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2CAN060901

June 1, 2009

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

SUBJECT: Response to Request for Additional Information for the Technical Specification Change to Modify RCS Flow Verification
Arkansas Nuclear One, Unit 2
Docket No. 50-368
License No. NPF-6

REFERENCES:

1. Entergy Letter to NRC dated November 13, 2008, "License Amendment Request Technical Specification Change to Modify RCS Flow Verification" (2CAN110801)
2. Email from Alan Wang (NRC) to Robert W. Clark (Entergy), "ANO-2 Request for Information Regarding RCS Flow Verification License Amendment Request (ME0125)," dated April 1, 2009

Dear Sir or Madam:

In Reference 1, Entergy Operations, Inc. (Entergy) proposed a change to the Arkansas Nuclear One, Unit 2 (ANO-2) Technical Specifications (TS). In particular, the change would modify TS 3.3.1.1, Reactor Protective Instrumentation, specifically Table 4.3-1 and associated Notes 7 and 8, to clarify and streamline Reactor Coolant System (RCS) flow verification requirements associated with the Departure from Nucleate Boiling Ratio (DNBR) reactor trip signal. The proposed change allows a more accurate Reactor Coolant Pump (RCP) differential pressure based flow indication, as calculated by the Core Operating Limits Supervisory System (COLSS), to be used as the calibration standard at all surveillance intervals.

During the submittal review process, the Nuclear Regulatory Commission (NRC) determined that additional information was required to complete the review of the Entergy request. The Request for Additional Information (RAI) was electronically transmitted to ANO-2 on April 1, 2009 (Reference 2). The response to RAI is to be provided within 60 days of receipt of the email.

The response to the RAI is included in the attachment to this letter.

A001
NRR

This letter contains no new commitments.

If you have any questions or require additional information, please contact David Bice at (479)-858-5338.

I declare under penalty of perjury that the foregoing is true and correct. Executed on June 1, 2009.

Sincerely,

BLB/rwc

Attachment: Response to RAI

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Attachment to

2CAN060901

Response to RAI

RESPONSE TO REQUESTS FOR ADDITIONAL INFORMATION

By letter dated November 13, 2008, Entergy Operations, Inc. (Entergy) proposed a change to the Arkansas Nuclear One, Unit 2 (ANO-2) Technical Specifications (TS). In particular, the change would modify TS 3.3.1.1, Reactor Protective Instrumentation, specifically Table 4.3-1 and associated Notes 7 and 8, to clarify and streamline Reactor Coolant System (RCS) flow verification requirements associated with the Departure from Nucleate Boiling Ratio (DNBR) reactor trip signal. The proposed change allows a more accurate and precise Reactor Coolant Pump (RCP) differential pressure based flow indication, as calculated by the Core Operating Limits Supervisory System (COLSS), to be used as the calibration standard at all surveillance intervals.

The NRC staff has reviewed the November 13, 2008, request and has determined that additional information is required to complete their review. Each portion of the Request for Additional Information (RAI) is listed below.

1. **Paragraph 4 on page 2 to Attachment 1 of letter dated November 13, 2008, indicates that the calorimetric method can be susceptible to the effects of temperature stratification of fluid in the reactor coolant system (RCS) hot-leg. It claims that these effects will result in calorimetric flow measurements being overly conservative as compared with the COLSS indicated flow rate.**

   (a) **Discuss the RCS hot-leg temperature measurements that are used for determining the calorimetric flow rate. The information should include a discussion of locations and numbers of temperature probes for hot-leg temperature measurements, and method of the hot-leg temperature determination.**

   The RCS hot-leg temperature instruments currently used in the calorimetric determination of flow consist of eight temperature elements on each hot leg (for a total of sixteen temperature elements). The eight temperature elements on each hot leg are arranged in pairs of two, with the two forming the pair being 90 degrees apart along the circumference of the pipe. On each hot leg, three instrument pairs are positioned on the top half of the pipe and one instrument pair is positioned on the bottom half of the pipe. The pairs on the top half of the pipe have elements approximately 45 degrees to the left and right of the top of the pipe. The single pair on the bottom of each hot leg pipe similarly has elements approximately 45 degrees to the left and right of the bottom. Figure 8 provides an illustration of the arrangement.

   The temperature instruments (Resistance Temperature Detectors) are in thermowells that protrude into the hot leg flow stream only 2.5 inches. The inside diameter of the hot leg piping is 42 inches.

   The average temperature of the hot leg coolant is determined by weighting instruments equally between the top and bottom of the piping. The technique currently used is equivalent to the following formula:

$$T_{hot} = \frac{\text{Average(Top 12 Elements)} + \text{Average(Bottom 4 Elements)}}{2}$$

In determining the average temperature, the aforementioned instrument pairs are considered as a complete set or not at all (i.e., single instrument failure or unavailability effectively removes the instrument pair from the average), such that instruments are also equally weighted from side-to-side of the pipe.

(b) Provide a discussion with applicable temperature measurement data to substantiate the claim that the calorimetric measured flow rate is "overly" conservative as compared with the COLSS indicated flow rate. The information should include a typical set of hot-leg temperature measurements that show temperature stratification, and a discussion to distinguish effects of uncertainties of RCS hot-leg temperature measurements and temperature stratification phenomena on the calorimetric flow rate determination. Also, quantify the conservatism in terms of a power level reduction in meeting the safety limit DNBR at a lowest value of the measured calorimetric flow rate.

The calorimetric flow rate is considered overly conservative based on observations of the RCP ΔP readings over time and comparison of recent and original calorimetric flow measurements. The relative change in flow indicated by pump ΔP readings in key cycles is shown in Table 1 below.

TABLE 1

Cycle	RCP ΔP Flow % Design Mass Flow @ 545 °F, 2200 psia
1	109.3
2	109.4
3	109.4
12	109.6
13	107.9
14	105.6
15 (1st Cycle with RSGs)	110.1
16 (1st Power Uprate Cycle)	110.1
20 (1/2 Core NGF)	109.1

RSG = Replacement Steam Generators
NGF = Next Generation Fuel

The data in Table 1 was compiled using a consistent set of pump curves across all cycles, corrected to a reference condition of 545 °F and 2200 psia. The data is intended only to indicate the relative change in flow between cycles, not to indicate the true magnitude of the flow rate. The data shows expected reductions of the RCS flow rate due to significant plugging of original steam generator (OSG) tubes (Cycles 12 through 14) and the partial introduction of NGF in Cycle 20. More importantly, the data shows the restoration of the flow rate following installation of RSGs to a level matching or exceeding the plant's original flow rate.

The full power calorimetric flow rate measured as part of the Cycle 1 startup test plan was 110.3% of the design mass flow rate (Design = 120.4 x 10^6 lb_m/hr). An alternate measurement, using ultrasonic flow meters, also supported the Cycle 1 calorimetric result. The Cycle 15 full power calorimetric flow rate was measured over the course of the cycle to be an average of approximately 106.4%. This drop in calorimetric flow rate, relative to the original flow rate, is inconsistent with the RCP ΔP indications and inconsistent with design predictions of the flow rate following steam generator replacement. The RSGs were designed to provide greater heat transfer than the OSGs while essentially maintaining the original primary side flow resistance. Considering uncertainty in the actual surface roughness of the OSG and RSG tubes, the Cycle 15 calorimetric flow rate was lower than the best estimate predicted flow rate by at least 3% of the design mass flow rate. Considering RSG tolerances at the extreme producing the minimum predicted flow, the Cycle 15 calorimetric flow rate was lower by at least 2% of the design mass flow rate.

The relative stability of RCP ΔP instrumentation over time is shown in Figure 1. Although the data does show evidence of instrument calibration errors, there is no indication of degrading pump performance. As part of the analyses performed to support the proposed change, surveillance criteria have been established to ensure calibration errors or instrumentation problems are detected and addressed. Sensitivity analyses have been performed to establish penalties for instrument deviations that will ensure a conservative pump ΔP flow rate.

Figures 2 and 3 show the stratification in Loop A and B hot legs during Cycle 15. Figure 4 provides an indication (excore raw signals) of the radial power distribution shift from the inside of the core to the outside of the core over the course of Cycle 15. Comparison of the trend in Figure 4 to Figures 2 and 3 clearly shows the influence that radial power distribution has on hot leg stratification. Further evidence of this connection is provided for Cycle 20 (the currently operating cycle) in Figures 5 through 7.

Figure 8 is included to illustrate typical temperature readings in relation to instrument location on the hot leg piping. Considering the depth of the thermowell penetration in relation to the diameter of the hot leg piping, the difference in measured temperatures at different locations around the pipe (high temperatures in one particular quadrant of each hot leg) implies that the bulk average temperature can not be reliably inferred. There is no firm basis to assume any given indication is higher or lower than the true bulk average. However, since the true bulk average hot leg temperature is expected to be constant during operation at a constant power level, indications that vary more over the course of a cycle than others are likely to be the least indicative of the real average temperature. As Figures 2, 3, 5 and 6 show, the most variation occurs in the hottest indications. A higher than actual average temperature is conservative with respect to calculating the flow rate. None of this is meant to say that the hot leg temperature instrumentation is meaningless or that the instrumentation can not be used conservatively, only that the accuracy and precision required for calorimetric flow calculations is not present.

The early ANO-2 cycles used core designs that placed fresh fuel on the core periphery and subsequently shuffled burned fuel to the core interior. Later core designs take essentially the opposite approach to minimize neutron leakage and vessel fluence. As a result, the radial power distributions are significantly different between early and later core designs. The early cycles are believed to have had hot leg temperature distributions less effected by the radial power distribution, such that hot leg average temperature and calorimetric flow calculations were not overly conservative.

The following table illustrates the sensitivity of the RCS calorimetric flow rate to the actual hot leg average temperature. The table is based on a simplified heat balance calculation with a cold leg average temperature of 551 °F, RCS pressure of 2200 psia and a reactor power of 3026 $MW_{thermal\ (th)}$ (current design conditions for full power operation).

TABLE 2

True T_{hot} Avg (°F)	T_{hot} Enthalpy (BTU/lb_m)	Approximate RCS Flow (Mlb_m/hr)	% Design Flow
608	625.099	134.8	111.9%
609	626.582	132.2	109.8%
610	628.071	129.7	107.7%
611	629.567	127.3	105.8%
612	631.071	125.0	103.8%
613	632.581	122.8	102.0%
614	634.100	120.6	100.2%
615	635.626	118.5	98.4%

As shown in Table 2, a 7 °F range of hot leg average temperature can affect the calculated RCS flow rate by more than 16 Mlb_m/hr (> 13% of the design mass flow rate). RCS flow based on RCP differential pressure instruments is not susceptible to the same instabilities over time as flow based on calorimetric measurements.

The discussion below quantifies the flow conservatism in terms of a power level reduction needed to maintain the DNBR safety limit at minimum flow.

At ANO-2, as well as other Combustion Engineering (CE) Nuclear Steam Supply System (NSSS) plants with digital Core Protection Calculator Systems (CPCS), violation of the DNBR safety limit is prevented during normal operation and Anticipated Operational Occurrences (AOOs) by a combination of the Limiting Conditions for Operation (LCOs) maintained by the operator using COLSS and the Reactor Protection System (which includes the CPCS). Both COLSS and CPCS use measured RCS flow to calculate DNBR and provide alarms (COLSS) or trips (CPCS) as required. An offline calorimetric flow measurement is currently used to calibrate the COLSS RCS flow monthly. Either the offline calorimetric or the calibrated COLSS calculation is used to calibrate the CPCS RCS flow once per shift, according to TS 3.3.1 Table 4.3-1 Notes 7 and 8. Therefore, excess conservatism of the offline calorimetric flow measurement directly impacts both the COLSS and CPCS DNBR calculations. On average, a 1% change in flow corresponds to approximately ¾% change in power margin as applied to the DNBR calculations in COLSS and CPCS.

Both COLSS and CPCS include a flow measurement uncertainty component associated with the calibration standard, as well as instrument uncertainties associated with their own flow algorithms, in the statistical combination of uncertainties performed according to methodology described in CEN-356(V)-P-A, Revision 01-P-A. The flow uncertainty for the proposed pump ΔP measurement method is larger than that for the calorimetric measurement method. This is partially a result of the increased drift period (i.e., ΔP instrument calibrations on refueling intervals vs. the current monthly calibration of the COLSS flow to calorimetric). Historically, the process effects shown in Figures 2, 3, 5 and 6 have only partially been accounted for in the uncertainties used. For reasons provided in these responses, the impact of the process effects is considered to be conservative.

When the pump ΔP based flows are calibrated to Cycle 1 and 2 reference flows, approximately 4% flow is expected to be gained relative to the calorimetric measured flow.

In the absence of the proposed change, power reductions to maintain compliance with the DNBR safety limit (i.e., compliance with the COLSS calculated DNBR Power Operating Limit or maintaining margin to CPCS DNBR trip) are not anticipated to be necessary. It is expected that sufficient operating margin in COLSS and CPCS will exist in upcoming ANO-2 reload cycles, regardless of the overly conservative calorimetric flow calculation. The change from a calorimetric flow to a pump ΔP based flow measurement method is driven primarily by the diminishing margin to the limit of TS 3.2.5. Although TS 3.2.5 does not specify a method for determining the flow, it is understood from TS 3.3.1 that a calorimetric method is the currently established reference flow indication.

2. **Paragraph 4 on page 3 indicates that the licensee has performed for ANO-2 validation of the calibration constants using manufacturer's reactor coolant pump (RCP) head curves, and validated calorimetric flow measurements (from early cycles less affected by flow streaming). It claims that the validation can be used as a one-time effort to qualify the COLSS indicated flow as a wholly independent calibration standard.**

(a) Explain the term, validated calorimetric flow measurements (from early cycles less affected by flow streaming). Does the term imply that the flow streaming effects will increase as fuel cycles increase? How is it determined that the calorimetric flow measurements are less or more affected by flow streaming phenomena? Discuss the validation steps and provide the results of validation with information used for validation, including RCP head curves with derivations of the associated uncertainties that define the RCP head curve bands, and calorimetric flow measurements with rationale to support that the measurements used are those of less affected by flow streaming at early fuel cycles.

"Validated calorimetric flow measurements" refers to the review of calculations performed for the Cycle 1 and 2 calorimetric flow measurements. Inputs for these calorimetric measurements were reviewed to ensure they were consistent with the documented uncertainties. The calculations themselves were repeated to verify the results. The measurements were also confirmed to be consistent with alternate, independent ultrasonic flow measurements not affected by flow streaming or stratification. An ultrasonic flow measurement was performed after loading the Cycle 1 core. The flow average from the two hot legs was determined to be 113.4% with a combined uncertainty of ±7.6%. Validating the accuracy of the Cycle 1 and 2 flow measurements did not rely on the RCP head curves. As described in the response to RAI 1.b, the RCP head curves were only used in a best estimate, relative manner, to compare flow rates between cycles (see Table 1).

Validation is not meant to imply that flow streaming effects will increase with time. The magnitude of hot leg stratification and connection to the core power distribution and core loading strategy have been discussed in response to RAI 1.b and illustrated in Figures 2 through 7. In general, the characteristics of hot leg stratification and the impacts to calorimetric flow measurements are expected to remain consistent across consistent fuel cycles. When reviewing Figures 2 through 7, note that Cycle 15 used Gadolinia as the burnable poison and by Cycle 20, core designs had transitioned to Zirconium Diboride as the burnable poison. Changes in burnable poison and resulting changes in radial power distribution can be seen as affecting the magnitude of stratification over the course of a cycle. The pattern of stratification among the instrument locations however, remains consistent, as did the use of low-leakage core designs.

With respect to determining whether current calorimetric flow measurements are more or less affected by flow streaming phenomena, there is no firm basis to assume that any bulk temperature estimated from the indicated hot leg temperatures is higher or lower than the true bulk average. However, the wide variation in temperature indications (both over the course of a cycle and with respect to the differences between pipe locations) and associated sensitivity of the flow rate to the average hot leg temperature (Table 2) make the accuracy and precision of calorimetric flow measurements questionable. Given the questionable calorimetric flow measurements, the constancy of pump ΔP instrumentation, the consistency of recent and original flow rates based on ΔP instrumentation (Table 1), the reasonable explanation of core design effects on hot leg temperature distribution, the validation of Cycle 1 and 2 calorimetric flow measurements described above and the incorporation of appropriate uncertainties, Entergy believes there is adequate basis to support the proposed change.

A cross-check of the proposed method's accuracy was conducted by back-calculating the average hot leg temperature that would need to exist if the expected flow rate using the proposed pump ΔP method were actually present. The back-calculation of T_{hot} was performed assuming:

- The flow rate is equal to the average of Cycle 1 and 2 calorimetric measurements.
- Actual Cycle 15 and 16 cold leg temperature and pressure conditions.
- The flow was adjusted down by the predicted change in resistance from OSGs to RSGs.
- The flow was reduced by the uncertainty (4.1% for TS monitoring) of the proposed pump ΔP method.

Figure 9 shows the back-calculated average hot leg temperature against 1) the average of the coolest and most stable hot leg temperature indications and 2) the individual hottest and most variable temperature indications. The back calculation shows that the real average hot leg temperature would have to be lower than normal instrumentation averaging would indicate (as expected). However, the results also show that the predicted average hot leg temperature, at one extreme of the method's uncertainty, bounds the coolest and least variable temperature indications by approximately 2 °F. Since the true average hot leg temperature should be constant during constant power operation, the hottest and most variable temperature indications are likely the least indicative of the real average temperature. The back calculation of the expected hot leg temperature for the increased flow rate therefore provides some evidence that the actual flow rate is within the bands of the proposed method's uncertainty.

The uncertainty of the proposed flow method applicable to safety analyses (5.8% for CPCs), is larger than that applied for TS monitoring. When the average hot leg temperature is predicted at the extreme of this higher uncertainty, it becomes approximately equal to or greater than the average temperature of all indications at the points of minimum stratification. This provides strong evidence that the flow used by the protection system will be within uncertainty of the actual flow and that conservative operation will be maintained.

(b) Justify that the validation performed for ANO-2 is adequate to support the licensee's claim that the COLSS indicated flow can be used as a wholly independent calibration standard over the entire operating temperature and pressure range for an extended period of RCP operating time. In addition, the licensee should satisfactorily address the following concerns - (i) the COLSS indicated flow rate is determined using the RCP head curves, which are developed on a specific testing configuration, temperature and pressure condition. The RCP curves may be changes for plant configurations,

temperature and pressure conditions that are different from that used in determining the RCP head curves, (ii) the other parameter used to determine the COLSS indicated flow rate is the RCP differential pressure (delta-P), which may be a very sensitive parameter to the RCP flow rate in a certain range of RCP head curves, i.e., a small uncertainty in the delta-P measurement may introduce a significant uncertainty in predicting RCP flow rate, and (iii) the RCP heads may be degraded through a long period of operating time.

With proper initial calibration to a valid reference flow rate and monitored input signal qualities, the COLSS indicated flow rate, based on RCP ΔP instrumentation, should serve as an accurate and precise indication of the actual RCS flow rate. The pump curve constants to be installed in COLSS were derived from the vendor test data. The vendor test data were compiled at temperature and pressure conditions very close to normal operating temperature and pressure (average test conditions of 2202 psia and 557 °F vs. normal operating pressure and cold leg temperature conditions of 2200 psia and 551 °F for full power). The vendor test data were also compiled using a range of differential pressures that more than encompass the differential pressures seen during normal operation and observed with significant tube plugging in earlier cycles.

The supporting analyses have considered deviation of operating conditions from those present at the point of the one time COLSS calibration. The nominal operating conditions for the calibration are a pressure of 2200 psia and a cold leg temperature of 551 °F. These are the current design pressure and cold leg temperature conditions for ANO-2 operating at 100% power (3026 MW_{th}).

Simulations performed as part of the supporting analyses show sensitivities to be as follows:

TABLE 3

Parameter	Sensitivity
RCS Pressure	0.001% Design Flow / psi
Cold Leg Temperature	0.006% Design Flow / °F

The corresponding uncertainty assumed in the analyses was used to establish an allowable deviation of ± 50 psi and ± 7 °F from nominal conditions. Based on actual operating conditions, changes within these limits have negligible effect on the validity of the COLSS calibration relative to uncertainties of the instrumentation involved.

The design inlet temperature program for the plant varies the cold leg temperature from 545 °F at zero power to 551 °F at full power. The RCS pressure is normally maintained well within the above tolerance by pressurizer proportional heater controls. The proportional heater control setpoints are for zero heater output at 2225 psia and full output at 2175 psia. The COLSS calibration is therefore expected to remain valid over the full range of normal operating conditions.

The above operating ranges directly address deviation of operating conditions from the reference point on the vendor pump curves used to perform the COLSS calibration to calorimetric based reference flow. If actual operating conditions are changed in the future to values exceeding nominal operating conditions for calibration by either of the above ranges, an uncertainty allowance must be applied based on the sensitivities or revised calibration constants must be determined. The ANO engineering change process ensures such impacts are addressed, as appropriate, when plant modifications are initiated.

The uncertainty of instrumentation supplying input to the COLSS flow algorithm (ΔP instrumentation, cold leg temperature and RCS pressure in particular) has been explicitly accounted for in flow uncertainty calculations. This uncertainty was calculated in the same manner as is currently performed for the calorimetric flow measurement method, except that uncertainty components were added to address the calculated change in resistance between the OSGs and the RSGs, variation of process inputs observed during the calibration calculations, and an increased drift interval (refueling calibration interval for ΔP instrumentation vs. the current monthly recalibration of COLSS flow based on calorimetric measurements). The uncertainties are statistically combined, according to the methodology described by CEN-356(V)-P-A, Revision 01-P-A.

In addition to the uncertainty analyses, guidelines have been developed for periodic surveillance of the pump ΔP and cold leg temperature instrumentation. The guidelines are designed to capture input data anomalies and ensure validity of flow measurements by compensating for any modified operation. Compensation is in the form of sensitivities and penalties to the COLSS calculated flow rate.

With respect to pump degradation over time, there is no evidence that this is occurring to any significant degree. The detailed trends of pump ΔP instruments shown in Figure 1 provide no trend indicative of degradation over time. As previously discussed in the response to RAI 1.b, Table 1 shows restoration of the flow rate following installation of RSGs to a level matching or exceeding the plant's original flow rate. The back calculation of hot leg temperature described in response to RAI 2.a also provides evidence that any degradation that has occurred is not significant.

Regarding the one time nature of the COLSS calibration and continued applicability without subsequent recalibration to a reference flow rate, this strategy is consistent with similar applications at other plants. Specifically, RCS flow measurements at Palo Verde units are performed using flow determined either using the RCP differential pressure instrumentation and the ultrasonic flow meter adjusted pump curves or by calorimetric calculations. The Palo Verde TS 3.3.1.5 reference to "ultrasonic flow meter adjusted pump curves" is associated with calibration or adjustment of the pump curves to match ultrasonic flow measurements conducted during functional tests performed after core loads for the initial cycles. These tests were conducted using temporary instrumentation installed on the hot legs. The Palo Verde units do not have permanently installed ultrasonic flow meters on the RCS and do not recalibrate the pump curves against a reference indication at any specific frequency. These details have been confirmed by review of historical Combustion Engineering internal correspondence and independently through conversations with Palo Verde staff.

Entergy has proposed to eliminate the monthly flow surveillance requirement from TS that presently still exists in the Palo Verde TS. On the surface, this may appear to be an inconsistency in surveillance requirements between the two sites. In reality, the once per shift surveillance required by the proposed Note 7 of TS Table 4.3-1 is equivalent to performing Palo Verde TS Surveillance Requirement 3.3.1.5 on a higher frequency, since the RCP differential pressure instrumentation to be used by the surveillance will be the COLSS indication following the one-time calibration to calorimetric. The proposed Note 7 to TS Table 4.3-1 could be re-stated as follows, without changing the intent:

> "Above 70% of RATED THERMAL POWER, verify that the total RCS flow rate as indicated by each CPC is less than or equal to the RCS total flow rate determined by either using the reactor coolant pump differential pressure instrumentation (previously calibrated to a valid reference) or by calorimetric calculations..."

The actual flow surveillances conducted at ANO and Palo Verde will be the same, using the same methods. The only differences will be 1) that one plant calibrated pump curves to ultrasonic flow meters while the other plant calibrated pump curves to calorimetric measurements and 2) the Palo Verde TS lists a redundant flow surveillance that ANO removed for clarity.

(c) Describe the uncertainty analysis and provide the associated results that account for process uncertainties, instrumentation uncertainties and the uncertainty associated with the one time adjustment of the COLSS flow algorithm constants indicated in paragraph 4 on page 3. Justify that the determined uncertainties are bounding values that adequately include the uncertainties discussed in above RAI 2.b, and are applicable to the entire operating temperature and pressure range for an extended period of RCP operating time.

Although both use pump ΔP instrumentation, the uncertainty of the proposed COLSS flow measurement method is significantly different from the current COLSS flow measurement. The current COLSS flow indication relies on monthly calorimetric measurement of the reference flow and calibration of the COLSS flow to the reference flow. The revised method relies on calibration of the COLSS flow to a single calorimetric based reference flow and no further adjustments.

The proposed change assumes that the calibration constants remain valid as long as the piping configuration and pump internals are not changed and that operating conditions (i.e., cold leg temperature and RCS pressure) remain within established limits (detailed in response to RAI 2.b). As previously discussed, there have been no observable signs of significant pump performance degradation over time. The ΔP instrument trends in Figure 1, relative change in flow indicated by Table 1, and the back calculation of the hot leg temperature shown in Figure 9 provide supporting evidence. The response to RAI 2.b includes justification for the COLSS calibration being valid over the entire operating temperature and pressure range.

The components of the uncertainty analysis covering the proposed COLSS method include the existing uncertainty components applicable to the calorimetric method. These uncertainty components are augmented by the following additional components:

- ΔP instrument loop uncertainty (with 22.5-month drift allowance to accommodate refueling interval calibrations)
- An uncertainty allowance of 1.65% of design flow to account for the fidelity of the simulation that provided a basis for adjusting OSG based reference flow to RSG conditions
- Uncertainty to cover observed variation of pump ΔP and cold leg temperature inputs used in the COLSS calibration constant calculations

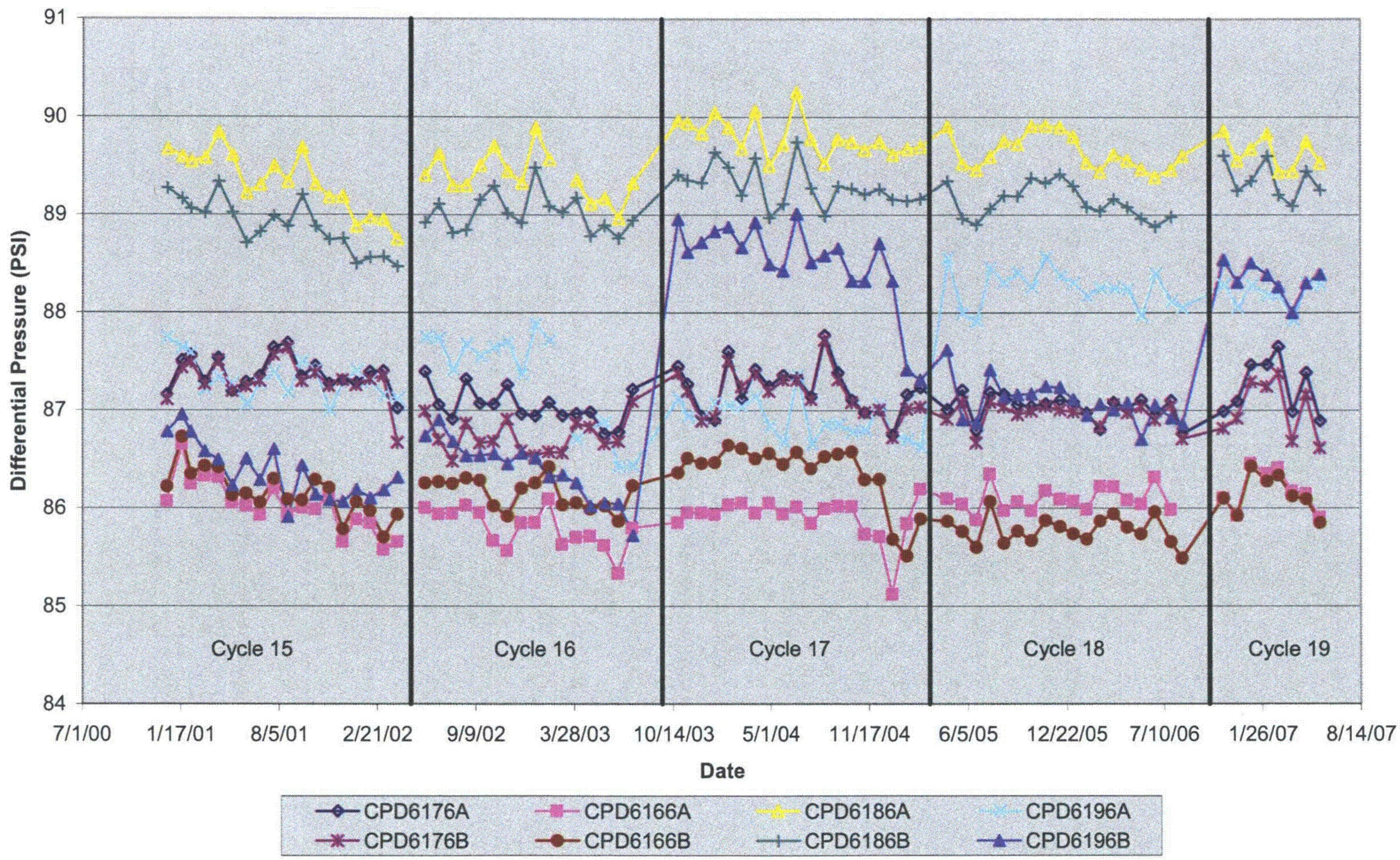
Uncertainties continue to be statistically combined according to the methodology described by CEN-356(V)-P-A, Revision 01-P-A. A summary of currently developed uncertainties for the proposed COLSS method (ΔP) and comparison to the existing Analysis of Record (AOR) are detailed in Table 4 below. The AOR values only partially account for the increased hot leg temperature variation evident in recent cycles. As outlined throughout this response, the hot leg temperature measurements are considered to result in a conservative flow measurement.

TABLE 4

Parameter	Safety Analysis		TS Monitoring	
	AOR	ΔP	AOR	ΔP
COLSS One-sided Mass Flow Uncertainty, % design flow [3,4]			3.9	4.1
COLSS Volumetric Flow Uncertainty, Uniform, % design flow [1,4]	4.9	5.2		
CPC Mass Flow Uncertainty, Uniform, % design flow [2,4]	5.5	5.8		
Reference Mass Flow Uncertainty, One-sided, 95/95 % design flow [4,5]			2.9	2.9

Notes:
1. To be used for COLSS Overall Uncertainty Analysis (OUA).
2. To be used for CPC OUA.
3. To be used for TS monitoring of RCS flow, based on COLSS indication.
4. Design mass flow is 120.4×10^6 lb_m/hr, design volumetric flow is 322,000 gpm.
5. To be used for TS monitoring of RCS flow, based on calorimetric calculations.

Figure 1: ANO-2 Reactor Coolant Pump Differential Pressures



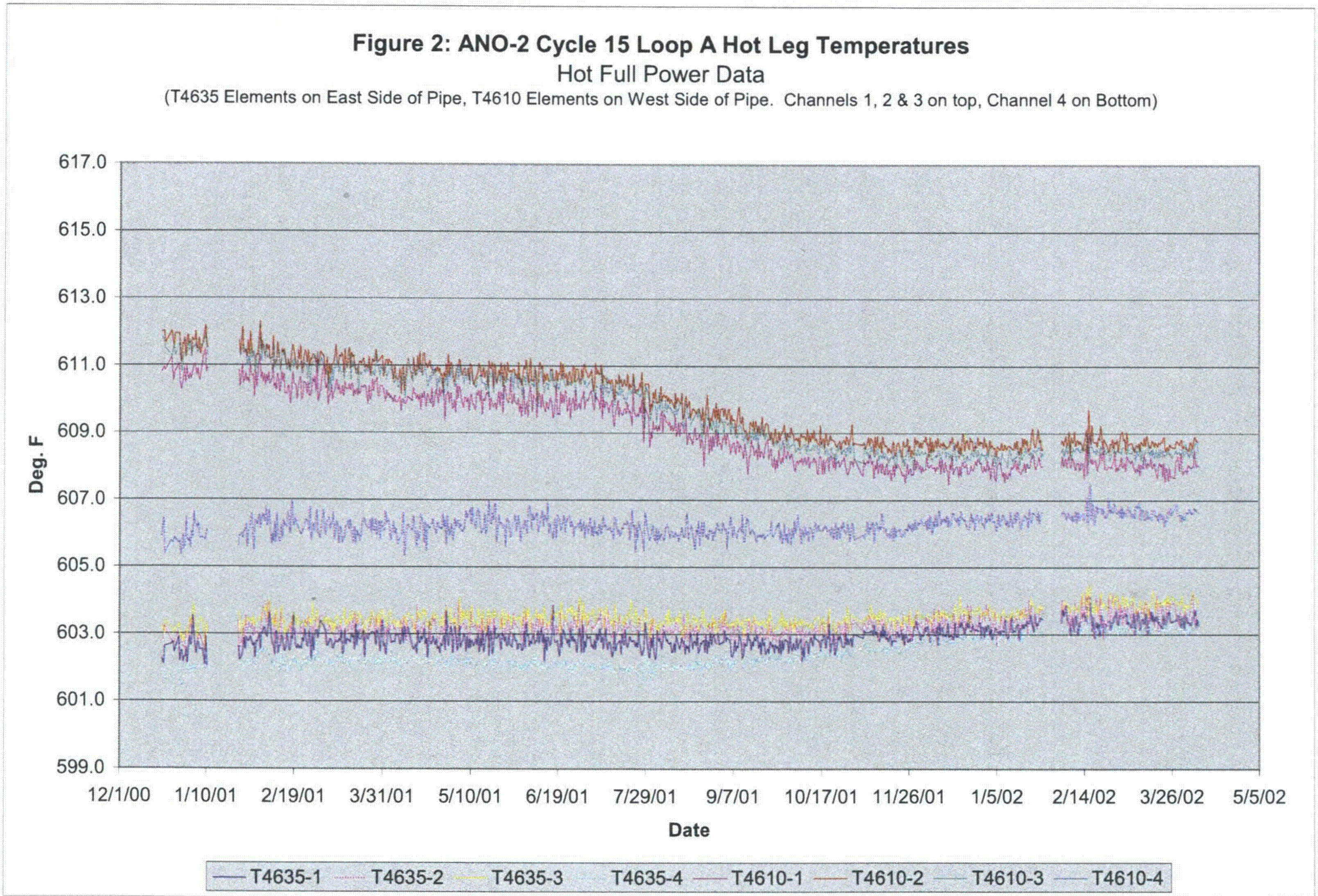


Figure 2: ANO-2 Cycle 15 Loop A Hot Leg Temperatures
Hot Full Power Data
(T4635 Elements on East Side of Pipe, T4610 Elements on West Side of Pipe. Channels 1, 2 & 3 on top, Channel 4 on Bottom)
617.0
615.0
613.0
611.0
609.0
607.0
605.0
603.0
601.0
599.0
Deg. F
12/1/00
1/10/01
2/19/01
3/31/01
5/10/01
6/19/01
7/29/01
9/7/01
10/17/01
11/26/01
1/5/02
2/14/02
3/26/02
5/5/02
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T4610-3
T4610-4

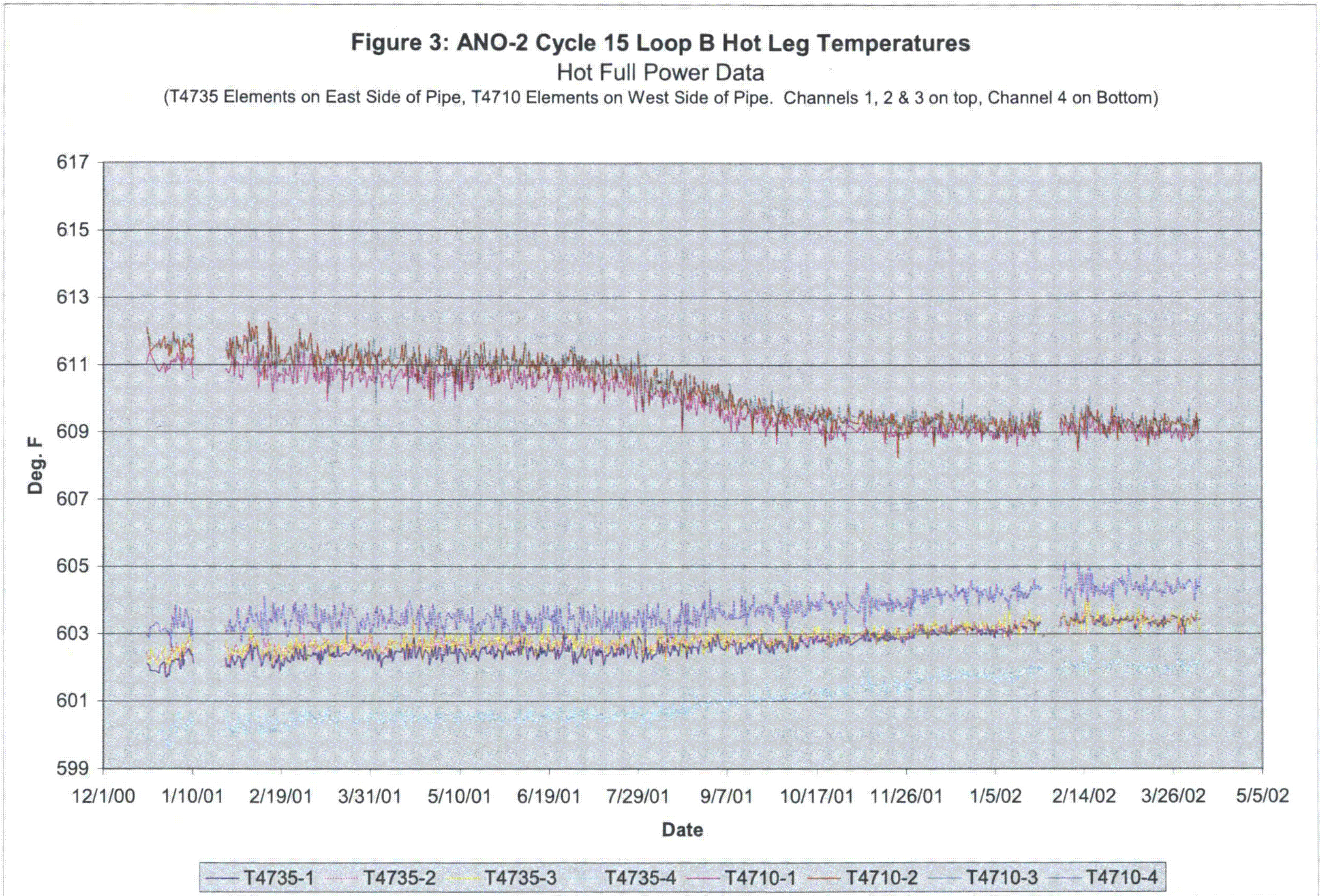


Figure 3: ANO-2 Cycle 15 Loop B Hot Leg Temperatures
Hot Full Power Data
(T4735 Elements on East Side of Pipe, T4710 Elements on West Side of Pipe. Channels 1, 2 & 3 on top, Channel 4 on Bottom)
617
615
613
611
609
607
605
603
601
599
Deg. F
12/1/00
1/10/01
2/19/01
3/31/01
5/10/01
6/19/01
7/29/01
9/7/01
10/17/01
11/26/01
1/5/02
2/14/02
3/26/02
5/5/02
Date
T4735-1
T4735-2
T4735-3
T4735-4
T4710-1
T4710-2
T4710-3
T4710-4

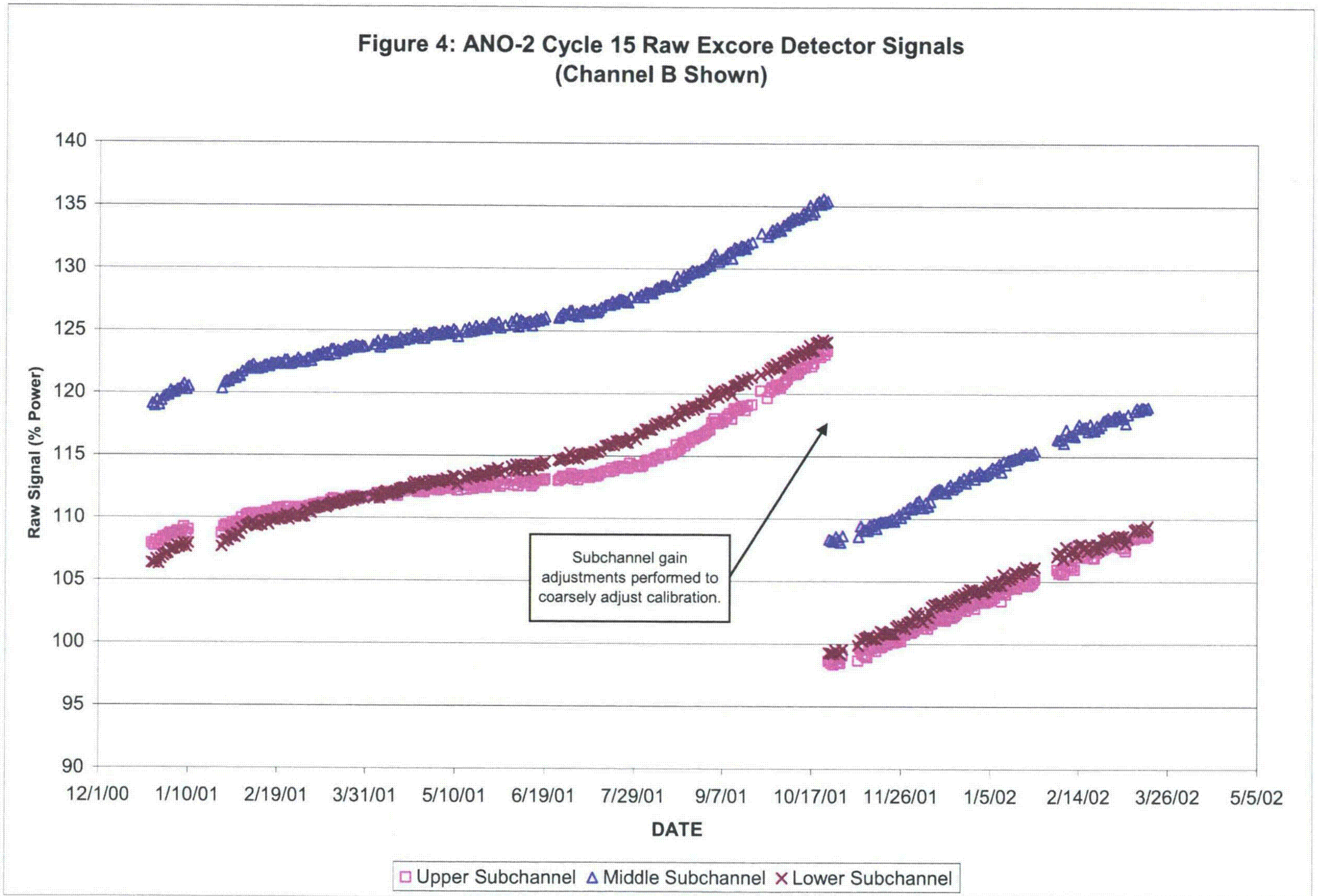


Figure 4: ANO-2 Cycle 15 Raw Excore Detector Signals
(Channel B Shown)
Raw Signal (% Power)
140
135
130
125
120
115
110
105
100
95
90
12/1/00
1/10/01
2/19/01
3/31/01
5/10/01
6/19/01
7/29/01
9/7/01
10/17/01
11/26/01
1/5/02
2/14/02
3/26/02
5/5/02
DATE
Subchannel gain adjustments performed to coarsely adjust calibration.
Upper Subchannel
Middle Subchannel
Lower Subchannel

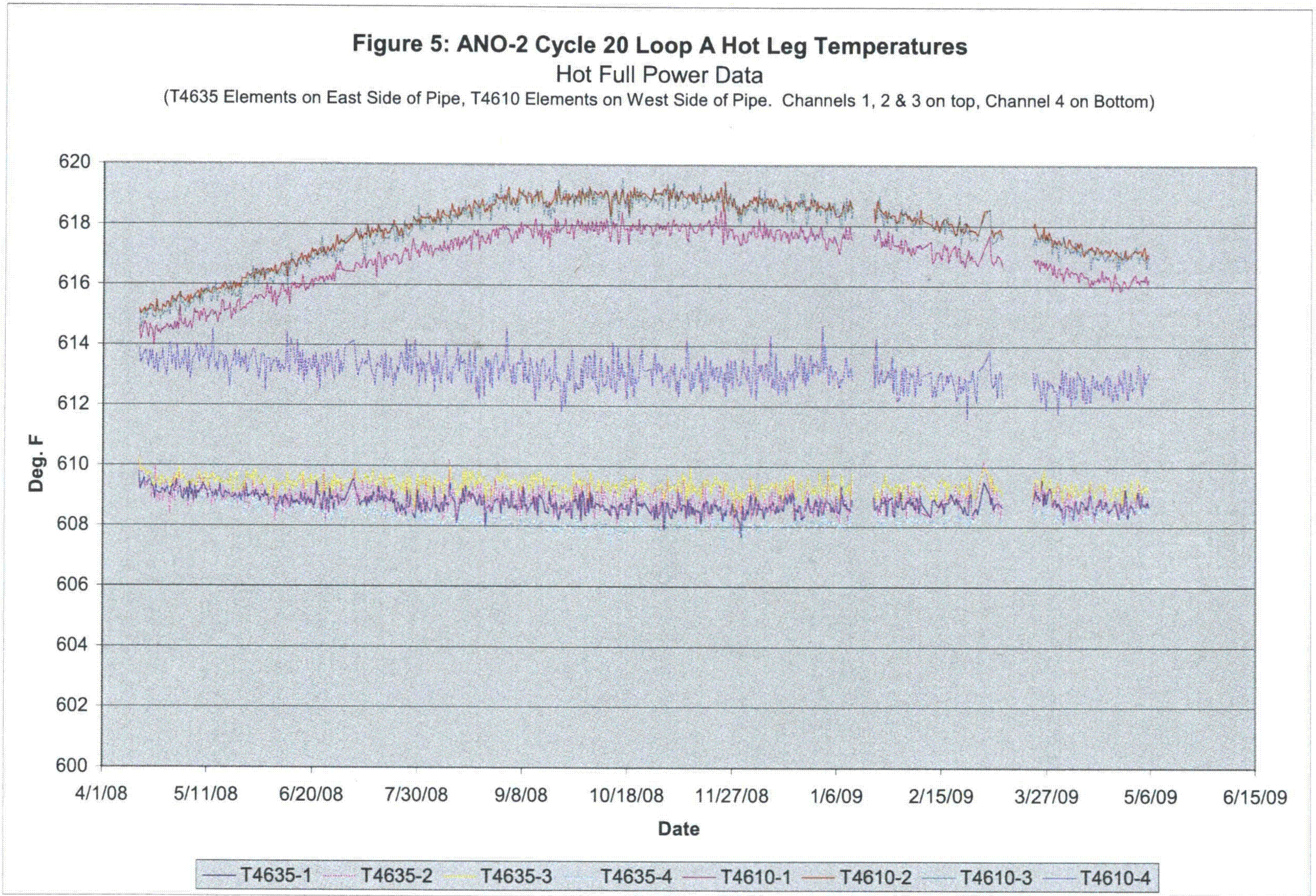


Figure 5: ANO-2 Cycle 20 Loop A Hot Leg Temperatures
Hot Full Power Data
(T4635 Elements on East Side of Pipe, T4610 Elements on West Side of Pipe. Channels 1, 2 & 3 on top, Channel 4 on Bottom)
Deg. F
620
618
616
614
612
610
608
606
604
602
600
4/1/08
5/11/08
6/20/08
7/30/08
9/8/08
10/18/08
11/27/08
1/6/09
2/15/09
3/27/09
5/6/09
6/15/09
Date
T4635-1
T4635-2
T4635-3
T4635-4
T4610-1
T4610-2
T4610-3
T4610-4

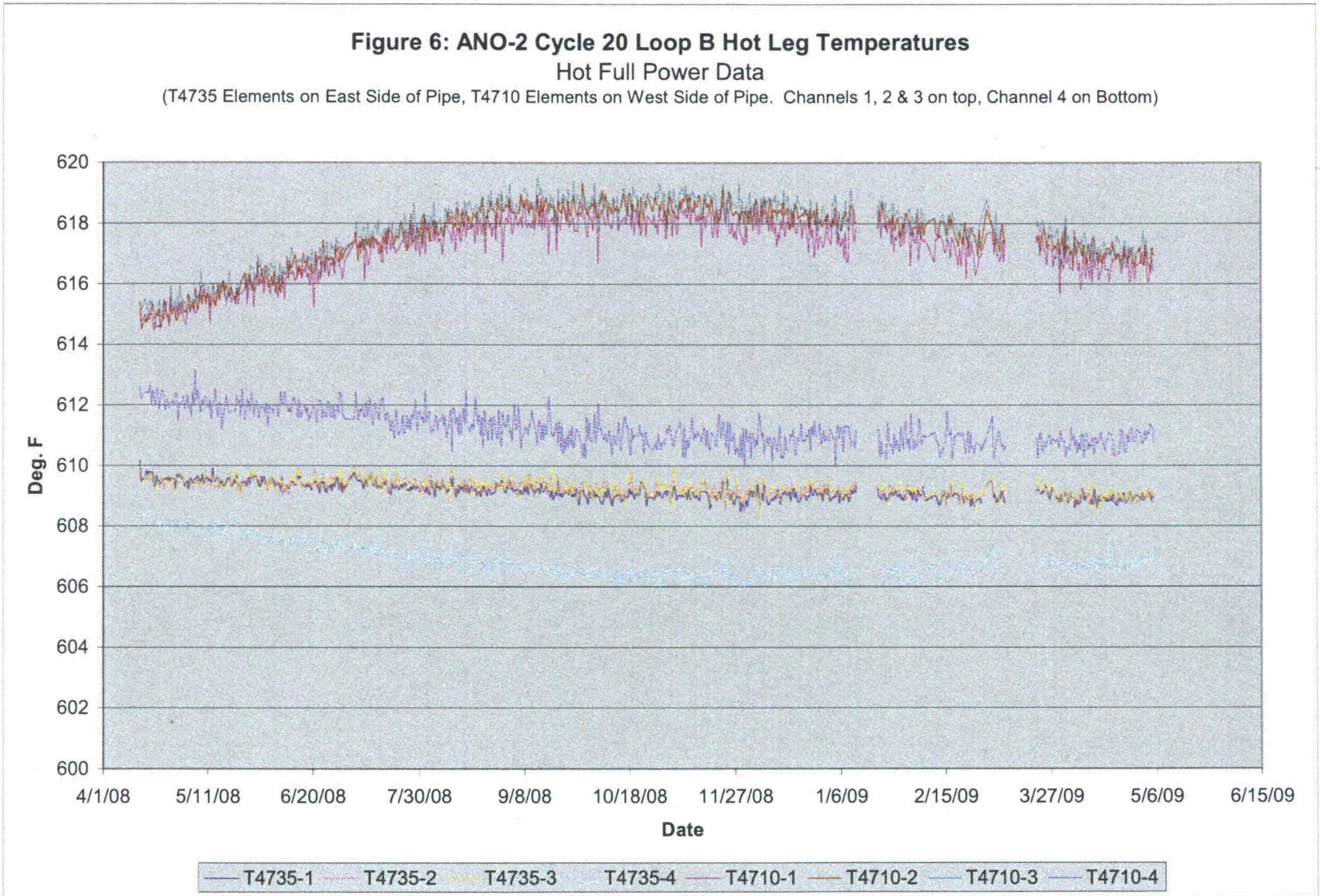


Figure 6: ANO-2 Cycle 20 Loop B Hot Leg Temperatures
Hot Full Power Data
(T4735 Elements on East Side of Pipe, T4710 Elements on West Side of Pipe. Channels 1, 2 & 3 on top, Channel 4 on Bottom)
620
618
616
614
612
610
608
606
604
602
600
Deg. F
4/1/08
5/11/08
6/20/08
7/30/08
9/8/08
10/18/08
11/27/08
1/6/09
2/15/09
3/27/09
5/6/09
6/15/09
Date
T4735-1
T4735-2
T4735-3
T4735-4
T4710-1
T4710-2
T4710-3
T4710-4

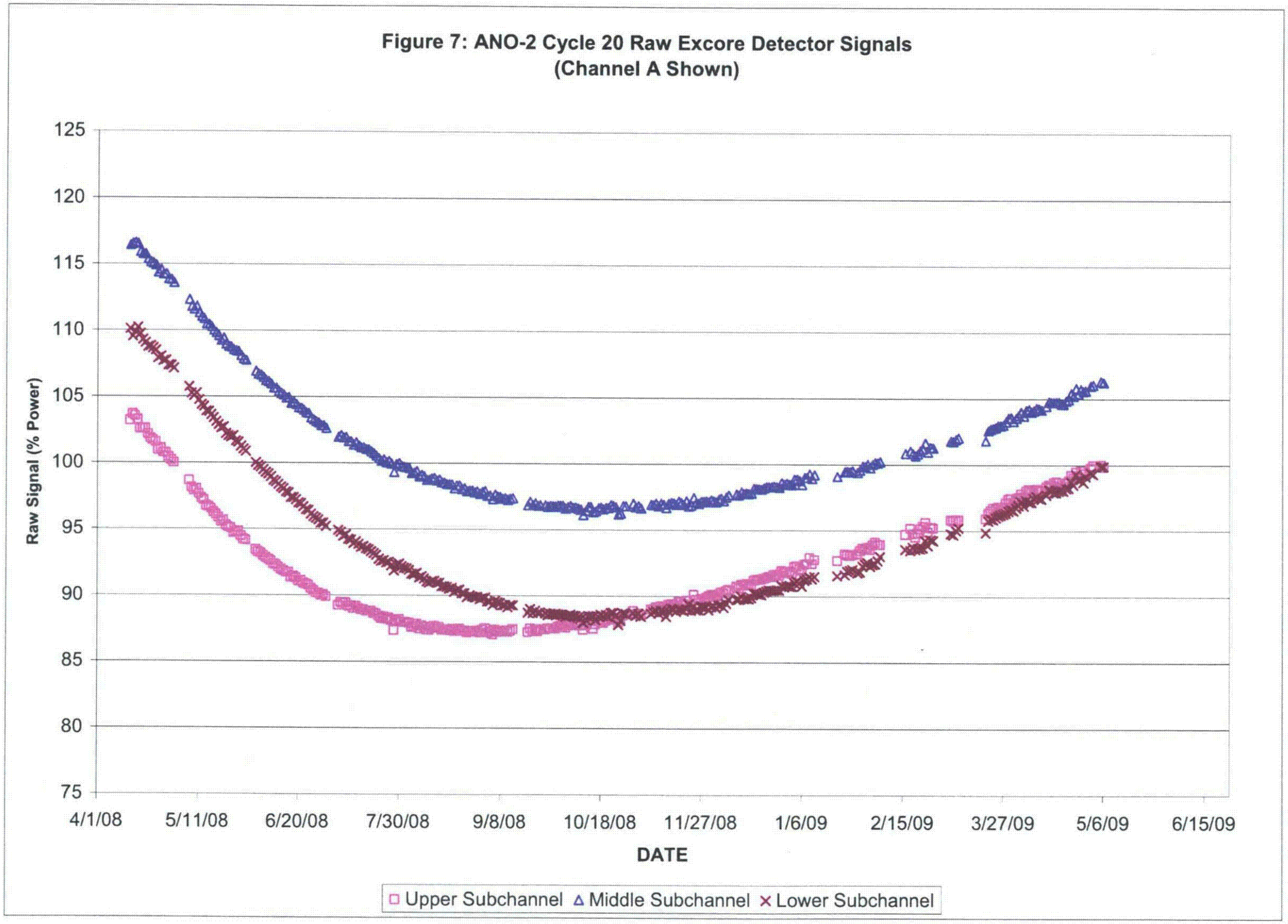
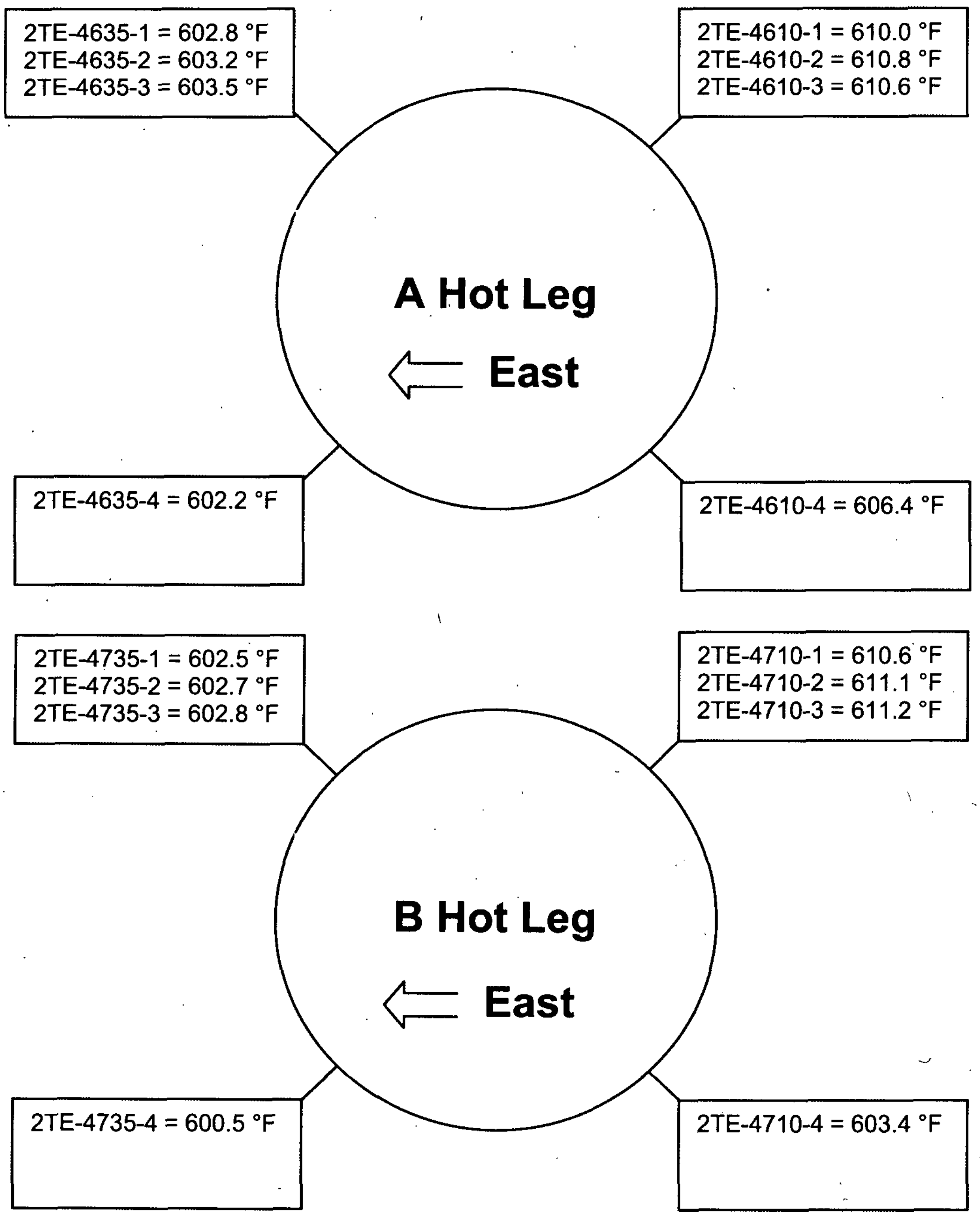


Figure 7: ANO-2 Cycle 20 Raw Excore Detector Signals
(Channel A Shown)
Raw Signal (% Power)
125
120
115
110
105
100
95
90
85
80
75
4/1/08
5/11/08
6/20/08
7/30/08
9/8/08
10/18/08
11/27/08
1/6/09
2/15/09
3/27/09
5/6/09
6/15/09
DATE
Upper Subchannel
Middle Subchannel
Lower Subchannel

Figure 8: Indicated Temperature vs. Instrument Location
(Cycle 15 Example Shown)



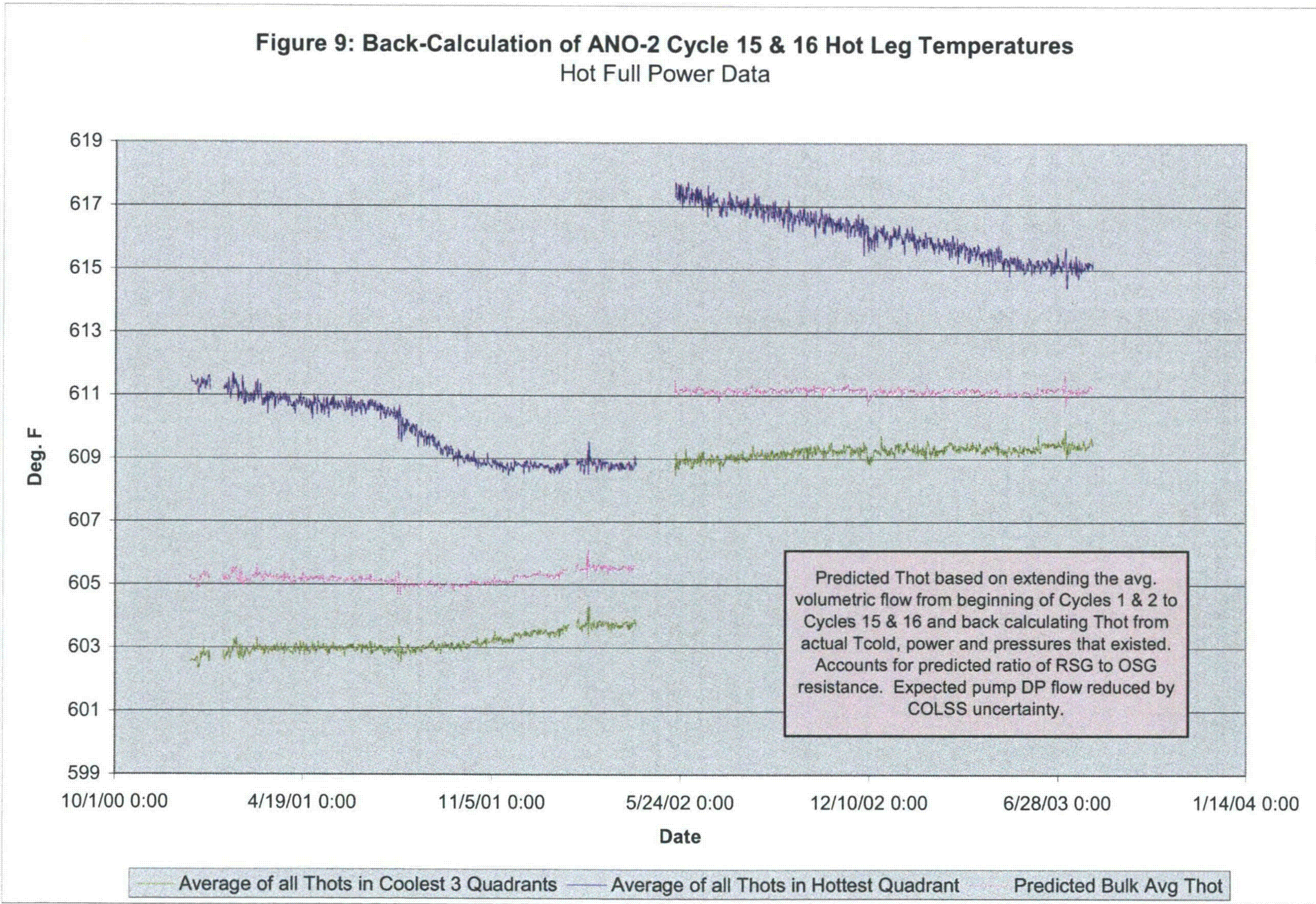


Figure 9: Back-Calculation of ANO-2 Cycle 15 & 16 Hot Leg Temperatures
Hot Full Power Data
619
617
615
613
611
609
607
605
603
601
599
Deg. F
10/1/00 0:00
4/19/01 0:00
11/5/01 0:00
5/24/02 0:00
12/10/02 0:00
6/28/03 0:00
1/14/04 0:00
Date
Predicted Thot based on extending the avg. volumetric flow from beginning of Cycles 1 & 2 to Cycles 15 & 16 and back calculating Thot from actual Tcold, power and pressures that existed. Accounts for predicted ratio of RSG to OSG resistance. Expected pump DP flow reduced by COLSS uncertainty.
Average of all Thots in Coolest 3 Quadrants
Average of all Thots in Hottest Quadrant
Predicted Bulk Avg Thot