impeller replacement was in agreement with the predicted flow change, and the elbow tap flow meters indicated similar changes. The 11-year flow comparison shows that the average difference between elbow taps and LEFMs was less than 0.3% flow. Another comparison of data obtained before and after impeller replacement showed that measurements agreed to within 0.2% flow on the ratio of flows with one and two pumps in operation, thus further confirming the relative flow measurements from elbow tap flow meters.

3.4.2 Elbow Tap Flow Measurement Procedure

The elbow tap flow measurement procedure relies on repeatability of elbow tap Δps to accurately verify RCS flow. Comparison of elbow tap measurements at or near full power from one cycle to the next provides an accurate indication of any change in flow. When normalized to calorimetric flows, the elbow tap Δps can accurately verify flow for any future fuel cycle. The elbow tap procedure for verifying RCS flows is described in detail below.

Baseline Calorimetric Flow

The Baseline Calorimetric Flow is defined as the calorimetric flow which best represents the actual plant flow at the beginning of plant life. Calorimetric flow measurements obtained during early fuel cycles before low leakage loading pattern application are expected to be consistent with the best estimate flow predictions, both in total flow and in changes in flow resulting from known hydraulics changes, based on the best estimate flow analyses described in Section 3.5.

Any early cycle calorimetric measurement which determines flow for the cycle to be within the specified measurement uncertainty could be used to define the baseline calorimetric flow. To improve accuracy, calorimetric flows from all fuel cycles are evaluated for use in defining baseline calorimetric flow. If a known hydraulics change (e.g., tube plugging) was made before a cycle, calorimetric flow for the cycle should be adjusted so all flows have a common hydraulic baseline. The hydraulic configuration that existed at initial plant startup is usually defined to be the common hydraulic baseline. After adjustment, all cycle calorimetric flows should be similar, differing only by a calorimetric measurement repeatability allowance. Calorimetric flows that fall well outside the allowance (either high or low) should not be used in defining baseline flow. Calorimetric flows appearing to be significantly impacted by low leakage loading patterns and hot leg streaming are not typically considered since the objective of the procedure is to correct for the impact of low leakage loading patterns. Additionally, calorimetric flows that are significantly higher than the best estimate flow should not be included in the baseline flow calculation because they introduce a non-conservative bias.

The accuracy of the baseline calorimetric flow measurement is based on plant specific instrumentation uncertainties that existed when the flow measurements used to define baseline flow were performed. Instrument uncertainty calculations, described in Section 3.7, define the total flow measurement uncertainty. Included in the baseline calorimetric flow measurement uncertainty is an allowance for non-conservative hot leg temperature streaming based on streaming gradients that existed when baseline flow measurements were performed. Although low leakage loading patterns cause larger streaming gradients, the streaming uncertainty becomes more conservative, so a larger, low leakage loading pattern induced streaming uncertainty is not needed.

Baseline Elbow Tap ΔP

Elbow tap Δps obtained in the first cycle define a baseline elbow tap flow coefficient, which is used in connection with the baseline calorimetric flow to define a future cycle flow. The baseline elbow tap flow coefficient (B) is defined by the following equation:

$$B = \Delta p_B * v_B \qquad \text{(Eq. 1)}$$

where: B = baseline elbow tap total flow coefficient, (inches H_2O * ft^3/ lb),
Δp_B = baseline average elbow tap Δp (inches H_2O),
v_B = average cold leg specific volume (ft^3/ lb).

The baseline elbow tap flow coefficient, based on the average Δp from all elbow taps, defines the total flow to be consistent with the total baseline calorimetric flow. Repeatability and accuracy are improved when all elbow tap Δp measurements are used.

Flow Verification for Future Cycles

Elbow tap Δps will be obtained at the beginning of a future cycle to define the change from the baseline flow. The average of all elbow tap Δps measured at or near full power defines the future cycle elbow tap flow coefficient (K), applying the equation:

$$K = \Delta p_F * v_F \qquad \text{(Eq. 2)}$$

where: K = future cycle elbow tap total flow coefficient, (inches H_2O * ft^3/ lb),
Δp_F = average future cycle elbow tap Δp (inches H_2O),
v_F = average future cycle cold leg specific volume (ft^3/ lb).

The change in flow from the baseline cycle to the future cycle is defined by the elbow tap flow ratio (R), based on the equation:

$$R = (K / B)^{1/2} \qquad \text{(Eq. 3)}$$

where: R = ratio of future cycle flow to baseline flow.

The future cycle flow is determined by multiplying the baseline calorimetric flow by the elbow tap flow ratio (R), applying the following equation:

$$FCF = R * BCF \qquad \text{(Eq. 4)}$$

where: FCF = total future cycle flow, gpm,
BCF = total baseline calorimetric flow, gpm.

Best Estimate Flow Confirmation

A future total flow determined from an elbow tap flow measurement is confirmed by comparing the measured elbow tap flow ratio (R) with an estimated flow ratio (R') based on the best estimate flow analysis (described in Section 3.5) of known RCS hydraulics changes such as steam generator tube plugging or fuel design changes. The estimated flow ratio is defined by the following equation:

$$R' = FEF / BEF \qquad \text{(Eq.5)}$$

where: FEF = future cycle estimated flow, the estimated RCS flow, based on actual RCS hydraulics changes,
BEF = best estimate flow, the estimated initial (baseline) cycle RCS flow, based on hydraulics analyses.

An acceptance criterion is applied to the comparison of R and R':

If $R \le (1.004 * R')$, the elbow tap flow ratio R is used to calculate the future cycle RCS total flow using Equation 4.

If $R > (1.004 * R')$, the quantity $(1.004 * R')$ is used to define the future cycle RCS total flow, modifying Equation 4 as indicated below.

$$FCF = 1.004 * R' * BCF \qquad \text{(Eq. 6)}$$

The multiplier (1.004) applied to R' is an allowance for the elbow tap flow measurement repeatability. Since the elbow tap flow measurement uncertainty includes this repeatability allowance, the measured flow ratio [R] can be 0.4% higher than the estimated flow ratio [R'] and still define a conservative flow.

Application of this acceptance criterion results in definition of a conservative future cycle flow, confirmed by both the elbow tap measurements and the best estimate hydraulics analysis.

TABLE 3.4-1

COMPARISONS of LEFM and ELBOW TAP FLOW MEASUREMENTS

AT PRAIRIE ISLAND UNIT 2

RCS FLOW MEASUREMENT COMPARISONS AT FULL POWER
gpm/loop

Loop/Meter	A/LEFM	A/Elbow	B/LEFM	B/Elbow
Feb 1980	97519	*	97950	*
Jul 1981	98673	98309	97763	97267
Aug 1991	98724	98557	97543	97607

* - Normalized to LEFM Flow

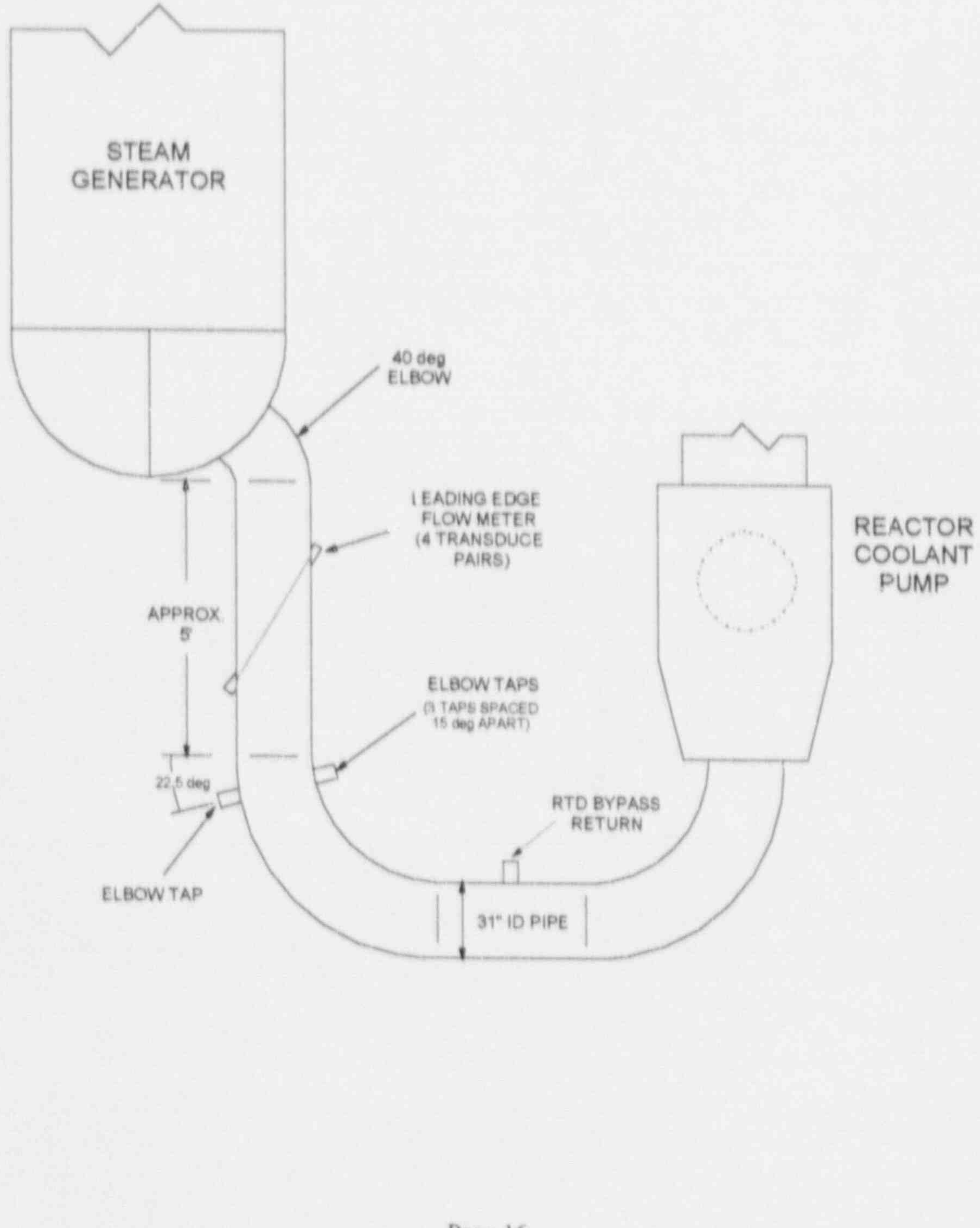
RATIO OF FLOW WITH 1 PUMP OPERATING
TO FLOW WITH 2 PUMPS OPERATING

Loop/Meter	A/LEFM	A/Elbow	B/LEFM	B/Elbow
Dec 1974	1.0819	1.0777	1.0852	1.0875
Jul 1981	1.0794	1.0816	1.0820	1.0820

FIGURE 3.4-1

LEADING EDGE FLOW METER AND ELBOW TAP FLOW METER LOCATIONS

AT PRAIRIE ISLAND UNIT 2



3.5 BEST ESTIMATE RCS FLOW ANALYSIS

3.5.1 Background

Westinghouse developed the best estimate RCS flow calculational procedure in 1974 and has applied the procedure to estimate RCS flows at all Westinghouse-designed plants. The procedure uses component flow resistances and pump performance with no margins applied, so the resulting flow calculations define a true best estimate of the actual flow.

Uncertainties in the best estimate hydraulics analysis, based on both plant and component test data, define a flow uncertainty of ±2% flow, indicating that actual flow is expected to be within 2% of the calculated best estimate flow.

The best estimate hydraulics analysis was developed and confirmed by numerous component flow resistance tests and analyses. The most significant input was the test data collected at Prairie Island Unit 2, where ultrasonic Leading Edge Flow Meters (LEFMs) were installed. This program and other tests are described in the following sections.

3.5.2 Prairie Island Hydraulics Test Program

The LEFM was installed in 1973 at Prairie Island Unit 2, on both loops as shown on Figure 3.4-1. Measurements were obtained during the hot functional and plant startup tests in 1974. In addition to the LEFM flows, concurrent measurements of reactor vessel and steam generator flow resistances were also obtained, as well as reactor coolant pump dynamic head, input power and speed.

The program collected data during plant heatup from 200°F to normal operating temperatures with one and two pumps operating. Full power flow measurements were obtained early in 1975. Subsequent flow and pump input power measurements were obtained in 1979, 1980, 1981 and 1991.

The LEFM accuracy for the Prairie Island plant measurements was established by a calibration test at Alden Laboratories and by analyses of dimensional tolerances to be ±0.67% of measured flow. The Alden test modelled the piping configuration both upstream and downstream from the metered pipe section. Tests performed at several circumferential locations of the ultrasonic transducers defined the optimum location for the transducers in the pipe section relative to the upstream and downstream elbows.

The component Δp accuracy for the Prairie Island measurements was established by calibrations to be within ±1% of the measured Δp. The sum of the Δps measured across the reactor and steam generator were within 1% of the pump Δp, confirming measurement accuracy.

The flows measured in 1974-75 were 5% higher than predicted, due to the following effects, evaluated in additional analyses.

Reactor Coolant Pump Performance

Reactor coolant pump performance was higher than predicted from hydraulic model tests, producing an additional 2% flow, partly due to pump impeller thermal expansion and partly due to conservatism in the hydraulics scaleup from the model tests. With flow, head, input power and speed data, hydraulic and electrical efficiency were verified. Since the LEFM also measures reverse flows, the resistance of the pump impeller to reverse flow was confirmed to be as originally specified.

Reactor Vessel Flow Resistance

The reactor vessel flow resistance was lower than predicted from reactor vessel model tests and fuel assembly flow resistance measurements, producing an additional flow of almost 3%. Tests with one pump operating provided additional data to confirm the division of flow resistances between vessel internals (total flow) and vessel nozzles (loop flow).

Steam Generator Flow Resistance

The steam generator flow resistance was the same as predicted from analysis, so changes in the analysis were not required. The large change in the predicted flow resistance resulting from the change in tubing Reynolds Number and friction factor during plant heatup was also confirmed by the flow resistance measurements.

Piping Flow Resistance

The reactor coolant piping flow resistance, 6% of the total system resistance, was reduced by about 25% to be consistent with measured component flow resistances, accounting for reduced Δp due to close coupling of components and elbows in the piping. Part of an elbow Δp loss occurs as increased turbulence in the downstream piping, but the loss is reduced if a component or another elbow is located at or close to the elbow outlet.

Flow vs Power

LEFM measurements at full power indicated that the Prairie Island Unit 2 RCS volumetric flow decreased by about 0.8% as the reactor was brought from zero to full power. This result confirmed the predicted effect of higher velocities in the core, hot leg, and steam generator tubes as these temperatures increase above cold leg temperature. The coolant volumetric flow and velocity in these regions increases by 5 to 12%, causing an increase in the total RCS flow resistance applied to the reactor coolant pumps. The decrease in flow as reactor power increases from zero to 100% differs from plant to plant, depending on plant specific coolant temperatures, coolant ΔT (T_{hot} - T_{cold}), and component flow resistances.

3.5.3 Additional Prairie Island Tests

The flow measurements in later years contributed additional data on system hydraulics performance which was used to revise and further validate the hydraulics analyses, as described in the following paragraphs.

Impeller Smoothing

LEFM and pump input power measurements were obtained at Prairie Island in 1979 and 1980 to reconfirm RCS flows and hydraulic performance. LEFM data indicated that RCS flows had decreased slightly, by 0.6 to 0.8%. It was also noted that pump input power had decreased by about 2%. After evaluating this data and considering other available information, Westinghouse concluded that the flow decrease was due to impeller "smoothing", where the impeller surface roughness decreases due to wear or crud buildup between high points on the impeller surfaces. The "smoothing" effect occurs within one or two fuel cycles after initial plant startup. This small flow decrease during the initial cycles has also been measured by elbow tap flow meters at several other 3-loop and 4-loop plants.

Pump Impeller Replacement

The LEFMs were used at Prairie Island in 1981 to confirm RCS flows after replacement of a pump impeller. The replacement impeller was predicted to have a higher performance than that of the original impeller, and an increase in loop flow was predicted. The LEFM data confirmed the prediction.

Elbow Tap Flow Comparison

LEFM measurements obtained in 1991 were compared with the 1980 data to confirm that the elbow taps measured the same flow changes over the same period. The comparison indicated that the elbow tap and LEFM flows were in good agreement, with an average difference in flow of less than 0.3% over 11 years.

3.5.4 System Flow Resistance Analyses

Flow resistances are calculated for each component, based on the component hydraulic design data and on hydraulics coefficients resulting from analyses of test data, such as but not limited to, the Prairie Island hydraulics test program. The component flow resistances are combined to define total system resistance, and then combined with the predicted pump head-flow performance to define individual loop and total RCS flow. The background and bases for the flow resistance calculations are described below.

Reactor Vessel

The reactor vessel flow resistance is defined in three parts.

a. The reactor core flow resistance is based on a full size fuel assembly hydraulic test, including the Δps at RCS total flow through the inlet and outlet core plates as well as the core.

b. The vessel internals flow resistance accounts for the Δps with total flow through the downcomer, lower plenum, and upper plenum. The flow resistances are determined from hydraulic model test data for each type of reactor vessel, based on Δp measurements within the model.

c. The vessel nozzle flow resistances include Δps based on loop flow through the inlet and outlet nozzles.

In addition, the overall analysis accounts for small flows that bypass the core through the upper head, hot leg nozzle gaps, baffle-barrel gaps, and control rod guide thimbles.

Steam Generator

The steam generator flow resistance is defined in five parts: inlet nozzle; tube inlet; tubes; tube outlet; and outlet nozzle. The overall flow resistance was confirmed by the Prairie Island hydraulics test program (Section 3.5.2). The analysis accounts for the plugged or sleeved tubes in each steam generator, so loop specific flows can be calculated when different numbers of tubes are plugged or sleeved in each loop.

Reactor Coolant Piping

The reactor coolant piping flow resistance combines the flow resistances for the hot leg, crossover leg, and cold leg piping. The flow resistance for each section is based on an analysis of the effect of upstream and downstream components on elbow hydraulic loss coefficients, using the results of industry hydraulics tests. The total flow resistance was consistent with the measurements from the Prairie Island hydraulics test program (Section 3.5.2).

3.5.5 Best Estimate RCS Flow Calculations

The best estimate RCS flow analysis defines Best Estimate Flow (BEF) and Future Cycle Estimated Flow (FEF) for the elbow tap RCS flow measurement procedure. The calculation combines component flow resistances and pump performance predictions based on hydraulic model tests, and defines RCS loop flows at the desired power or temperature with any combination of pumps operating, with any fuel assembly design, and with different tube plugging in each steam generator. The calculated best estimate flows are in good agreement with calorimetric flow measurements from many plants before low leakage loading patterns were implemented, as discussed in Section 3.3. For the many plants where the comparisons have been made, the calculated best estimate changes in flow from cycle to cycle have been in good agreement with changes measured by elbow taps.

3.6 EVALUATION OF SOUTH TEXAS PROJECT RCS FLOW PERFORMANCE

RCS elbow tap flow and calorimetric flow measurements from South Texas Project Units 1 & 2 were evaluated and compared with best estimate flow to determine RCS flow performance. Elbow tap flow measurements indicate actual flow changes and are expected to compare well with changes predicted by the best estimate analysis. Calorimetric data from each unit established the baseline flow and identified flow changes caused by hydraulics changes as well as hot leg temperature streaming biases in later fuel cycles. The South Texas Project RCS flow measurement evaluation is described in the following paragraphs.

3.6.1 Best Estimate Flow Predictions

South Texas Project Unit 1

Best estimate flow analyses defined flows for each of the seven cycles for Unit 1. The Cycle 1 initial startup flow was defined to be 407,472 gpm. Hydraulics changes affecting subsequent cycle flows defined the following changes in flow, listed on Table 3.6-1.

a. Impeller Smoothing: As stated in Section 3.5, impeller smoothing is expected to cause a flow decrease of about 0.6% flow after the first cycle. Since the Unit 1 pre-startup tests required longer than normal reactor coolant pump operating time, some impeller smoothing may have occurred before Cycle 1 startup. For this analysis, the flow decrease due to impeller smoothing prior to Cycle 2 was defined to be 0 to -0.6% flow, to allow for smoothing that may have occurred before Cycle 1.

b. Steam Generator Tube Plugging: The tube plugging at Unit 1 had a negligible impact on RCS flow until Cycle 6 when the average plugging reached 0.8%, causing an estimated decrease of 0.2% flow. Prior to Cycle 7, an additional 0.5% plugging occurred, causing an additional estimated decrease of 0.1% flow.

c. Fuel Design Changes: Although the fuel design changed over the seven cycles, the best estimate analyses determined that the overall impact of the changes on RCS flow was negligible.

Considering all of the above, the overall impact of the hydraulic changes was expected to be 0.3 to 0.9% flow over seven cycles of operation, as indicated in Table 3.6-1. Cycle 1 is defined as the baseline for best estimate flow, and the trend defined on Table 3.6-1 is plotted on Figure 3.6-1, with the Cycle 1 flow specified as 100%.

Based on the elbow tap flow measurement procedure described in Section 3.4.2, the future cycle estimated flow (FEF) is 99.1%, so the estimated flow ratio (R') for Cycle 7 and for future cycles if no hydraulics changes are made is, therefore, 0.991.

South Texas Project Unit 2

Best estimate flow analyses defined flows for each of the six fuel cycles for Unit 2. The Cycle 1 initial startup flow was defined to be 405,756 gpm. Hydraulics changes affecting subsequent cycle flows defined the following changes in flow, listed on Table 3.6-1.

a. Impeller Smoothing: As stated in Section 3.5, impeller smoothing is expected to cause a flow decrease of about 0.6% flow after the first cycle. Unit 2 pre-startup testing was normal, so the flow decrease for Cycle 2 was defined to be -0.6% flow.

b. Steam Generator Tube Plugging: The tube plugging at Unit 2 had a negligible impact on RCS flow until Cycle 6 when the average plugging reached 3.5%, causing a decrease of 0.8% flow.

c. Fuel Design Changes: Although the fuel design changed over the six cycles, the best estimate analyses determined that the overall impact of the changes on RCS flow was negligible.

Considering all of the above, the overall impact of the hydraulic changes was expected to be 1.4% flow over six cycles of operation, as indicated in Table 3.6-1. Cycle 1 is defined as the baseline for best estimate flow, and the trend defined on Table 3.6-1 is plotted on Figure 3.6-2, with the Cycle 1 flow specified as 100%.

Based on the elbow tap flow measurement procedure described in Section 3.4.2, the future cycle estimated flow (FEF) is 98.6%, so the estimated flow ratio (R') for Cycle 6 and for future cycles if no hydraulics changes are made is, therefore, 0.986.

3.6.2 Evaluation of Elbow Tap Flows

South Texas Project Unit 1

Elbow tap Δp measurements were obtained from all 12 transmitters at the beginning of each Unit 1 fuel cycle. When the Δp measurements were obtained, Unit 1 was operating at about 70% power for Cycles 1 through 5, and about 100% power for Cycles 6 and 7. As discussed in Section 3.5, RCS flow decreases as power increases from zero to 100%. Based on the Unit 1 specific parameters, the decrease is 1.2% flow from zero to 100% power, and 0.4% flow from 70 to 100% power. Considering this flow decrease, the elbow tap Δps were adjusted so all measurements were at a common flow (at full power). The adjusted Δps expressed in inches of water at 100% flow are listed on Table 3.6-2. Another adjustment was made in normalizing flows to the baseline flow to account for the decrease in cold leg temperature in Cycles 6 and 7, in accordance with the elbow tap flow measurement procedure defined in Section 3.4.2.

The Cycle 1 elbow tap Δps define the baseline for subsequent elbow tap measurements. Table 3.6-2 lists the elbow tap flow comparison of subsequent cycles normalized to the Cycle 1 flow, expressed as 100% flow. Figure 3.6-1 shows normalized elbow tap flows for the seven cycles, for comparison to best estimate and calorimetric flows.

South Texas Project Unit 2

Elbow tap Δp measurements were obtained from all 12 transmitters, as for Unit 1, at the beginning of each Unit 2 fuel cycle. When the Δps were measured, Unit 2 was operating at about 70% power for Cycles 1 through 4, and about 100% power for Cycles 5 and 6. As for Unit 1, Unit 2 elbow tap Δps were adjusted so the measurements were all at a common (full power) flow. The adjusted Δps expressed in inches of water at 100% flow are listed on Table 3.6-2.

The adjustment was also made in normalizing flows to the baseline flow to account for the cold leg temperature decrease in Cycles 5 and 6, in accordance with the procedure defined in Section 3.4.2.

The comparison of elbow tap measurements normalized to the Cycle 1 elbow tap baseline flow is listed on Table 3.6-2 and shown on Figure 3.6-2 for comparison to best estimate and calorimetric flows.

3.6.3 Evaluation of Calorimetric Flows

Calorimetric flow measurements were obtained from the South Texas Project units at the beginning of each cycle. The initial data was obtained at about 70% power for Cycles 1-5 in Unit 1 and Cycles 1-4 in Unit 2, but calorimetric data was also obtained shortly after full power was attained in these cycles. Since calorimetric flow measurements at full power are more accurate than measurements at reduced power, this evaluation is based on full power measurements. The calorimetric flows are listed in Table 3.6-3 and compared with the best estimate flows. The definitions of columns on the table are as follows:

* MEASURED CAL is the total calorimetric flow for the indicated cycle. Listed at the bottom of the column is the average of the cycle flows, conservatively defined to be the baseline calorimetric flow for the unit.

* % of BASE CAL shows the cycle flow differences from the baseline calorimetric flow defined above.

* BEST EST shows the change in the cycle flows from the baseline best estimate flow, normalized to 100% flow as on Table 3.6-1.

* ADJUSTED CAL is the measured calorimetric flow adjusted for the known hydraulics changes defined on Table 3.6-1.

South Texas Project Unit 1

Total calorimetric and best estimate flows for Unit 1 are listed on Table 3.6-3. The procedure described in Section 3.4.2 would normally be used to define baseline flow. The Cycle 1 flow of 404,716 gpm, which is in good agreement with the best estimate flow of 407,472 gpm, would normally be used to define baseline calorimetric flow. For additional conservatism, a baseline calorimetric flow based on the average flow for all cycles (404,092 gpm) was defined. The resulting baseline flow is only slightly less than the Cycle 1 flow.

A baseline calorimetric flow more representative of actual flow in the early operating cycles would be based on the average flow for Cycles 1, 2 and 4, which is 405,316 gpm, and closer to the best estimate flow. Including all cycles in the baseline flow calculation introduces a conservative flow bias of 0.3% below the baseline flow based on the early fuel cycles.

South Texas Project Unit 2

Total calorimetric and best estimate flows for Unit 2 are listed on Table 3.6-3. The procedure described in Section 3.4.2 would normally be used to define baseline flow. The Cycle 1 flow of 406,944 gpm, which is in good agreement with the best estimate flow of 405,756 gpm, would normally be used to define baseline calorimetric flow. For additional conservatism, a baseline calorimetric flow based on the average flow for all cycles (402,456 gpm) was defined. The resulting baseline flow is over 1% less than the Cycle 1 flow. The flows for Cycles 5 and 6 are well below the best estimate flow and are considered to be affected by low leakage loading patterns and hot leg streaming.

3.6.4 Flow Comparisons

South Texas Project Unit 1

Figure 3.6-1 compares total best estimate, elbow tap and calorimetric flows for Unit 1. Best estimate and elbow tap flows, normalized to the flows for Cycle 1, are in good agreement for the seven cycles, considering that there is some uncertainty on the time when flow decreased due to impeller smoothing, and that less precision was used when averaging elbow tap data during early cycles. Elbow tap and best estimate flows are in very good agreement in the recent cycles.

Figure 3.6-1 also shows calorimetric flows normalized to the average calorimetric flow for the seven fuel cycles. Although Figure 3.6-1 shows only small differences between calorimetric and best estimate or elbow tap flows for Cycles 5 through 7, Table 3.6-3 indicates that the difference in adjusted calorimetric flow from Cycle 1 to Cycle 7 would be about 1% flow if impeller smoothing actually occurred before Cycle 1.

South Texas Project Unit 2

Figure 3.6-2 compares total best estimate, elbow tap and calorimetric flows for Unit 2. Best estimate and elbow tap flows, normalized to the flows for Cycle 1, are in good agreement in the later cycles. The larger differences in Cycles 2 and 3 have been attributed to the reduced precision used when averaging elbow tap data during these cycles. Elbow tap and best estimate flow trends are in very good agreement in the recent cycles.

Figure 3.6-2 also shows calorimetric flows normalized to the average calorimetric flow for the six cycles. As noted above, the Cycle 1 flow would have provided a sufficiently accurate baseline flow. If Cycle 1 had been used to define baseline calorimetric flow, the flow difference in Cycles 5 and 6 would be larger and would be a more representative indication of the low leakage loading pattern impact. Based on comparisons of adjusted calorimetric flows in Table 3.6-3, the Cycle 6 flow is almost 2% below the Cycle 1 flow.

3.6.5 Power/Flow Correlation for South Texas Project

Westinghouse's review of the radial power distribution and measured calorimetric flows from South Texas Project Units 1 & 2 indicated that the data, especially from the most recent fuel cycles, was consistent with the power/flow trend shown in Figure 3.3-4. Figure 3.6-3 plots the apparent flow decreases versus the power difference between second row and outer row assemblies for South Texas Project Units 1 & 2. The decreases in RCS flow are based on calorimetric flows adjusted for hydraulics effects, as listed on Table 3.6-3. The data from both units defines a similar correlation to that shown on Figure 3.3-4, with the decrease in flow approaching 2% at Unit 2. The Unit 1 data has a similar trend, but with a smaller flow decrease, probably due to the pump impeller smoothing uncertainty discussed earlier. The flow decreases for recent cycles predicted by the power/flow correlation are consistent with the conclusions discussed above. The power/flow correlation thus provides a qualitative confirmation of the hot leg streaming theory and differences between elbow tap and calorimetric flow measurements.

TABLE 3.6-1

SOUTH TEXAS PROJECT BEST ESTIMATE FLOW SUMMARY

UNIT 1

CYCLE 1 BEST ESTIMATE FLOW = 407,472 GPM

CYCLE	HYDRAULICS CHANGE	FLOW CHANGE (%)	FLOW (%)
1	N/A	0.0	100.0
2	Impeller Smoothing	-0.6 (*)	99.4
3	N/A	0.0	99.4
4	N/A	0.0	99.4
5	N/A	0.0	99.4
6	S/G Tube Plugging	-0.2	99.2
7	S/G Tube Plugging	-0.1	99.1

(*) Impeller smoothing impact = 0 to -0.6%. Only the maximum impact is considered here.

UNIT 2

CYCLE 1 BEST ESTIMATE FLOW = 405,756 GPM

CYCLE	HYDRAULICS CHANGE	FLOW CHANGE (%)	FLOW (%)
1	N/A	0.0	100.0
2	Impeller Smoothing	-0.6	99.4
3	N/A	0.0	99.4
4	N/A	0.0	99.4
5	N/A	0.0	99.4
6	S/G Tube Plugging	-0.8	98.6

TABLE 3.6-2

SOUTH TEXAS PROJECT ELBOW TAP DIFFERENTIAL PRESSURE SUMMARY

UNIT 1

DIFFERENTIAL PRESSURES IN INCHES OF WATER

CYCLE	LOOP 1	LOOP 2	LOOP 3	LOOP 4	AVERAGE	T_{COLD} (°F)	ELBOW TAP % of BASELINE
1	496.09	483.96	500.86	460.37	485.32	562.7	100.00
2	494.51	482.62	494.75	457.84	482.43	561.1	99.70
3	497.71	487.92	497.21	460.47	485.83	563.6	100.05
4	492.21	484.82	493.02	458.32	482.09	563.1	99.67
5	497.53	479.29	502.60	458.48	484.48	562.6	99.91
6	489.64	482.46	490.00	455.83	479.48	557.5	99.02
7	490.18	487.00	490.49	455.55	480.81	556.5	99.09

ELBOW TAP BASELINE FLOW COEFFICIENT (B) = 10.5455 inches * ft³/#
B is based on Cycle 1 Average Δp (485.32 psi), Cycle 1 Tcold (562.7°F), and 2250 psia

UNIT 2

DIFFERENTIAL PRESSURES IN INCHES OF WATER

CYCLE	LOOP 1	LOOP 2	LOOP 3	LOOP 4	AVERAGE	T_{COLD} (°F)	ELBOW TAP % of BASELINE
1	487.59	454.65	511.04	468.11	480.35	562.7	100.00
2	492.67	456.45	511.17	472.33	483.16	562.8	100.30
3	484.38	452.19	511.41	468.39	479.09	563.2	99.87
4	480.17	445.40	505.19	465.09	473.96	563.6	99.33
5	487.14	454.42	513.98	468.82	481.09	556.7	99.64
6	479.67	447.19	505.14	464.99	474.25	556.8	98.94

ELBOW TAP BASELINE FLOW COEFFICIENT (B) = 10.4375 inches * ft³/#
B is based on Cycle 1 Average Δp (480.35 psi), Cycle 1 Tcold (562.7°F), and 2250 psia

TABLE 3.6-3

SOUTH TEXAS PROJECT CALORIMETRIC FLOW SUMMARY

UNIT 1

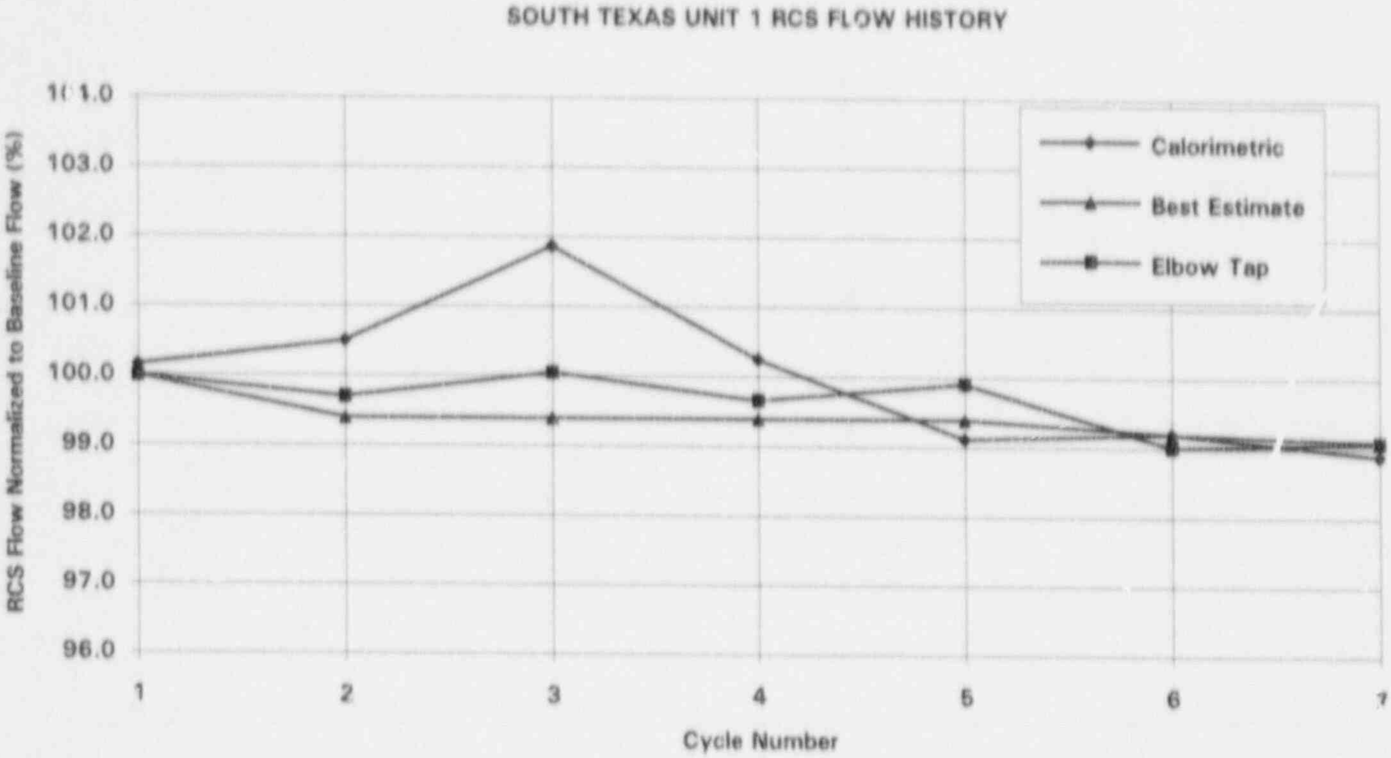
CYCLE	MEASURED CAL gpm	% OF BASE CAL	BEST EST gpm	ADJUSTED CAL gpm
1	404,716	100.2	407,472	404,716
2	406,124	100.5	405,028	408,575
3	411,628	101.9	405,028	414,112
4	405,104	100.3	405,028	407,549
5	400,544	99.1	405,028	402,962
6	400,880	99.2	404,212	404,113
7	399,656	98.9	403,804	403,286
AVG (BASE)	404,092	100.0		

UNIT 2

CYCLE	MEASURED CAL gpm	% OF BASE CAL	BEST EST gpm	ADJUSTED CAL gpm
1	406,944	101.1	405,756	406,944
2	406,188	100.9	403,320	408,640
3	402,988	100.1	403,320	405,420
4	404,852	100.6	403,320	407,296
5	399,644	99.3	403,320	402,056
6	394,116	97.9	400,076	399,712
AVG (BASE)	402,456	100.0		

FIGURE 3.6-1

SOUTH TEXAS PROJECT UNIT 1 FLOW COMPARISONS



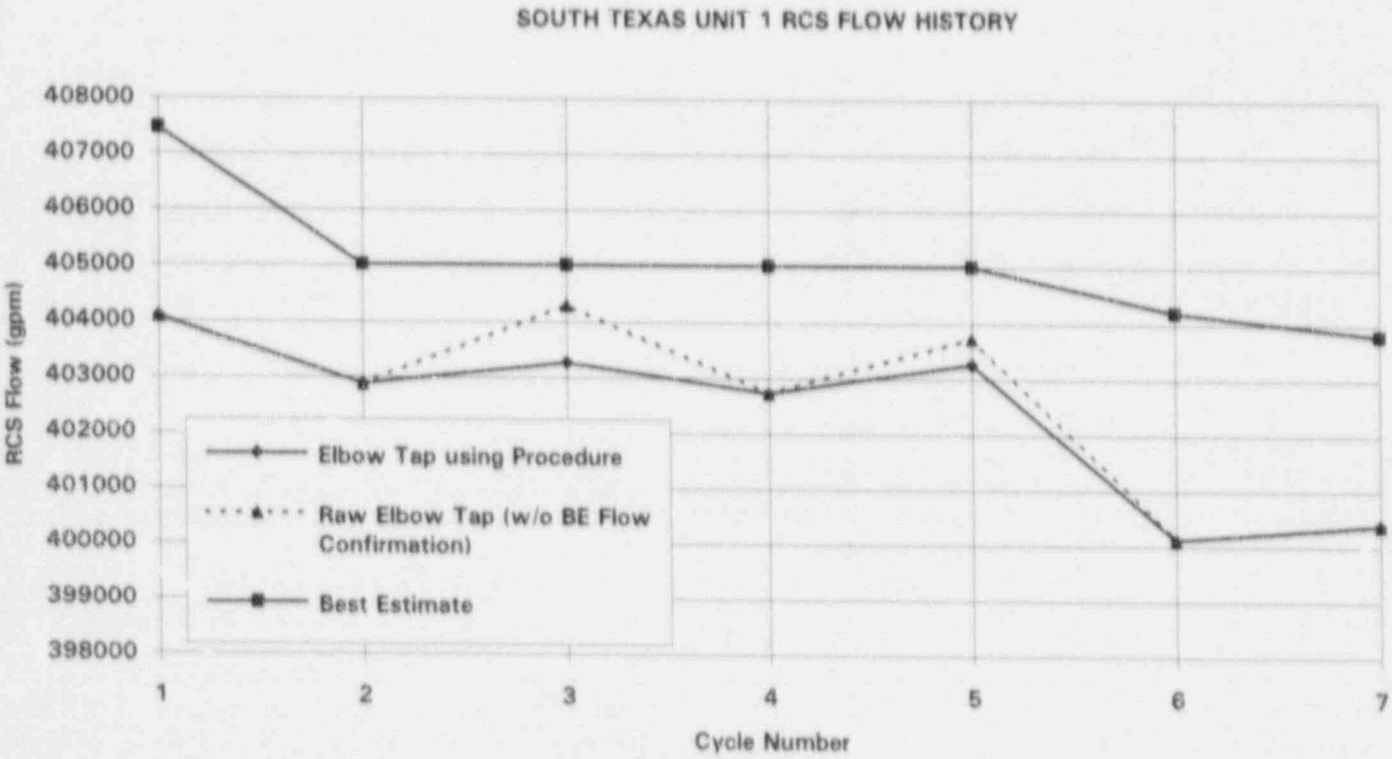
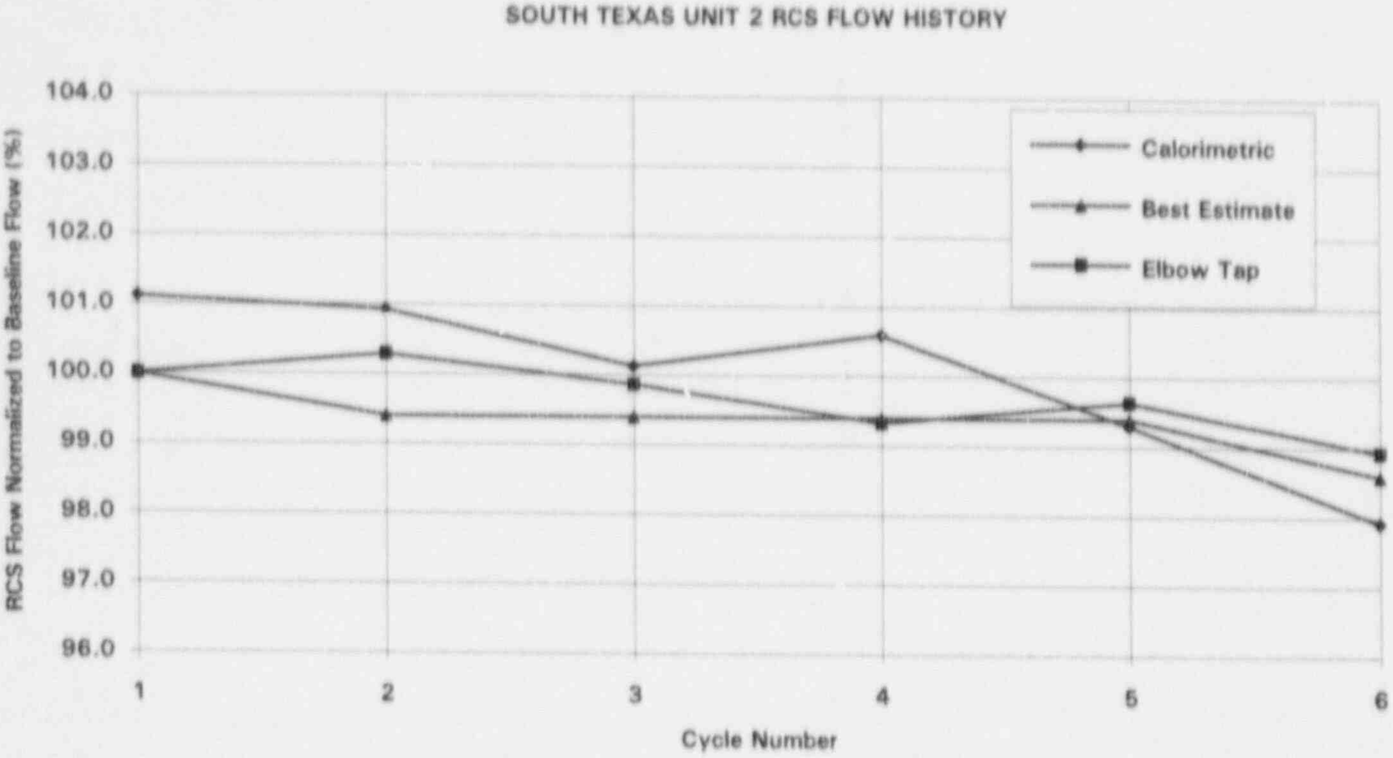


FIGURE 3.6-2

SOUTH TEXAS PROJECT UNIT 2 FLOW COMPARISONS



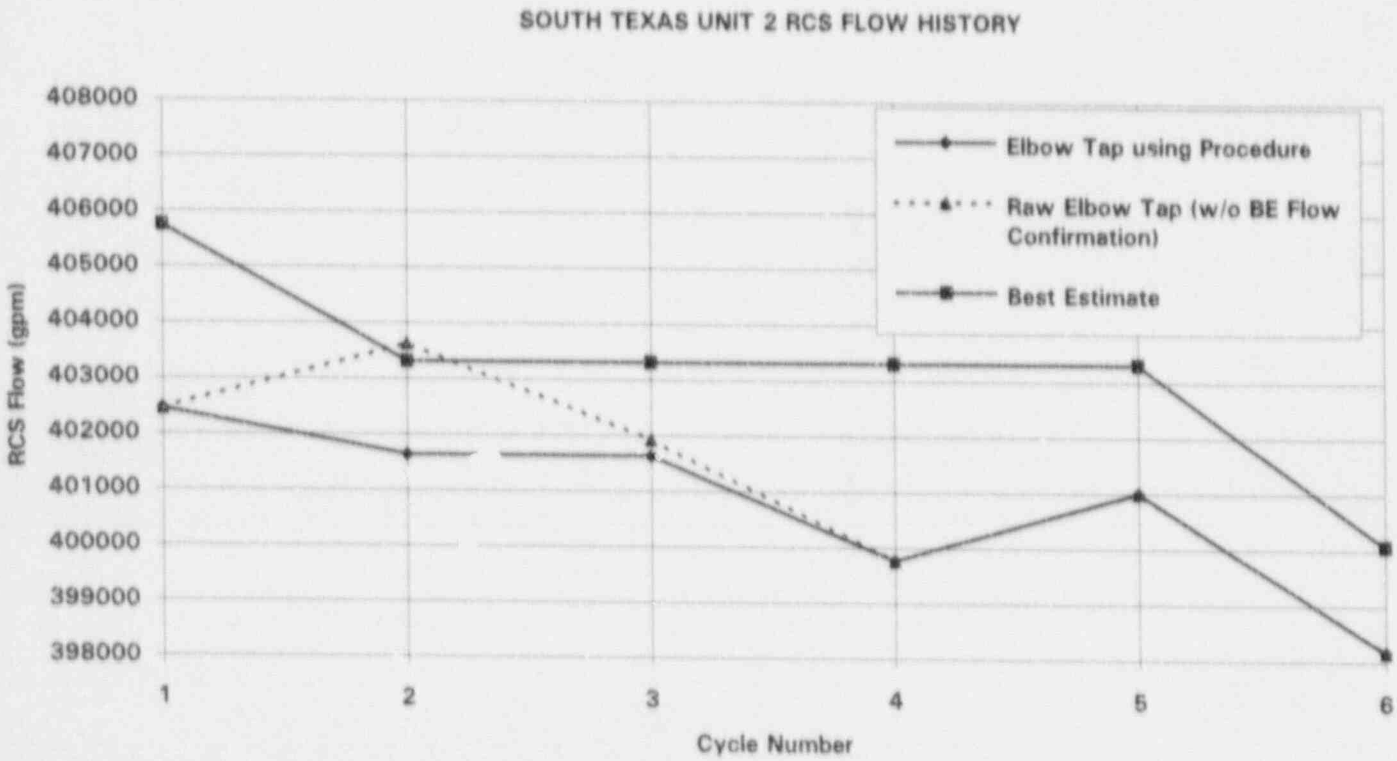
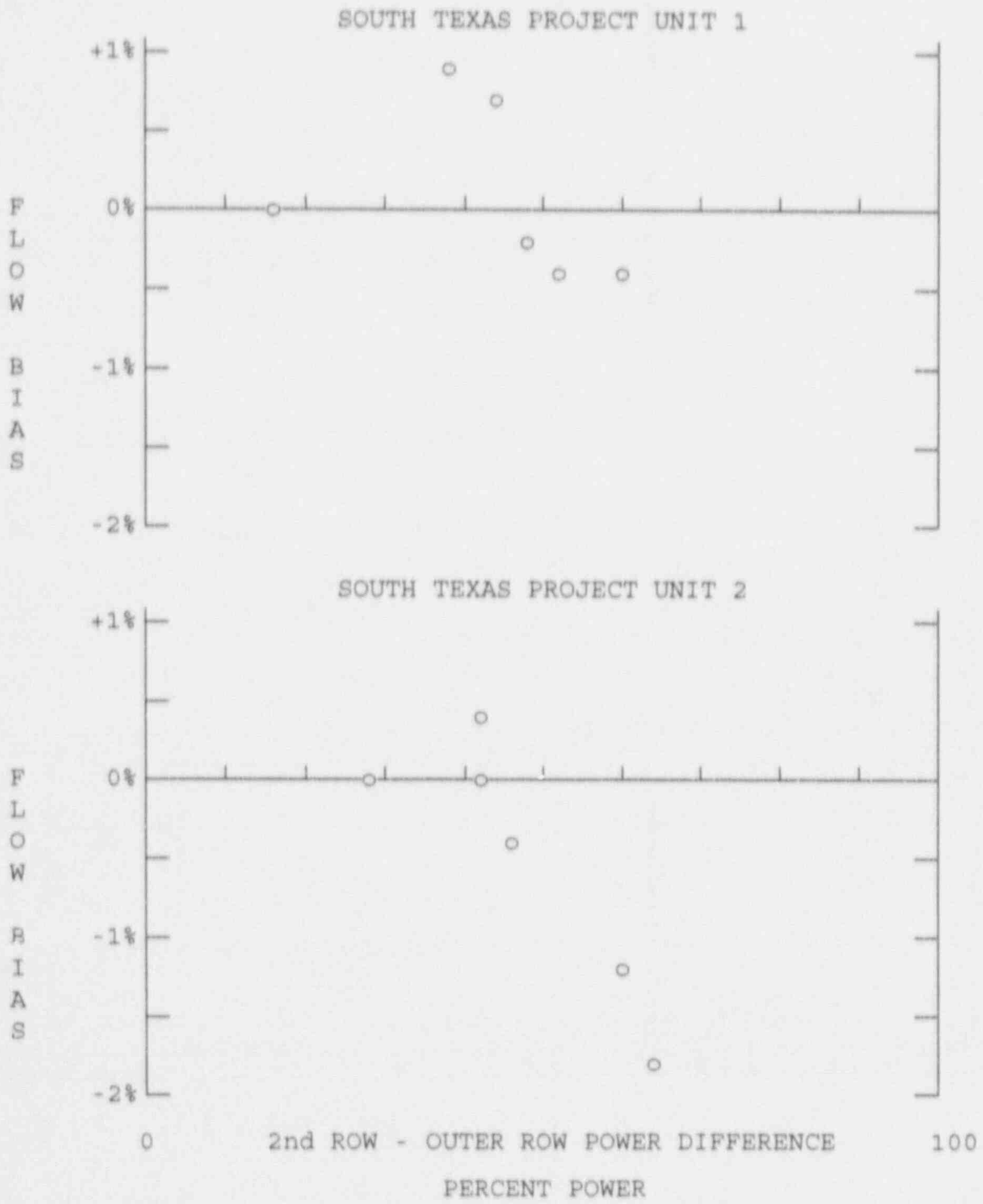


FIGURE 3.6-3

FLOW BIAS VS POWER DIFFERENCE



3.7 ELBOW TAP FLOW MEASUREMENT LICENSING CONSIDERATIONS

3.7.1 Background

Plant Technical Specifications require that an RCS total flow measurement be performed every 18 months to verify that sufficient RCS flow is available to satisfy the safety analysis assumptions. This surveillance is normally performed at the beginning of each operating cycle. Technical Specifications also require that a qualitative RCS flow verification (i.e., channel check) be performed every 12 hours during Mode 1. These surveillances ensure RCS flow is maintained within the assumed safety analysis value, i.e., Minimum Measured Flow (MMF).

The 18-month RCS flow surveillance is typically satisfied by a secondary power calorimetric-based RCS flow measurement and the 12 hour RCS flow surveillance is satisfied by control board RCS flow indicator or plant process computer readings using inputs from the RCS elbow tap Δp channels. These surveillances and the RCS Low Flow reactor trip are interrelated since the calorimetric RCS flow measurement is used to correlate elbow tap Δp measurements to flow, and the flow at the Δp setpoint for the RCS Low Flow reactor trip is verified to be at or above the flow assumed in the safety analysis. The process computer output is normalized to the calorimetric flow. The uncertainty associated with the 18-month precision calorimetric is, therefore, included in the uncertainty calculations for the surveillance criterion and the RCS Low Flow trip.

The purpose of this evaluation is to support the use of elbow tap Δp measurements as an alternate method for performing the 18-month RCS flow surveillance. Many plants in recent cycles have experienced apparent decreases in flow rates which have been attributed to variations in hot leg streaming, as discussed in previous sections of this document. Hot leg steaming effects directly impact the hot leg temperatures used in the precision calorimetric, resulting in the calculation of apparently low RCS flow rates. In using the elbow tap Δp method, the RCS elbow tap measurements are correlated (as described in Section 3.4.2) to precision calorimetric measurements performed during earlier cycles when the hot leg streaming effects were decreased.

3.7.2 Supporting Calculations

In order to implement the elbow tap Δp method of measuring RCS flow, calculations have been performed to determine the uncertainty associated with the precision RCS flow calorimetric(s) for the baseline cycle(s). These calculations account for the plant instrumentation, test equipment, and procedures that were in place at the time the calorimetric was performed.

In addition, uncertainty calculations have been performed for the indicated RCS flow (computer and control board indication) and the RCS low flow reactor trip. These calculations reflect the correlation of the elbow taps to the baseline precision RCS flow calorimetric(s) noted above. Additional instrument uncertainties are required to reflect this correlation. Appendix A contains uncertainty calculations that were performed using South Texas Project specific inputs.

These uncertainty calculations have confirmed the acceptability of previously performed South Texas Project specific safety analyses and associated protection and/or control system setpoints when the periodic surveillance is performed via use of Qualified Display Processing System (QDPS) or plant process computer indication on an 18 month basis. In particular, no increase in the RCS total flow uncertainty due to the elbow tap Δp method has been determined when using the QDPS or plant process computer indication. Thus revision to the Westinghouse Revised Thermal Design Procedure (RTDP) instrumentation uncertainties (currently 2.8% flow), which are used in deriving the Technical Specifications reactor core safety limits and the corresponding DNB limits is not required. If control board indication is utilized, there is a small increase in the instrumentation uncertainty for RCS flow which does not affect the RTDP results or the Technical Specifications reactor core safety limits nor the corresponding DNB limits. The low flow reactor trip setpoint uncertainty has increased somewhat but does not require a change to either the Technical Specifications trip setpoint (91.8% flow) or to the current Safety Analysis Limit (87% flow) due to the availability of margin in the uncertainty calculation. The revised Technical Specifications including the change to the allowable value is noted in Appendix C.

Technical Specification Table 2.2-1 columns headed TA, Z, and S are marked as N/A in revised Technical Specifications for the Reactor Coolant Flow-Low trip. A two column approach (Nominal Trip Setpoint and Allowable Value) is consistent with the NRC's position for the Improved Technical Specifications (NUREG-1431) where there is no longer the TA, S and Z columns and is the Westinghouse recommended approach. With the two column approach, the Allowable Value is based on an appropriate determination of channel operability consistent with the uncertainty calculations and the process rack drift allowance. Z and S terms are not applicable to the process racks and therefore are marked N/A. Since TA in Technical Specification Table 2.2-1 is only used in conjunction with columns S and Z, and is not part of an operability determination, the TA column is also marked N/A.

3.7.3 Potential Document Impacts

The South Texas Project Technical Specifications are affected in four areas:

1) Specification 2.2.1, Table 2.2-1, Item 12, Reactor Coolant Flow - Low (Trip Setpoint, Allowable Value; magnitude changed to reflect uncertainty calculation results);
2) Specification 3.2.5 (Surveillance Requirement 4.2.5.3 is modified); and
3) Associated Bases for this specification (to include a description of the elbow tap Δp method of flow measurement and to note the indication sources).

Appendix B contains the 50.92 input for licensing documentation purposes.

Appendix C contains a markup of the South Texas Project Technical Specifications.

In the case of the South Texas Project specific instrument uncertainty analyses shown in Appendix A, the RCS flow uncertainty associated with the elbow tap Δp method (when indication is provided by QDPS or the plant process computer) was less than or equal to the current Technical Specification value. RCS low flow reactor trip setpoint uncertainty calculations also verify that the current trip setpoint and Safety Analysis Limit remain valid.

APPENDIX A

INDICATED RCS FLOW and REACTOR COOLANT FLOW - LOW REACTOR TRIP INSTRUMENT UNCERTAINTIES

TABLE A-1 BASELINE FLOW CALORIMETRIC INSTRUMENTATION UNCERTAINTIES

+a,c

(% SPAN)	T_{FW}	P_{FW}	ΔP_{FW}	P_{STM}	T_{HOT}	T_{COLD}	P_{RCS}
Sensor							
SCA =							
M&TE=							
SRA =							
SPE =							
STE =							
SD =							
BIAS=							
R/E-A/D							
RCA =							
M&TE=							
RTE =							
RD =							
D/A							
RCA =							
M&TE=							
RTE =							
RD =							
RDOUT=							
Noise=							
CSA =							
# INST USED	1	1	1	1	3	1	*
	°F	psia	% ΔP	psia	°F	°F	psia
INST SPAN	300	1400	120	1400	100+	100+	800
INST UNC. (RANDOM) =							
INST UNC. (BIAS) =							
NOMINAL =	440	1298		1106	622.4	562.3	2250

+a,c

* Pressurizer pressure is not measured, but is assumed based on the controller. A conservative uncertainty value is used.

\+ T_{AVG} span

TABL. '-2 FLOW CALORIMETRIC SENSITIVITIES

FEEDWATER FLOW			+a,c
FA			
TEMPERATURE	=		%/°F
MATERIAL	=		%
DENSITY			
TEMPERATURE	=		%/°F
PRESSURE	=		%/psi
ΔP	=		%/%ΔP
FEEDWATER ENTHALPY			
TEMPERATURE	=		%/°F
PRESSURE	=		%/psi
hS	=	1188	Btu/lbm
hF	=	419.6	Btu/lbm
Δh(SG)	=	768.4	Btu/lbm
STEAM ENTHALPY			+a,c
PRESSURE	=		%/psi
MOISTURE	=		%/0.25% Moisture
HOT LEG ENTHALPY			
TEMPERATURE	=		%/°F
PRESSURE	=		%/psi
hH	=	646.1	Btu/lbm
hC	=	562.3	Btu/lbm
Δh(VESS)	=	83.8	Btu/lbm
Cp(TH)	=	1.579	Btu/lbm-°F
COLD LEG ENTHALPY			+a,c
TEMPERATURE	=		%/°F
PRESSURE	=		%/psi
Cp(TC)	=	1.273	Btu/lbm-°F
COLD LEG SPECIFIC VOLUME			+a,c
TEMPERATURE	=		%/°F
PRESSURE	=		%/psi

TABLE A-3 CALORIMETRIC RCS FLOW MEASUREMENT UNCERTAINTIES

COMPONENT		INSTRUMENT ERROR	FLOW UNCERTAINTY
FEEDWATER FLOW		+a,c	+a,c
VENTURI		% K	% FLOW
THERMAL EXPANSION COEFFICIENT			
TEMPERATURE		°F	
MATERIAL		%	
DENSITY (ρ)			
TEMPERATURE		°F	
PRESSURE		psi	
ΔP		% ΔP	
FEEDWATER ENTHALPY (h)			
TEMPERATURE		°F	
PRESSURE		psi	
STEAM ENTHALPY (h)			
PRESSURE		psi	
MOISTURE		% Moisture	
NET PUMP HEAT ADDITION		%	
HOT LEG ENTHALPY (h)			
TEMPERATURE		°F	
STREAMING, RANDOM		°F	
STREAMING, SYSTEMATIC		°F	
PRESSURE		psi	
COLD LEG ENTHALPY (h)			
TEMPERATURE		°F	
PRESSURE		psi	
COLD LEG SPECIFIC VOLUME (υ)			
TEMPERATURE		°F	
PRESSURE		psi	
BIAS VALUES			
FEEDWATER PRESSURE	ρ		
	h		
STEAM PRESSURE	h		
PRESSURIZER PRESSURE	h - HOT LEG		
	h - COLD LEG		
	υ - COLD LEG		
FLOW BIAS TOTAL VALUE			

*,**,+,++ INDICATE SETS OF DEPENDENT PARAMETERS

		+a,c
SINGLE LOOP UNCERTAINTY	(NO BIAS)	% FLOW
N LOOP UNCERTAINTY	(NO BIAS)	% FLOW
N LOOP UNCERTAINTY	(WITH BIAS)	% FLOW

TABLE A-4
COLD LEG ELBOW TAP FLOW UNCERTAINTY
(QDPS/PROCESS COMPUTER)

INSTRUMENT UNCERTAINTIES

	% ΔP SPAN	% FLOW [+a,c]
PMA =		
PEA =		
SCA =		
M&TE=		
SRA =		
SPE =		
STE =		
SD =		
BIAS=		
7300 Racks		
RCA =		
M&TE=		
RTE =		
RD =		
A/D		
RCA =		
M&TE=		
RTE =		
RD =		
FLOW CALORIM BIAS =		
FLOW CALORIMETRIC =		

INSTRUMENT SPAN = 120.0 % Flow

NUMBER TAPS PER LOOP = 3

N LOOP RCS FLOW UNCERTAINTY = 2.6 % FLOW

TABLE A-5 LOW FLOW REACTOR TRIP

	% ΔP SPAN	% FLOW SPAN
PMA1 =	[	]+a,c
PMA2 =		
PEA =		
SCA =		
M&TE =		
SRA =		
SPE =		
STE =		
SD =		
BIAS1=		
RCA =		
M&TE =		
RTE =		
RD =		
BIAS =		

INSTRUMENT RANGE = 0 TO 120.0 % FLOW

FLOW SPAN = 120.0 % FLOW

SAFETY ANALYSIS LIMIT = 87.0 % FLOW

NOMINAL TRIP SETPOINT = 91.8 % FLOW

TA = 4.0 % FLOW SPAN

CSA = [ ]+a,c % FLOW SPAN

MAR = [ ]+a,c % FLOW SPAN

APPENDIX B

NO SIGNIFICANT HAZARDS CONSIDERATION

Pursuant to 10CFR50.92 each application for amendment to an operating license must be reviewed to determine if the proposed change involves a Significant Hazards Consideration. The amendment, as defined below, describing the Technical Specification change associated with the change has been reviewed and determined to not involve Significant Hazards Considerations. The basis for this determination follows.

Proposed Change: The current Technical Specification Table 2.2-1 (page 2-4) "Reactor Trip System Instrumentation Trip Setpoints," provides the Trip Setpoint and Allowable Value for the RCS Flow -Low trip. The Allowable Value will be changed to reflect the increased uncertainty associated with the correlation of the elbow taps to a previous baseline calorimetric. In addition, Technical Specification 3.2.5 (page 3/4.2-11), "Power Distribution Limits, DNB Parameters", will be changed to allow the RCS total flow to be measured by the elbow tap Δp method. These changes will include the modification of surveillance requirement 4.2.5.3, which currently requires performance of a precision heat balance every 18 months, to allow use of the elbow tap Δp method for RCS flow measurement. Appropriate Technical Specification Bases sections will also be revised to reflect use of the elbow tap Δp method for flow measurement and to provide clarification. The revised Technical Specifications are in Appendix C.

Background: The 18-month total RCS flow surveillance is typically satisfied by a secondary power calorimetric-based RCS flow measurement. In recent cycles, South Texas Project has experienced apparent decreases in flow rates which have been attributed to variations in hot leg streaming effects. These effects directly impact the hot leg temperatures used in the precision calorimetric, resulting in the calculation of low RCS flow rates. The apparent flow reduction has become more pronounced in fuel cycles which have implemented aggressive low leakage loading patterns. Evidence that the flow reduction was apparent, but not actual, was provided by elbow tap measurements. The results of this evaluation, including a detailed description of the hot leg streaming phenomenon, are documented in Westinghouse report SAE/FSE-TGX/THX-0152, "RCS Flow Verification Using Elbow Taps."

South Texas Project intends to begin using an alternate method of measuring RCS flow using the elbow tap Δp measurements. For this alternate method, the RCS elbow tap measurements are correlated to precision calorimetric measurements performed during earlier cycles which decreased the effects of hot leg streaming.

The purpose of this evaluation is to assess the impact of using the elbow tap Δp measurements as an alternate method for performing the 18-month RCS flow surveillance on the licensing basis and demonstrate that it will not adversely affect the subsequent safe operation of the plant. This evaluation supports the conclusion that implementation of the elbow tap Δp measurement as an alternate method of determining RCS total flow rate does not represent a significant hazards consideration as defined in 10CFR50.92.

Evaluation: Use of the elbow tap Δp method to determine RCS total flow requires that the Δp measurements for the present cycle be correlated to the precision calorimetric flow measurement which was performed during the baseline cycle(s). A calculation has been performed to determine the uncertainty in the RCS total flow using this method. This calculation includes the uncertainty associated with the RCS total flow baseline calorimetric measurement, as well as uncertainties associated with Δp transmitters and indication via QDPS or the plant process computer. The uncertainty calculation performed for this method of flow measurement is consistent with the methodology recommended by the Nuclear Regulatory Commission (NUREG/CR-3659, PNL-4973, 2/85). The only significant difference is the assumption of correlation to a previously performed RCS flow calorimetric. However, this has been accounted for by the addition of instrument uncertainties previously considered to be zeroed out by the assumption of normalization to a calorimetric performed each cycle. Based on these calculations, the uncertainty on the RCS flow measurement using the elbow tap method is 2.6% flow which results in a minimum RCS total flow of 391,500 gpm and must be measured via indication with QDPS or the plant process computer at approximately 100% power.

The specific calculations performed were for Precision RCS Flow Calorimetrics for the specified baseline cycles, Indicated RCS Flow (either QDPS or the plant process computer), and the Reactor Coolant Flow - Low reactor trip. The calculations for Indicated RCS Flow and Reactor Coolant Flow - Low reactor trip reflect correlation of the elbow taps to baseline precision RCS Flow Calorimetrics. As discussed above, additional instrument uncertainties were included for this correlation.

The uncertainty associated with the RCS Flow - Low trip increased slightly. It was determined that due to the availability of margin in the uncertainty calculation, no change was necessary to either the Trip Setpoint (91.8% flow) or to the current Safety Analysis Limit (87% flow) to accommodate this increase. The Allowable Value is to be modified to allow for the increased instrument uncertainties associated with the Δp to flow correlation.

Since the flow uncertainty did not increase over the currently analyzed value, no additional evaluations of the reactor core safety limits must be performed. In addition, it was determined that the current Minimum Measured Flow (MMF) assumed in the safety analyses (389,200 gpm) bounds the required MMF calculated for the elbow tap method (391,500 gpm).

Based on these evaluations, the proposed change would not invalidate the conclusions presented in the UFSAR.

1. Does the proposed modification involve a significant increase in the probability or consequences of an accident previously evaluated?

Sufficient margin exists to account for all reasonable instrument uncertainties; therefore, no changes to installed equipment or hardware in the plant are required, thus the probability of an accident occurring remains unchanged.

The initial conditions for all accident scenarios modeled are the same and the conditions at the time of trip, as modeled in the various safety analyses, are the same. Therefore, the consequences of an accident will be the same as those previously analyzed.

2. Does the proposed modification create the possibility of a new or different kind of accident from any accident previously evaluated?

The proposed change revises the method for RCS flow measurement, and therefore does not introduce any new accident indicators or failure mechanisms.

No new accident scenarios have been identified. Operation of the plant will be consistent with that previously modeled, i.e., the time of reactor trip in the various safety analyses is the same, thus plant response will be the same and will not introduce any different accident scenarios that have not been evaluated.

3. Does the proposed modification involve a significant reduction in a margin of safety.

There are no changes to the Safety Analysis assumptions. Therefore, the margin of safety will remain the same.

The proposed change does not impact the results from any accidents analyzed in the safety analysis.

Conclusion: Based on the preceding information, it has been determined that this proposed change to allow an alternate RCS total flow measurement based on elbow tap Δp measurements does not involve a Significant Hazards Consideration as defined in 10 CFR 50.92(c).

APPENDIX C

MARKUPS TO SOUTH TEXAS PROJECT TECHNICAL SPECIFICATIONS and BASES

TABLE 2.2-1

REACTOR TRIP SYSTEM INSTRUMENTATION TRIP SETPOINTS

FUNCTIONAL UNIT	TOTAL ALLOWANCE (TA)	Z	SENSOR ERROR (S)	TRIP SETPOINT	ALLOWABLE VALUE
1. Manual Reactor Trip	N.A.	N.A.	N.A.	N.A.	N.A.
2. Power Range, Neutron Flux					
a. High Setpoint	7.5	6.1	0	≤109% of RTP**	≤110.7% of RTP**
b. Low Setpoint	8.3	6.1	0	≤25% of RTP**	≤27.7% of RTP**
3. Power Range, Neutron Flux, High Positive Rate	2.1	0.5	0	≤5% of RTP** with a time constant ≥2 seconds	≤6.7% of RTP** with a time constant ≥2 seconds
4. Deleted					
5. Intermediate Range, Neutron Flux	16.7	8.4	0	≤25% of RTP**	≤31.1% of RTP**
6. Source Range, Neutron Flux	17.0	10.0	0	$\leq 10^5$ cps	$\leq 1.4 \times 10^5$ cps
7. Overtemperature ΔT	10.7	8.7	1.5 + 1.5#	See Note 1	See Note 2
8. Overpower ΔT	4.7	2.1	1.5	See Note 3	See Note 4
9. Pressurizer Pressure-Low	5.0	2.3	2.0	≥1870 psig	≥1860 psig
10. Pressurizer Pressure-High	5.0	2.3	2.0	≤2380 psig	≤2390 psig
11. Pressurizer Water Level-High	7.1	[illegible].3	2.0	≤92% of instrument span	≤94.1% of [illegible]ment span
12. Reactor Coolant Flow-Low	N/A ~~4.0~~	N/A ~~2.1~~	N/A ~~0.6~~	≥91.8% of loop design flow*	≥91.4 ~~90.5%~~ of loop design flow*

*Loop design flow = 95,400 gpm
**RTP = RATED THERMAL POWER
#1.5% span for ΔT; 1.5% span for Pressurizer Pressure

POWER DISTRIBUTION LIMITS

3/4.2.5 DNB PARAMETERS

LIMITING CONDITION FOR OPERATION

3.2.5 The following DNB-related parameters shall be maintained within the limits following:

a. Reactor Coolant System T_{avg}, ≤ 598°F

b. Pressurizer Pressure, > 2189 psig*

c. Reactor Coolant System Flow, ≥ 392,300 gpm**

APPLICABILITY: MODE 1.

ACTION:

With any of the above parameters exceeding its limit, restore the parameter to within its limit within 2 hours or reduce THERMAL POWER to less than 5% of RATED THERMAL POWER within the next 4 hours.

SURVEILLANCE REQUIREMENTS

4.2.5.1 Each of the parameters shown above shall be verified to be within its limits at least once per 12 hours. The provisions of Specification 4.0.4 are not applicable for verification that RCS flow is within its limit.

4.2.5.2 The RCS flow rate indicators shall be subjected to a channel calibration at least once per 18 months.

4.2.5.3 The RCS total flow rate shall be determined by ~~precision heat balance~~ measurement~~s~~ at least once per 18 months. The provisions of Specification 4.0.4 are not applicable.

* Limit not applicable during either a Thermal Power ramp in excess of 5% of RTP per minute or a Thermal Power step in excess of 10% RTP.

**Includes a 2.8% flow measurement uncertainty.

POWER DISTRIBUTION LIMITS

BASES

HEAT FLUX HOT CHANNEL FACTOR and NUCLEAR ENTHALPY RISE HOT CHANNEL FACTOR (Continued)

When an F_Q measurement is taken, an allowance for both experimental error and manufacturing tolerance must be made. An allowance of 5% is appropriate for a full-core map taken with the Incore Detector Flux Mapping System, and a 3% allowance is appropriate for manufacturing tolerance.

The Radial Peaking Factor, $F_{xy}(Z)$, is measured periodically to provide assurance that the Hot Channel Factor, $F_Q(Z)$, remains within its limit. The F_{xy} limit for RATED THERMAL POWER (F_{xy}^{RTP}) as provided in the Core Operating Limits Report (COLR) per Specification 6.9.1.6 was determined from expected power control maneuvers over the full range of burnup conditions in the core.

3/4.2.4 QUADRANT POWER TILT RATIO

The QUADRANT POWER TILT RATIO limit assures that the radial power distribution satisfies the design values used in the power capability analysis. Radial power distribution measurements are made during STARTUP testing and periodically during power operation.

The limit of 1.02, at which corrective action is required, provides DNB and linear heat generation rate protection with x-y plane power tilts. A limit of 1.02 was selected to provide an allowance for the uncertainty associated with the indicated power tilt.

The 2-hour time allowance for operation with a tilt condition greater than 1.02 is provided to allow identification and correction of a dropped or misaligned control rod. In the event such action does not correct the tilt, the margin for uncertainty on F_Q is reinstated by reducing the maximum allowed power by 3% for each percent of tilt in excess of 1.

For purposes of monitoring QUADRANT POWER TILT RATIO when one excore detector is inoperable, the moveable incore detectors are used to confirm that the normalized symmetric power distribution is consistent with the QUADRANT POWER TILT RATIO. The incore detector monitoring is done with a full incore flux map or two sets of four symmetric thimbles. The two sets of four symmetric thimbles is a unique set of eight detector locations. These locations are C-8, E-5, E-11, H-3, H-13, L-5, L-11, N-8.

3/4.2.5 DNB PARAMETERS

The limits on the DNB-related parameters assure that each of the parameters are maintained within the normal steady-state envelope of operation assumed in the transient and accident analyses. The limits are consistent with the

POWER DISTRIBUTION LIMITS

BASES

3/4.2.5 DNB PARAMETERS (Continued)

initial FSAR assumptions and have been analytically demonstrated adequate to maintain a minimum DNBR of greater than or equal to the design limit throughout each analyzed transient. The T_{avg} value of 598°F and the pressurizer pressure value of 2189 psig are analytical values. The readings from four channels will be averaged and then adjusted to account for measurement uncertainties before comparing with the required limit. The flow requirement (392,300 gpm) includes a measurement uncertainty of 2.8%. The RCS flow measurement uncertainty of 2.8% bounds the precision calorimetric measurement method and the elbow tap Δp measurement method. The elbow tap Δp measurement uncertainty (2.6%) presumes that elbow tap Δp measurements are obtained from either QDPS or the plant process computer.

The 12-hour periodic surveillance of these parameters through instrument readout is sufficient to ensure that the parameters are restored within their limits following load changes and other expected transient operation.