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September 15, 2010

U. S. Nuclear Regulatory Commission
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Dresden Nuclear Power Station, Units 2 and 3
Renewed Facility Operating License Nos. DPR-19 and DPR-25
NRC Docket Nos. 50-237 and 50-249

Subject: Additional Information Supporting the Request for License Amendment
Regarding Shutdown Cooling System Isolation Instrumentation

- Reference:**
1. Letter from Mr. Jeffrey L. Hansen (Exelon Generation Company, LLC) to U. S. NRC, "Request for License Amendment Regarding Shutdown Cooling System Isolation Instrumentation," dated February 4, 2010
 2. Letter from U. S. NRC to Mr. Michael J. Pacilio (Exelon Nuclear), "Dresden Nuclear Power Station, Units 2 and 3 – Request for Additional Information Related to a Modification That Replaces the Temperature-Based Isolation Instrumentation with Reactor Pressure-Based Isolation Instrumentation (TAC Nos. ME3354 and ME3355)," dated September 3, 2010

In Reference 1, Exelon Generation Company, LLC (EGC) requested an amendment to Renewed Facility Operating License Nos. DPR-19 and DPR-25 for Dresden Nuclear Power Station (DNPS), Units 2 and 3, respectively. Specifically, the proposed amendment revises Technical Specification (TS) 3.3.6.1, "Primary Containment Isolation Instrumentation," Table 3.3.6.1-1, "Primary Containment Isolation Instrumentation," Function 6.a, "Shutdown Cooling System Isolation, Recirculation Line Water Temperature - High," to enable implementation of a modification that replaces the temperature-based isolation instrumentation with reactor pressure-based isolation instrumentation. The proposed modification will address instrumentation reliability problems that have led to interruptions of Shutdown Cooling (SDC) system operation. The proposed change to Primary Containment Isolation System (PCIS) instrumentation function 6.a is needed to ensure reliable heat removal capability, avert plant transients and challenges to equipment, and minimize unnecessary operator actions during plant shutdowns.

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In Reference 2, the NRC forwarded requests for additional information (RAIs) concerning the Reference 1 license amendment request. Attachment 1 to this letter provides the information requested by the NRC. In addition, the proposed changes to the TS Bases have been revised and are being re-submitted as Attachment 2 for information only.

EGC has reviewed the information supporting a finding of no significant hazards consideration that was provided to the NRC in Reference 1. The additional information provided in this submittal does not affect the bases for concluding that the proposed license amendment does not involve a significant hazards consideration. No new regulatory commitments are established by this submittal.

If you have any questions concerning this letter, please contact Mr. Timothy A. Byam at (630) 657-2804.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 15th day of September 2010.

Respectfully,



Jeffrey L. Hansen
Manager – Licensing
Exelon Generation Company, LLC

Attachments:

1. Additional Information Supporting the Request for License Amendment Regarding Shutdown Cooling System Isolation Instrumentation
2. Revision to Mark-up of Proposed Technical Specifications Bases Pages

ATTACHMENT 1

**Additional Information Supporting the Request for License Amendment Regarding
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Additional Information Supporting the Request for License Amendment Regarding Shutdown Cooling System Isolation Instrumentation

In reviewing the Exelon Generation Company's (Exelon's, the licensee's) submittal dated February 4, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML100470776), for the Dresden Nuclear Power Station (DNPS), Units 2 and 3, to change the sensors and Shutdown Cooling (SDC) system isolation logic that prevents exceeding the SDC system design temperature, the Nuclear Regulatory Commission (NRC) staff has determined that additional information is needed to evaluate Exelon's compliance with Title 10 of the Code of Federal Regulations, Section 50.36, and current review criteria that govern setpoints. This information is needed to verify the licensee's ability to identify inoperability and degradation of equipment based upon its setpoint methodology, and the calibration and surveillance check procedures associated with this license amendment request (LAR).

Also, additional information is required to evaluate the plant's ability to prevent a potential loss-of-coolant through means that ensure the SDC system's maximum design temperature of 350°F is not exceeded. This information is needed to verify applicable portions of the NRC Standard Review Plan (SRP) (NUREG-0800), Branch Technical Position 7-1 "Guidance on Isolation of Low-Pressure Systems from the High-Pressure Reactor Coolant System" (ADAMS Accession No. ML070460345) and General Design Criteria (GDC) 15, as discussed in the Updated Final Safety Analysis Report, are met.

Setpoints – General: *The following four RAIs (1-4) address the licensee's overall approach to meeting the current regulatory criteria for Technical Specification (TS) content in accordance with NRC Regulatory Issue Summary 2006-17 (ADAMS Accession No. ML051810077). The LAR proposes the following TS changes:*

- *Replacement of the "Recirculation Line Water Temperature-High" setpoint and its allowable value of "≤ 346°F" with one setpoint "Reactor Vessel Pressure-High" with two allowable values as follows:*
 - *"≤ 114.1 psig (Loop 1, Reactor Wide Range Pressure)"*
 - *"≤ 110.4 psig (Loop 2, Reactor Pressure Feedwater Control)"*
1. **Setpoint Calculation Methodology:** *In addition to the calculations, which were provided in the LAR, provide documentation of the setpoint methodology used for establishing the limiting setpoint (NSP) and the limiting acceptable values for the As-Found and As-Left setpoints as measured in periodic surveillance testing.*
- i) *the limiting setpoint is referred to as calculated setpoints in the LAR.*
 - ii) *the limiting acceptable values for the As-Found setpoints are referred as "Expanded Tolerance" in the LAR.*
 - iii) *the limiting acceptable values for the As-Left setpoints are referred as "Setting Tolerance" in the LAR.*

This documentation should:

- a. *Provide NES-EIC-20.04, "Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy," Revision 5, which is Reference 3.1.2 of Attachment 4, Setpoint Calculation No. DRE09-0041, "Shutdown Cooling*

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Reactor High Pressure (Cut-in Permissive) Setpoint Calculation," of the LAR.

- b. *Explicitly identify the methodology and its current revision that is referenced within the TS Design Bases statements:*
- i) *"Any setpoint adjustment shall be consistent with the assumptions of the current plant specific setpoint methodology" (reference "Dresden 2 and 3 Technical Specification Bases", page B 3.3.6.1-6, Revision 0)*
 - ii) *"there is a plant-specific program which verifies that the instrument channel functions as required, by verifying the as-left and as-found settings are consistent with those established by the setpoint methodology" (see proposed "Dresden 2 and 3 Technical Specification Bases", page B 3.3.6.1-26, Revision 0).*
 - iii) *Or, provide a confirmatory statement that this methodology is identical to the methodology identified in 1.a above.*

EGC Response:

- 1.a Exelon Generation Company, LLC (EGC) is providing a copy of NES-EIC-20.04, "Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy," Revision 5 as Enclosure 1 to this Attachment.
- 1.b NES-EIC-20.04, Revision 5 is the EGC standard used to prepare calculation DRE09-0041, "Shut Down Cooling Reactor High Pressure (Cut-In Permissive) Setpoint Calculation," Revision 0. The calculation determines the setpoints, as-left setting tolerance, as-found expanded tolerance, and Technical Specification (TS) allowable values associated with the proposed Shutdown Cooling Reactor High Pressure Cut-In Permissive. During periodic calibration, the maintenance procedure ensures that the as-found and as-left settings are consistent with the results of the calculation.

The current version (i.e., Revision 5) of the EGC setpoint methodology standard (i.e., NES-EIC-20.04) is equivalent to Revisions 2 and 3 which were previously provided to the NRC as discussed below.

In letters dated March 30, 2001, the NRC issued license amendments and the associated Safety Evaluation (SE) for Dresden Nuclear Power Station (DNPS) (ADAMS Accession Number ML011130121) implementation of Improved Technical Specifications. This SE documents the NRC's review of Revisions 1 (ADAMS Accession No. ML003698624) and 2 (ADAMS Accession No. ML003721342) to NES-EIC-20.04. In addition, as stated in the SE, EGC provided Revision 3 of NES-EIC-20.04 to the NRC, and submitted a letter dated November 30, 2000, (ADAMS Accession No. ML003776648) to state that a graded approach to setpoint determination was not used by EGC. The March 30, 2001 NRC SE concluded that, "The staff also finds that the instrument setpoint methodology used by the licensee to determine the allowable values is acceptable."

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Subsequent to the March 30, 2001 license amendments and associated SE, EGC issued Revisions 4 and 5 to NES-EIC-20.04. The scope of the change in Revision 4 was limited. For example, Revision 4 corrected a typographical error to a table in Appendix J, "Guideline for the Analysis and Use of As-Found/As-Left Data," added clarification to Appendix J Sections 2.1.1 and 2.1.2.2, and incorporated the changing of the company name from "ComEd" to "Exelon." Revision 5 captures Rosemount guidance for addressing static head effects on differential pressure transmitters, updates references, and corrects minor typographical errors. Previously, EGC calculations would reference Rosemount documents for guidance on addressing static head effects. The calculational methodology that was used for the current license amendment request (i.e., Revision 5 of NES-EIC-20.04) is the same as that reviewed by the NRC in 2001 (i.e., Revision 3 of NES-EIC-20.04).

- 2. Safety Limit (SL)-Related Determination:** *Provide a statement as to whether or not the setpoint is a Limiting Safety System Setting (LSSS) for a variable on which a SL has been placed as discussed in 10 CFR 50.36(c)(1)(ii)(A), so as to represent a "SL-Related" setpoint. Such setpoints are described as "SL-Related" in the discussions that follow. In accordance with 10 CFR 50.36(c)(1)(ii)(A), the following guidance is provided for identifying a list of functions to be included in the subset of LSSSs specified for variables on which SLs have been placed as defined in Standard Technical Specifications, Sections 2.1.1, "Reactor Core SLs," and 2.1.2, "Reactor Coolant System Pressure SL." This subset includes automatic protective devices in TSs for specified variables on which SLs have been placed that: (1) initiate a reactor trip; or (2) actuate safety systems. As such, these variables provide protection against violating reactor core safety limits, or reactor coolant system pressure boundary safety limits.*

Examples of instrument functions that might have LSSSs included in this subset in accordance with the plant-specific licensing basis, are pressurizer pressure reactor trip (pressurized-water reactors), rod block monitor withdrawal blocks (boiling-water reactors), feedwater and main turbine high water level trip (boiling-water reactors), and end of cycle recirculation pump trip (boiling-water reactors). For each setpoint, or related group of setpoints, that you determined not to be SL-Related, explain the basis for this determination.

EGC Response:

The setpoint is not considered to be a Limiting Safety System Setting (LSSS) and does not represent an "SL-Related" setpoint. On TS Bases page B 3.3.6.1-18 it is stated for function 6.a, Recirculation Line Water Temperature—High, that "The Recirculation Line Water Temperature—High Function is provided to isolate the Shutdown Cooling System. This interlock is provided for equipment protection to prevent exceeding the system design temperature, and credit for the interlock is not assumed in the accident or transient analysis in the UFSAR." The existing bases description of this function is not changed by the proposed License Amendment Request (LAR). Prior to the LAR, the existing temperature instrumentation is classified as non-safety related.

The Dresden SDC system is designed for a pressure of 1250 psig and 350°F, and is therefore a higher pressure and lower temperature system and no safety related high

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pressure isolation signal is provided. Later vintage BWR plants utilize a low pressure residual heat removal system for the SDC function and are provided with a safety related isolation on high pressure. Such safety related isolation signals fulfill the guidance in Branch Technical Position 7-1, "Guidance on Isolation of Low-Pressure Systems from the High-Pressure Reactor Coolant System" and Generic Letters 87-12, "Loss of Residual Heat Removal (RHR) While the Reactor Coolant System (RCS) is Partially Filled," and 88-17, "Loss of Decay Heat Removal," for isolation of low-pressure systems from high-pressure reactor coolant systems. Since the SDC system at Dresden is a high pressure system, no safety related signal is provided for isolation of SDC on high pressure.

Dresden does utilize the safety related Reactor Vessel Water Level – Low function to provide SDC isolation as part of group 3 of the Primary Containment Isolation System. This isolation is provided for protection from a steam system piping break outside containment associated with SDC. This function is not affected by the proposed change.

Function 6.a of TS Table 3.3.6.1-1 is a non-safety related function provided for equipment protection since the SDC heat exchangers are designed for 350°F.

3. ***For setpoints that are determined to be SL-related:*** *The NRC letter to the NEI Setpoint Methods Task Force dated September 7, 2005 (ADAMS Accession No. ML052500004), describes Setpoint-Related TS (SRTS) that are acceptable to the NRC for instrument settings associated with SL-related setpoints. Specifically: Part "A" of the Enclosure to the letter provides limiting condition for operation notes to be added to the TS, and Part "B" includes a check list of the information to be provided in the TS Bases related to the proposed TS changes.*
 - a. *Describe whether and how you plan to implement the SRTS suggested in the September 7, 2005, letter. If you do not plan to adopt the suggested SRTS, explain how you will ensure compliance with 10 CFR 50.36 by addressing items 3.b and 3.c, which follow.*
 - b. ***As-Found Setpoint evaluation:*** *Describe how surveillance test results and associated TS limits are used to establish operability of the instrument channels that are used for initiating the applicable safety system functions. Show that this evaluation is consistent with the assumptions and results of the setpoint calculation methodology. Discuss the plant corrective action processes (including plant procedures) for restoring channels to "operable" status when channels are determined to be "inoperable" or "operable but degraded." Describe the processes that will be used to track corrective actions required for channels whose performance has been identified as "operable but degraded." If the criteria for determining operability of the instrument channel being tested are located in a document other than the TS (e.g. plant test procedure), explain how the requirements of 10 CFR 50.36 are met.*
 - c. ***As-Left Setpoint control:*** *Describe the controls employed to ensure that the instrument setpoint is, upon completion of surveillance testing, consistent with*

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the assumptions of the associated analyses. If the controls are located in a document other than the TS (e.g. plant test procedure), explain how the requirements of 10 CFR 50.36 are met.

EGC Response:

As described above in the response to Request 2, the setpoint is not considered to be an LSSS and does not represent an "SL-Related" setpoint. Therefore, the requested information is not applicable to this proposed change.

4. **For setpoints that are not determined to be SL-related:** *Describe the measures to be taken to ensure that the associated instrument channel is capable of performing its specified safety functions in accordance with applicable design requirements and associated analyses. Include in your discussion information on the controls you employ to ensure that the as-left trip setting after completion of periodic surveillance is consistent with your setpoint methodology. Also, discuss the plant corrective action processes (including plant procedures), for restoring channels to operable status when channels are determined to be "inoperable" or "operable but degraded." If the controls are located in a document other than the TS (e.g., plant test procedure), describe how it is ensured that the controls will be implemented.*

EGC Response:

The EGC administrative controls that ensure consistency of As-Left instrument values with the setpoint methodology (i.e., NES-EIC-20.04) are contained in a series of Engineering and Corrective Action Program (CAP) procedures. The current surveillance procedure for this function requires resetting the setpoint to a value within the as-left tolerance of the actual trip setpoint.

Engineering procedure ER-AA-520, "Instrument Performance Trending," defines the administrative process to implement an instrument trending program in order to monitor the behavior of instrumentation, thus providing an early warning of failure. The ER-AA-520 procedure works with additional EGC Engineering procedures (i.e., ER-AA-2030, "Conduct of Plant Engineering," ER-AA-2002, "System Health Indicator Program," and ER-AA-2003, "System Performance Monitoring and Trending"), and the EGC CAP procedures (i.e., LS-AA-120, "Issue Identification and Screening Process," and LS-AA-125, "Corrective Action Program (CAP) Procedure") to form a program that provides both timely and in-depth monitoring of surveillance results.

These procedures ensure that the results of instrument calibrations are monitored and periodic reviews of calibration data are conducted to determine instrument performance, relative to expectations. As such, the instrument trending program also provides control of the As-Found/As-Left data analysis program at DNPS.

ER-AA-520 also establishes the required actions when an As-Found instrument setpoint exceeds the AV, as well as when an As-Found setpoint is within the Allowable Value (AV), but exceeds the Expanded Tolerance (ET):

- If an As-Found instrument setpoint exceeds the AV, the instrument technician will enter the condition into the CAP by initiating a Condition Report (CR), and

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will notify the operating Shift Manager (SM) that the instrument is potentially inoperable. The operating SM will utilize LS-AA-120 to initially screen the condition, including the determination of operability. The SM will also initiate a Work Request (WR) to evaluate and repair/replace the instrument, prior to resetting the instrument to within a setting tolerance (ST).

- If an As-Found instrument setpoint is within the AV, but exceeds the ET, the instrument technician will reset the instrument to within the ST, and enter the condition into the CAP by initiating a CR and notifying the operating SM that the instrument is out-of-tolerance (OOT).
- If an instrument cannot be reset to within the ST during calibration, then the instrument technician will initiate a CR to document the information and the instrument will be repaired/replaced.

Licensee Setpoint Methodology: The following RAI (5) requests the basis for a specific aspect of the licensee's general setpoint methodology.

5. *Explain how an expanded tolerance (ET) could be less than the setting tolerance (ST), as it is calculated and identified as a check criterion. This explanation should make it apparent the mechanism by which the calculated ET could result in a value less than the ST for the equation discussed in section 2.4.4 of Attachment 4, Setpoint Calculation No. DRE09-0041, "Shutdown Cooling Reactor High Pressure (Cut-in Permissive) Setpoint Calculation," and provided as "ET = ± [0.7 * (DTI - ST)] + ST."*

EGC Response:

The as-left ST is treated as a three sigma value since it represents 100% of the results for successful periodic calibrations. Any periodic calibration that did not result in the instrument being within the ST would result in the instrument not being declared OPERABLE by a licensed operator and the calibration results entered into the CAP.

The DTI value and the results of the setpoint calculation are treated as two sigma values in accordance with the guidance of Regulatory Guide 1.105, "Setpoints for Safety-Related Instrumentation." While it is very rare, the two sigma value for the administrative as-found ET can be less than the three sigma ST. This check in the setpoint calculation ensures that the ET is greater than or equal to the ST as explained in section 2.4.4 of calculation DRE09-0041. A check is also performed to ensure that the ET is less than or equal to the value for the allowable value.

Within the setpoint calculation, uncertainties that are independent and random are combined at the same sigma level in accordance with the guidance of EGC standard NES-EIC-20.04.

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LAR Setpoint Specific: *The following RAI (6) addresses a specific aspect of the licensee's setpoint calculation.*

6. *Provide a justification for excluding errors associated with 'dynamic effects.'*
Currently, the LAR does not discuss 'dynamic effects.'

Reference 3.1.1 of Attachment 4, Setpoint Calculation No. DRE09-0041, "Shutdown Cooling Reactor High Pressure (Cut-in Permissive) Setpoint Calculation" of the LAR is Part 1 of ANSI/ISA-S67.04-1994, "Setpoints for Nuclear Safety-Related Instrumentation." Its Section 4.4(g) 'dynamic effects' states:

"The behavior of a channel's output as a function of the input with respect to time shall be accounted for, either in the determination of the trip setpoint or included in the safety analyses. Normally, these effects are accounted for in the safety analyses."

Regulatory Guide 1.105, "Setpoints for Safety-Related Instrumentation," Rev. 3 endorses—with exceptions and clarifications - Part 1 of ANSI/ISA-S67.04-1994; however, contrary to this endorsement, the 'process effects' described in the LAR do not address time-dependency (i.e. dynamic effects) associated with the temperature to pressure transmitter change or any additional time-dependency deltas that have been introduced by differing measurement systems (in other words, the introduction of the feedwater control system into Loop 2). The LAR only addresses pressure transmitter static process errors, which the LAR deems as insignificant by engineering judgment. Therefore, the LAR does not presently address design modifications that change the instrument dynamic characteristics and relocate sensors.

EGC Response:

The existing non-safety related temperature detectors for SDC Recirculation Line Water Temperature – High are located on the recirculation loops between the reactor pressure vessel and the reactor recirculation pump suction isolation valves. SDC isolation function 6.a is required for reactor modes 1, 2, and 3. The proposed pressure transmitters monitor reactor steam dome pressure and are required for the same reactor modes. The pressure that corresponds to a reactor coolant temperature of 350°F is the design limit for the proposed TS. In provided calculation DRE09-0041, this design limit is treated the same way as an analytical limit from a safety analysis when the proposed TS Allowable Value is determined. No process time-dependent deltas are introduced by the change from monitoring reactor coolant temperature to reactor coolant pressure when reactor coolant is greater than 350°F.

The introduction of the non-safety related Bailey Feedwater Control System into the loop is addressed in our response to Request 7.b below, but does not introduce a significant delay into the response time of the isolation signal.

Therefore, there is no time-dependency (i.e. dynamic effects) associated with the temperature to pressure change. Any additional time-dependency deltas, as described in the response to Request 7.b, are bounded by the thermal lag in the existing instrumentation.

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The topic of time dependent uncertainty (drift) for instrument Loop Two, Modules 2 and 3 are addressed within the setpoint calculation (I.E., LAR Attachment 4) and are considered to have a numerical value of zero. The justification for this position is in sections 4.12.7 and 4.12.8 of the setpoint calculation. The analog to digital (A/D) and digital to analog (D/A) conversion portions of the instrument have a calibration frequency of 2 years (24 months + 25%). Vendor documentation for the instrument addresses drift with the statement, "There are no drift effects because once a minute the multi-function processor corrects the measured values for drift and temperature variations." All vendor identified uncertainties for the signal conversions have been included within the setpoint calculation. The analysis of instrument Loop Two, Modules 2 and 3 results in an allowance for signal conversion uncertainty that is consistent with the manufacturer's guidance.

Resolution of Inconsistencies: *The following RAI (7) requests information to resolve apparent inconsistencies within the LAR and supporting documentation in order to clarify the scope and intent of the LAR instrumentation and control changes.*

7. *The licensee is requested to provide clarifications to apparent inconsistencies among the DNPS, Units 2 and 3, TS Bases and other information currently available to the NRC in order to clarify the full scope and nature of the proposed change. The licensee should address the inconsistencies to consistently describe the SDC isolation function, such that the maximum design temperature will not be exceeded. The licensee is requested to submit appropriate clarifications that address the following items 7.a through 7.f. These clarifications may include additional revisions/markups pages.*
 - a. *The continued use of the term 'temperature' for the isolation function: Specifically, the title on Bases Page B 3.3.6.1-18, for Function 6.a, should be changed from "Recirculation Line Water Temperature-High," to "Reactor Vessel Pressure – High," to match the proposed title for TS 3.3.6.1, Table 3.3.6.1-1, Function 6.a.*
 - b. *The continued use of the term 'bypass' in consideration of the proposed one-out-of-two-taken-twice logic configuration: The licensee response should clearly, correctly, and consistently describe the sense-trip-logic-actuation sequence in order to evaluate the acceptability of the TSs, Table 3.7.6.1-1 entries for FUNCTION 6.a. under "Shutdown Cooling System Isolation," and in particular, the "REQUIRED CHANNELS PER TRIP SYSTEM," its referenced condition F, and any dependency of the function on the non-safety-related feedwater control system. The licensee response should consider whether 'bypassing' a failed channel, which is typical of one-out-of-four logic, remains appropriate, or rather forcing a one-half trip, which is typical of one-out-of-two-taken-twice logic, is now appropriate. Currently, there is a lack of clarity, because the LAR indicates that one-out-of-four logic currently exists; however, the common DNPS, Units 2 and 3, TS Bases (see Revision 6, Page B 3.3.6.1-23) contains actions consistent with placing the failed channel in the tripped state (versus bypass-non-tripped). The licensee response should fully resolve this inconsistency.*

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- c. Definition and description of terms: *The licensee should provide a definition for each of the following: 1) trip string, 2) trip channel, and 3) trip system, and a corresponding figure that identifies and shows each of these items in the configuration proposed by the LAR: one-out-two-taken-twice logic using all pressure sensor inputs (for Loops 1 and 2). This information is required to provide the complete context of the proposed modification. This clarification is required, because the DNPS, Units 2 and 3, TS Bases (see Revision 8, Page B 3.3.6.1-5) does not currently describe the use of 'trip strings' for the Recirculation Line Water Temperature-High Function, but rather only describes this aspect of the isolation function in terms of 'trip channels' and 'trip systems.'*
- d. Consistency of logic function description: *The DNPS, Units 2 and 3, TS Bases (see Revision 8, Page B 3.3.6.1-5) describes the Recirculation Line Water Temperature-High isolation logic as one-out-of-four; however, it does not identify DNPS, Unit 2 as currently having a one-out-of-two-taken-twice logic configuration (reference the 4th paragraph on Page 4 of 13 of Attachment 1). It is noted that the cause for this difference between units is described in LAR (see the 4th complete paragraph of Page 6 of 13 of the Attachment 1) despite it not being reflected in the common TS Bases.*
- e. Clarification of the term "loop:" *The DNPS, Units 2 and 3, TS Bases (see Revision 31, Page B 3.3.6.1-18), which currently describes the logic as one-out-of-four, includes a statement, "Only two channels (one channel from each loop) are required to be operable." Within the licensee's response, the licensee should clarify the term 'loop,' which had been understood to reference the previous recirculation 'loops' where the previously relied-upon temperature sensors reside. Also, as currently written, the statements are consistent with one-out-of-four logic where a bypass may be permitted; however, the LAR now describes the proposed two pressure-based 'loops' to feed one-out-of-two-taken-twice logic. Therefore, the statement, as currently written, should be modified, as appropriate, in consideration of item 7.b.*
- f. Clarification of Loop 2 operability: *The licensee should clarify its considerations of the adequacy of the TS surveillance requirements in order to address the insertion of the digital feedwater control system into the SDC isolation function. The clarification should address Loop 2's operability in a manner that considers failure modes of the digital feedwater control system for the "Reactor Vessel Pressure-High" function.*

EGC Response:

- 7.a EGC agrees with the comment provided by the NRC. Therefore, the title of Function 6.a, as defined on Bases page B 3.3.6.1-18, will be revised to read "Reactor Vessel Pressure – HIGH." This will ensure that the Bases are consistent with the proposed TS 3.3.6.1, Table 3.3.6.1-1, Function 6.a.
- 7.b It appears that there is a typographical error in NRC Request 7.b where it refers to Table 3.7.6.1-1. It seems based on our review of the request that the correct

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reference should be to Table 3.3.6.1-1. Therefore, the following response is based on this understanding.

An administrative error caused the confusion between the one-out-of-four logic and the one-out-of-two-taken-twice logic by not properly deleting the following wording from the description of Function 6, "Shutdown Cooling (SDC) System Isolation," on page B 3.3.6.1-5: "For Unit 3 the Recirculation Line Water Temperature-High Function receives input from four channels, each of which provides input to both logic systems. Any channel will trip both logic systems. This is one-out-of-four logic for the trip system." The revised circuit is a one-out-of-two-taken-twice logic configuration and in this configuration, a failed channel is required to be placed in a half trip condition.

The objective of the SDC system is described in UFSAR Section 5.4.7. In summary, it is required to cool the reactor water when the temperature and pressure in the reactor fall below the point when the main condenser can no longer be used as a heat sink during reactor shutdown. The long-term containment cooling function is performed by the containment cooling mode of low pressure coolant injection (see UFSAR Section 6.2.2), separate from the SDC system. The existing Dresden SDC Recirculation Line Water Temperature-High interlock logic function is for equipment protection and is a non-safety related function. This function utilizes non-safety related temperature elements (i.e., thermocouples and RTD's) and trip units to monitor and initiate the interlock function for equipment protection. The existing SDC Recirculation Line Water Temperature-High interlock circuit interfaces with the Group 3 Isolation circuitry for the SDC isolation valves via an interfacing relay that is classified as safety related. This interfacing relay provides a coil to contact isolation between the non-safety related SDC temperature interlock circuitry and the Group 3 safety related isolation circuitry.

The proposed change revises the process parameter from using temperature, to using pressure that has a known relationship as documented in the steam tables for saturation conditions. To accomplish this proposed change the existing non-safety related Recirculation temperature elements (i.e., thermocouples and RTD's) and trip units that make up the interlock function will be replaced with non-safety related pressure trip units.

This proposed design uses four existing pressure channels by installing a new pressure trip unit in each channel that is configured to perform the interlock function. Two of the existing pressure channels are from the Analog Trip System (ATS) that is safety related and the other two are from the Bailey Feedwater System which is non-safety related. Since the existing temperature components used for the interlock function are non-safety related, non-safety related components can be used without affecting the component classification. Because the two existing ATS pressure channels are safety related and the new components are non-safety related isolation is required. One of the existing ATS pressure channels already has an existing isolator that will be utilized and a new isolator will be installed in the second pressure channel. These isolators are qualified devices that will protect the existing safety related ATS function from a fault on the non-safety related SDC interlock circuit.

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The remaining two existing non-safety related pressure channels provide an analog input signal to the Bailey Feedwater system where the pressure channel is processed and sent to main control panel indicators. To prevent a failure of the new trip units from affecting the Feedwater System and causing a feedwater transient, the new pressure interlock circuits are connected to the reactor pressure output signals from the Bailey Feedwater system.

The Bailey system processes the analog pressure signal by digitizing it and verifying that it is a good quality signal while concurrently processing the pressure signal through a lead/lag function. This lead/lag function is currently setup as a pass through function where the output equals input (i.e., no lag). After the lead/lag function, the signal goes to a transfer switch and then to the output digital to analog card, if the input signal quality is good. If the input signal quality is bad, the transfer switch forces the output to the digital to analog card to zero. A sketch showing the circuit layout for the proposed change is provided as Enclosure 2 to this Attachment.

The Bailey Feedwater system executes function blocks in sequential order within a process scan cycle time of approximately 250 Milliseconds. The function blocks that perform this function are sequentially numbered with the exception of one function block that is out of sequence. Because of this, it could take up to a maximum of two scan cycles to process a pressure change. Similar Rosemount transmitters, used in the Feedwater system, have been response time tested along with their analog trip unit in some safety related circuits. This response time test was performed to demonstrate that these safety related circuits meet the Updated Final Safety Analysis Report (UFSAR) response time requirement of being less than or equal to 50 milliseconds. It is reasonable to expect that the existing Rosemount pressure transmitters will have a 50 millisecond response time. The new trip units are similar to the existing trip units and are expected to have similar response times. Therefore, the dynamic affect of the proposed change is insignificant and bounded by the thermo lag of the existing thermo well and system response.

The contacts from the new trip units are configured in a one-out-of-two-taken-twice logic configuration where a contact from an ATS and the Bailey Feedwater System channel are connected in series to form a trip system. In this configuration, a complete loss of either Analog Trip Systems or the Bailey Feedwater System will not prevent the isolation function from occurring.

Arranging the ATS and the Bailey Feedwater System channel trip unit contacts, as shown in Enclosure 2, will ensure that a sensing line condensing chamber failure will not prevent the interlock function from occurring. Each of the two pressure channels within a trip system senses reactor pressure on opposite sides of the vessel similar to the existing Recirculation temperature channels.

In the proposed design, a second interfacing relay is installed to prevent a single failure of the interfacing relay from preventing the interlock function from occurring. This interface relay is used to provide coil to contact isolation and as a contact

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multiplier. The existing and new interface relays are classified as safety related since it is the interface between the non-safety SDC interlock and safety related isolation circuits.

- 7.c A sketch showing the circuit layout for the proposed change is provided as Enclosure 2 to this Attachment. This sketch shows the trip channels, trip strings, and trip systems arrangement as well as the safety and non-safety related boundaries.

The Trip Channel is an arrangement of components and modules as required to generate a single protective action signal when required. A Trip Channel loses its identity where single protective action signals are combined.

The Trip String is an arrangement of one or more trip channels in a series configuration arrangement to form a trip system.

The Trip System in a one-out-of-two-taken-twice logic configuration is an arrangement of two Trip Strings in a parallel configuration arrangement.

- 7.d An administrative error caused the confusion between the one-out-of-four logic and the one-out-of-two-taken-twice logic by not properly deleting the following wording from the description of Function 6, "Shutdown Cooling (SDC) System Isolation," on page B 3.3.6.1-5: "For Unit 3 the Recirculation Line Water Temperature-High Function receives input from four channels, each of which provides input to both logic systems. Any channel will trip both logic systems. This is one-out-of-four logic for the trip system." The revised circuit is a one-out-of-two-taken-twice logic configuration.

At the time of the LAR submittal, the Unit 2 interlock logic was a one-out-of-two-taken-twice logic configuration and Unit 3 was a one-out-of-four-taken-once logic configuration. The proposed change will configure the Unit 3 interlock logic to be the same as the Unit 2 one-out-of-two-taken-twice logic arrangement configuration. With the resolution of the above administrative error, the one-out-of-two-taken-twice logic arrangement configuration will be correctly reflected in the TS Bases.

- 7.e The term "loop" reflects the two pressure channels. Instrument Loop 1 is the Reactor Wide-Range Pressure and instrument Loop 2 is the Reactor Pressure Feedwater Control.

At the time of the LAR submittal the current revision for TS Bases B 3.3.6.1-18 was revision 49 not 31. The Bases markups provided with the LAR were made on the current revision of the Bases at that time (i.e., Revision 49). Revision 49 to the Dresden TS Bases provides a separate description for Unit 2 and Unit 3 since the circuits were different. The Unit 2 interlock logic was a one-out-of-two-taken-twice logic configuration and Unit 3 was a one-out-of-four-taken-once logic configuration. In the Unit 3 one-out-of-four-taken-once logic configuration, it was permissible to bypass a failed channel for each of the recirculation loops since each recirculation loop had two channels and no single failure could prevent the interlock function from occurring. In the existing Unit 2 one-out-of-two-taken-twice logic

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configuration, bypassing a failed channel is not allowed. In the proposed change both Unit 2 and Unit 3 logic will be configured in a one-out-of-two-taken-twice logic configuration and the failed channel will be required to be placed in a half trip condition. Therefore, the statement as currently written is correct.

- 7.f The applicable surveillance procedures are being revised to incorporate the required TS surveillance requirements for the four pressure channels. See the circuit description in the response to Request 7.b above. There are no common mode software or hardware failures associated with the Bailey Feedwater system that could cause the SDC system to misoperate. Therefore, the revised surveillance procedures are adequate to verify proper operation.

SDC Isolation Functions: *The following RAI (8) requests information to support evaluation of the LAR against criteria applicable to the SDC isolation functions, including those related to the plant's diversity and defense-in-depth. This information is necessary because the LAR proposes to replace instrumentation used to perform the SDC isolation function (currently performed by analog safety-related instrumentation) with partial reliance upon the non-safety-related digital feedwater control system.*

8. *Provide sufficient information to justify reliance upon the non-safety-related digital feedwater control system to perform SDC Isolation functions. This information should:*
- a. *Address compliance with U.S. NRC SRP, Chapter 7, Section 7.6, "Interlock Systems Important to Safety" (ADAMS Accession No. ML070460348).*
 - b. *Demonstrate that any single failure of the equipment used to support the SDC isolation functions, including the isolation devices and non-safety related digital feedwater system, does not result in a vulnerability to which either DNPS Unit 2 or Unit 3 has an inability to cope. This response should explain how the diversity and defense-in-depth that will remain following proposed LAR ensures reliable operation of the SDC Isolation functions (autoclosure and interlocks), so that the SDC system:*
 - i) *Isolates when required to prevent potential damage to the SDC components and possible radiological release;*
 - ii) *Remains sealed-in and does not inadvertently isolate when needed, thereby interrupting shutdown cooling; and*
 - iii) *Does not un-isolate when the temperature is above 350°F.*

Within this response, the licensee should clarify all considerations made to address software common-cause failures that might affect the SDC Isolation functions.

The LAR proposes to use the non-safety digital feedwater control system to generate half of the actuation signals (Loop 2) that isolate the SDC system from the reactor pressure vessel. However, SDC isolation functions are important to safety, because

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these functions are relied upon to meet portions of Appendix A to Part 50--General Design Criteria for Nuclear Power Plants: a) Criterion 14, "Reactor Coolant Pressure Boundary," Criterion 15, "Reactor Coolant System Design," and Criterion 34, "Residual Heat Removal," by preventing an improper connection of the SDC system to the Reactor Coolant System (RCS) when the RCS temperature is above 350°F. The SDC isolation function is designed to prevent exceeding the SDC system design temperature of 350°F, in part, to prevent subsequent equipment damage and resultant loss of coolant. SRP 7.6 addresses interlocks consistent with the type included in this LAR and identifies acceptance criteria.

EGC Response:

The description of the SDC isolation functions provided above incorrectly states that "the LAR is proposing to replace instrumentation used to perform the SDC isolation function (currently performed by analog safety-related instrumentation) with partial reliance upon the non-safety related digital feedwater control system." The current existing SDC analog interlock components are non-safety related and remain non-safety related under the proposed modification. A description of the current and proposed circuit descriptions are provided in the response to Request 7.b above.

- 8.a The proposed change is only affecting non-safety related equipment with the exception of the existing and new interfacing relays and isolators that meets the IEEE 279-1971, "Criteria for Protection Systems for Nuclear Power Generating Stations," requirements. The non-safety related portion of the proposed change is not required to meet the IEEE 279-1971 or NRC SRP, Chapter 7, Section 7.6, "Interlock Systems Important to Safety" requirements. Refer to the system discussion provided above in the response to request 7.b. Although the SDC interlock function is non-safety related the proposed change has been designed to be single failure fault tolerant such that no single failure will prevent the interlock function from performing its design function. The proposed change meets the requirements of the IEEE 279-1971, Section 4.7. Multiple non-safety related faults will not affect the safety related function of the Wide Range Pressure channels or the Group 3 Isolation logic function.

No credit is taken for the SDC interlock within the UFSAR Chapter 15 accident analysis.

- 8.b As previously discussed, the non-safety related isolation function is for equipment protection and the existing design is not diverse. Diversity is not provided as a part of the design of this proposed change since it is not required.
- i. The existing Dresden SDC Recirculation Line Water Temperature-High isolation logic function is non-safety and utilizes non-safety related components to monitor and initiate the interlock function for equipment protection as described above in the response to Request 7.b and Enclosure 2. In the proposed change there are no single failures that will prevent the interlock function from closing the isolation valves when the reactor pressure exceeds the predefined pressure setting. This proposed change uses pressure components that have a history of being highly reliable.

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This proposed design uses pressure channels from the ATS and the Bailey Feedwater systems that are diverse. The new trip strings consist of a pressure channel from each of these diverse systems. Each pressure transmitter within a trip string is connected to a diverse sensing line on the reactor vessel. This ensures that no single sensing line failure will prevent the isolation from occurring. Because each trip string uses a pressure channel from the ATS and the Bailey Feedwater systems no single or common mode software failure will prevent the isolation from occurring.

The existing and new pressure channels are continuously monitored for an adverse condition indicating a component failure. If a component failure occurs the operator would be notified by alarms and adverse indication that would require immediate operator action to identify and resolve the issue. In the proposed configuration, a failed component can be replaced on line whereas the existing temperature elements can only be replaced during an outage. This feature improves system reliability since a failed component would be replaced in a timely manner instead of waiting for an outage.

- ii. The proposed circuit configuration minimizes single failures to the extent practical. In the existing design the primary cause of the failures are temperature elements that are located within the Drywell that cannot be replaced while the unit is on line. The proposed change uses highly reliable pressure components that have a long history of reliable service. In addition, if a pressure component fails it can be replaced on line since the pressure components are located outside the Drywell.

The intent of the design change is to improve equipment reliability by using highly reliable pressure channel components that have a history of proven reliability. A failure of a single pressure transmitter or trip unit will not cause the SDC to isolate. In the Bailey Feedwater system, there are no single hardware, software, or common mode failures that will prevent the SDC from isolating when required or cause an inadvertent isolation from occurring.

This design change does not eliminate all single failures associated with this circuit since the existing and revised circuits use a common power source for both trip strings and the isolation circuits. A failure of the power source will cause an inadvertent isolation of the SDC system.

- iii. To un-isolate the SDC system requires manual operator actions. No single failure can cause the system to un-isolate when the temperature is above 350°F. There are no common mode software or hardware failures that could cause the SDC system to un-isolate.

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ENCLOSURE 1

NES-EIC-20.04, "Analysis of Instrument Channel Setpoint Error
and Instrument Loop Accuracy," Revision 5

ANALYSIS OF INSTRUMENT CHANNEL SETPOINT ERROR AND INSTRUMENT LOOP ACCURACY

If this standard does not address your particular application, or is not appropriate to your application,
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Rev No	Description	Prepared by	Reviewed by	Approved by
3	Revised Appendix I and J. Updated References. Approved for use 10/23/00	R. Fredricksen	D. Ugorcak	R. Beavers
4	Revised Appendix J and replaced ComEd with Exelon	W. Kurth	R. Fredricksen	R. Hall
5	Revised Appendix A. Updated References. Corrected Minor Typographical Errors. Approved for use 09/19/2008.	G. Hoopes	R. DiSandro	R. Libra

Latest Revision indicated by a bar in right hand margin.

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ANALYSIS OF INSTRUMENT CHANNEL SETPOINT ERROR AND INSTRUMENT LOOP ACCURACY

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1.0 PURPOSE

This engineering standard defines a methodology for the determination of instrument setpoints, allowable values and instrument loop accuracy, that is consistent with ANSI/ISA-67.04.01-2000 (reference 3.1). This standard may be used to:

- combine instrument uncertainties and errors used in the determination of instrument channel and setpoint accuracy,
- develop a basis for establishing instrument setpoints with respect to applicable acceptance criteria, and
- provide criteria to ensure that setpoints are maintained within specified limits.

ANSI/ISA RP67.04.02-2000 (reference 3.2) shall be used when this document does not provide the necessary guidance for a particular application.

Upon issue, this document replaces in their entirety: TID-E/I&C-10, Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy, rev. 0, and TID-E/I&C-20, Basis for Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy, rev. 0.

2.0 SCOPE

This standard defines an acceptable method for establishing the uncertainties associated with instruments, instrument loops, and instrument setpoints and for applying these uncertainties in the determination of instrument loop accuracy, allowable values and calculated setpoints at Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) nuclear stations. This document shall be used when establishing specific values for loop accuracy, allowable values, and instrument setpoints.

This standard shall be utilized by qualified Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) personnel, non-Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) organizations and integrated teams in the development of uncertainty analyses for the purpose of:

- establishing new setpoints (both safety and non-safety related),
- evaluation or justification of existing setpoints,
- determining instrument indication uncertainties and indication accuracies, and
- performing uncertainty analyses as required by other engineering evaluations.

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- 3.0 REFERENCES
- 3.1 ANSI/ISA-67.04.01-2000, Setpoints for Nuclear Safety-Related Instrumentation, Approved February 29, 2000
- 3.2 ISA- RP67.04.02-2000, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation, Approved January 1, 2000
- 3.3 ISA-TR67.04.08-1996, Setpoints for Sequenced Actions, Approved March 21, 1996
- 3.4 ISA-dTR67.04.09-1996, Graded Approaches to Setpoint Determination (draft)
- 3.5 ANSI/ISA S37.1-1969, Electrical Transducer Nomenclature and Terminology (formerly ANSI MC6.1-1975)
- 3.6 ANSI/ISA S51.1 - 1979, Process Instrumentation Terminology
- 3.7 ISA Aerospace Industries Division, Measurement Uncertainty Handbook, revised 1980
- 3.8 ISA-MC96.1-1982, Temperature Measurement Thermocouples
- 3.9 ISO/TAG 4/WG 3: June 1992, Guide to the Expression of Uncertainty in Measurement
- 3.10 ANSI/ASME PTC6 Report - 1985, Guidance for Evaluation of Measurement Uncertainty in Performance Tests of Steam Turbines
- 3.11 ANSI/ASME PTC 19.1 - 1985, Part 1, Measurement Uncertainty
- 3.12 ANSI/ASME MFC-2M-1983, Measurement Uncertainty for Fluid Flow in Closed Conduits
- 3.13 ASME MFC-3M-1989, Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi
- 3.14 ASME Application, Part II of Fluid Meters, Sixth Edition 1971, Interim Supplement 19.5 on Instruments and Apparatus
- 3.15 SAMA PMC 20.1-1973, Process Measurement & Control Terminology (for information only, standard withdrawn)
- 3.16 NUREG/CR-3659, A Mathematical Model for Assessing the Uncertainties of Instrumentation Measurements for Power and Flow of PWR Reactors, February 1985
- 3.17 Exelon Nuclear Procedure CC-AA-309, Control of Design Analysis

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- 3.18 ANSI/IEEE Std 344-1975, IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations
- 3.19 EPRI TR-103335, Guidelines for Instrument Calibration Extension/Reduction Programs, October 1998, Revision 1
- 3.20 EPRI AP-106752, Instrument Performance Analysis Software System, IPASS User's Guide, August 1996
- 3.21 Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) Nuclear Operating Division Standard NES- EIC -20.01, Standard for Evaluation of M&TE Accuracy When Calibrating Instrument Components and Channels, rev. 0, January 23, 1996
- 3.22 Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) Nuclear Operating Division Procedure ER-AA-520, Instrument Performance Trending
- 3.23 Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) Nuclear Operating Division Standard NES-G-14, Calculations
- 3.24 Rosemount Publication 00816-0100-3044, Model 1151DP/HP Calibration for Operation at High Static Pressure
- 3.25 Exelon (Limerick, Peach Bottom) Nuclear Procedure IC-C-11-00305, Calibration of Rosemount Models 1151, AP, 1151DP, 1151GP and 1151HP Transmitters

4.0 DEFINITIONS

Note: symbols in parenthesis represent the Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) methodology symbols used in setpoint accuracy calculations.

- 4.1 **allowable value (AV):** the limiting value that the trip setpoint may have when tested periodically, beyond which appropriate action shall be taken.

The allowable value provides operability criteria for those setpoints or channels that have a limiting operating condition. This limiting condition is typically imposed by the Technical Specification, but may also result from regulatory requirements, vendor requirements, design basis criteria or other operational limits.

The allowable value applies to the "as-found" condition or "as-found" calibration values.

- 4.2 **allowance for spurious trip avoidance (AST):** an evaluation to ensure that sufficient margin exists between the steady state operating value and the trip setpoint. May include a statistical

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combination of instrument channel accuracy (normal environment) including drift, processes effects and the effect of the limiting operating transient.

- 4.3 **analytical limit (AL):** limit of a measured or calculated variable established by the safety analysis to ensure that a safety limit is not exceeded.
- 4.4 **bias (e):** an uncertainty component that consistently has the same algebraic sign and is expressed as an estimated limit of error.
Bias error terms may also be represented by:
 - 1) Symmetrical bias errors: the estimated limit of error is known but not its sign. The limit of error is evaluated separately in both the positive and negative directions.
 - 2) Deterministic errors that may not be sufficiently random or independent to be combined with other random errors using the square-root-sum-of-squares (SRSS) methodology.
- 4.5 **calibration block:** the basic unit of evaluation in this standard. A calibration block is that part of the instrument channel between the point(s) where input test signals are applied and the point where the module performance is monitored (e.g. signal output, bi-stable actuation, etc.).

A calibration block may be a single component or module, or an assembly of interconnected components that are calibrated as a single unit (commonly referred to as a “string calibration”).
- 4.6 **calibration error (CAL):** an uncertainty affecting the accuracy of an instrument channel or component resulting from the calibration method and calibration components. Calibration components include the uncertainties and errors associated with use of M&TE (e.g. reference accuracy, reading error, environmental effects, etc.) and uncertainties associated with the calibration and maintenance of the M&TE (e.g. calibration standard error or STD).
- 4.7 **calibration standard error (STD):** an uncertainty affecting the accuracy of an instrument channel or component resulting from the standards used to calibrate or validate the M&TE accuracy.
- 4.8 **drift (D):** an undesired change in output over a period of time where change is unrelated to the input, environment, or load.
- 4.9 **error:** the algebraic difference between the indication and the ideal value of the measured signal. Refer to sections 5.1:1 and 5.1.2 for a discussion of measurement uncertainty and measurement error.
- 4.10 **humidity error (eH):** an uncertainty affecting the accuracy of an instrument channel or component resulting from variations in ambient humidity.

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4.11 **insulation resistance error (eIR):** an uncertainty affecting the accuracy of an instrument channel or component resulting from leakage currents caused by the degradation of the insulating properties of instrument channel components.

4.12 **limiting safety system setting (LSSS):** limiting safety system settings for nuclear reactors are settings for automatic protective devices related to those variables having significant safety functions.

The LSSS values may have been defined by the station Technical Specifications to correspond to either the allowable value or the trip setpoint. The LSSS values used in setpoint error analysis must be consistent with each station's Technical Specifications.

4.13 **margin (m):** in setpoint determination, an allowance added to the instrument channel uncertainty. Margin moves the setpoint farther away from the analytical limit.

Margin may result from 2 conditions:

- 1) margin is a method for arbitrarily adding additional conservatism or confidence, often as a result of engineering judgment, and
- 2) margin may exist where the instrument channel uncertainty is less than the difference between the calculated setpoint and the analytical limit. This margin may be utilized as an additional conservatism.

4.14 **module:** any assembly of interconnected components that constitutes an identifiable device, instrument, or piece of equipment. A module can be removed as a unit and replaced with a spare. It has definable performance characteristics that permit it to be tested as a unit. A module can be a card, a drawout circuit breaker, or other subassembly of a larger device, provided it meets the requirements of this definition

4.15 **power supply error (eV):** an uncertainty affecting the accuracy of an instrument channel or component resulting from variations in the electrical power supply voltage, current or frequency.

4.16 **pressure error (eP):** an uncertainty affecting the accuracy of an instrument channel or component resulting from changes in either 1) process pressure or 2) ambient pressure.

4.17 **process error (ep):** an uncertainty affecting the accuracy of an instrument channel or component resulting from process effects, e.g. flow turbulence, temperature stratification, process fluid density changes, etc. The process error may also include uncertainties resulting from the metering device itself, e.g. nozzle fouling. This uncertainty may also be referred to as "process measurement error" in some Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) calculations.

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- 4.18 **radiation error (eR):** an uncertainty affecting the accuracy of an instrument channel or component resulting from exposure to ionizing radiation.
- 4.19 **random (σ):** a variable whose value at a particular future instant cannot be predicted exactly but can only be estimated by a probability distribution function.
- As used in this standard, the term “random” means random and approximately normally distributed.
- 4.20 **reading error (RE):** an uncertainty affecting the accuracy of an instrument channel or component resulting from the ability to interpret an indicated value.
- 4.21 **reference accuracy (RA):** a number or quantity that defines a limit that errors will not exceed, when a device is used under specified operating conditions. Reference accuracy includes the combined effects of linearity, hysteresis, deadband, and repeatability.
- Caution should be used when applying vendor supplied values for reference accuracy to ensure that all of the above components that contribute to reference accuracy are included.
- 4.22 **safety limit:** a limit on an important process variable that is necessary to reasonably protect the integrity of physical barriers that guard against the uncontrolled release of radioactivity.
- 4.23 **seismic error (eS):** a temporary or permanent uncertainty affecting the accuracy of an instrument channel or component caused by seismic activity or vibration.
- 4.24 **setting tolerance (ST):** the accuracy to which a module is calibrated or maintained by a station calibration procedure. As used in this standard, the setting tolerance is equivalent to the “calibration tolerance” specified in the station calibration procedure.
- 4.25 **static pressure error (eSP):** an uncertainty affecting the accuracy of dP sensors resulting from operation at a pressure different from that to which it was calibrated. Static pressure error may consist of zero error and span error components.
- 4.26 **temperature error (eT):** an uncertainty affecting the accuracy of an instrument channel or component resulting from the effects of ambient temperature changes. The temperature error can affect component accuracy, M&TE accuracy, or process error.
- 4.27 **trip setpoint (SP):** a predetermined value for actuation of the final setpoint device to initiate a protective action. The actual calibrated setpoint may be more conservative than the calculated setpoint obtained from the analysis of instrument channel setpoint error.
- 4.28 **uncertainty:** the amount to which an instrument channel’s output is in doubt (or the allowance made therefore) due to possible errors, either random or systematic, that have not been corrected. The uncertainty is generally identified within a probability and confidence

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level. Refer to sections 5.1.1 and 5.1.2 for a discussion of measurement uncertainty and measurement error.

5.0 METHODOLOGY

5.1 BASIC CONCEPTS

5.1.1 Measurement Error

The objective of a measurement is to determine the value of the measurand (ref. 3.8). The following contributors are included in the measurement:

- the specification of the measurand,
- the method of measurement and
- the measurement procedure.

The result of a measurement is an approximation or estimate of the value of the measurand due to errors, effects and corrections to these three contributors. For this reason, a measurement must be accompanied by a statement of the uncertainty of that estimate.

The measurement process includes imperfections that result in an error in the measurement result. Errors may be of 2 types: random or systematic. Random error results from unpredictable variations and is evidenced by variations in repeated observations or measurements of the measurand. Random errors of a measurement result cannot be compensated by correction. They can be minimized or reduced by increasing the number of observations, increasing the accuracy of the measurement device or by incorporating a measurement procedure that reduces sources of error. Similarly, systematic error also cannot be eliminated. Systematic errors resulting from identified effects can be quantified and a correction or correction factor may be applied to the measurement result to compensate for this type of error.

An error in the measurement results is not the same as measurement uncertainty, and should not be confused in the process of instrument channel setpoint error analysis or instrument loop accuracy.

5.1.2 Measurement Uncertainty

“The word ‘uncertainty’ means ‘doubt’, and thus in its broadest sense uncertainty of measurement means doubt about the exactness or accuracy of the result of a measurement” (reference 3.8). Typically, uncertainty is defined and quantified using a parameter associated with the result of the measurement, e.g. standard deviation, width or confidence interval, dispersion interval, etc.

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The uncertainty of measurement is a combination of a number of components. Some of these components may be determined from the statistical evaluation of the distribution of a number of measurement results. These are characterized by a level of confidence in the uncertainty and a level of confidence in the distribution of the results. Some components may rely on assumed probability distributions based on experience or other information.

5.1.3 Methodology

Methodology defines a consistent means of:

- identifying sources of uncertainties and errors that may effect instrument channel accuracy,
- defining the mechanisms and processes used to evaluate the magnitude of these effects,
- defining the process for combining individual effects into a channel accuracy, and
- defining the equations used to determine setpoints and allowable values.

Given the uniqueness of many of the instrument channels and the special requirements of many instrument setpoints, situations that are not consistent with this methodology are expected. Where specific documentation, references or experience exists that dictates a deviation from this methodology, this information may be incorporated in the basis for channel accuracy and instrument setpoints.

Changes to this methodology require the review and approval of the NES Electrical/I&C Chief Engineer. Deviations from this methodology shall be documented in an associated engineering calculation as required by NEP-12-02, Preparation, Review, and Approval of Calculations.

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5.1.4 Accuracy

Accuracy is the combination of:

- known or expected process effects,
- known or expected instrument or instrument channel performance characteristics,
- known or expected measurement errors,
- known or expected measurement uncertainties, and
- allowances for conservatism (margin).

Determination of instrument loop accuracy, instrument setpoints and the associated allowable values must consider all of these areas. Appendix A provides a minimum list of the errors and uncertainties that must be included in this analysis.

5.2 ESTABLISHMENT OF SETPOINTS AND ALLOWABLE VALUES

This methodology should be used to provide sufficient allowance between the trip setpoint and an analytical limit, safety limit or other acceptance limit, to account for instrument channel accuracy.

The relationship between the analytical limit and the trip setpoint is shown in Figure 1. Figure 1 also indicates the relationship between the safety limit, the analytical limit, the allowable value, the trip setpoint and the normal process condition. These relationships are described by the following allowances.

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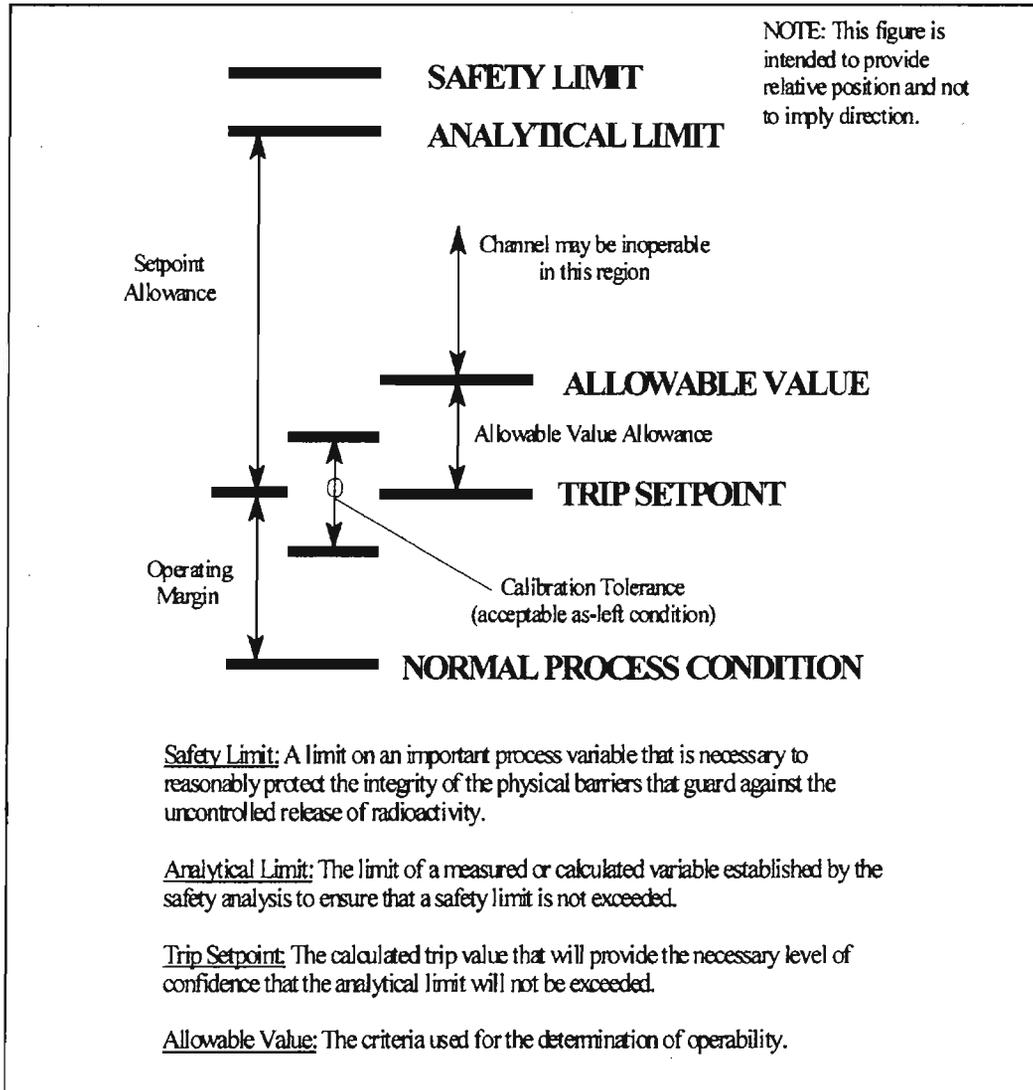


Figure 1, Setpoint Relationships

5.2.1 Setpoint Allowance: The setpoint allowance describes the relationship between the trip setpoint and the analytical limit. This allowance may be determined through the evaluation of the instrument channel accuracy, operating experience (including as-found/as-left analysis), equipment qualification tests, vendor design specifications, engineering analyses, laboratory tests, engineering drawings, etc.

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The setpoint allowance shall account for all applicable design basis events (normal and abnormal) and the following process instrument uncertainties unless they were included in the determination of the analytical limit.

Instrument uncertainties included in the setpoint allowance:

- 1) Instrumentation calibration uncertainties; including:
 - calibration standards,
 - calibration M&TE, and
 - setting tolerances.
- 2) Calibration methods
- 3) Instrument uncertainties during normal operation; including:
 - reference accuracy,
 - power supply voltage and frequency changes,
 - ambient temperature changes,
 - humidity changes,
 - pressure changes,
 - in service vibration allowances,
 - radiation exposure, and
 - A/D and D/A conversion.
- 4) Instrument drift
- 5) Uncertainties caused by design basis events
- 6) Process dependent effects
- 7) Calculation effects
- 8) Dynamic effects
- 9) Installation biases

It is often difficult to determine what errors and uncertainties have been included by the NSSS supplier or A/E in the determination of the original design basis analytical limit. This is especially true for the environmental conditions. It should not be assumed that analytical limits contained in Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) documents and/or Tech Specs are correctly implemented as LSSS setpoints or calculated setpoints without evaluation of the original setpoint accuracy analysis or preparation of a new analysis using this standard.

5.2.2 Allowable Value Allowance: This allowance describes the relationship between the trip setpoint and the allowable value. The purpose of the allowable value is to identify a value that, if exceeded, may mean that the instrument, device or channel has not performed within the basis of the setpoint calculation. A channel whose as-found condition exceeds the allowable value should be evaluated for operability, taking into account the setpoint calculation methodology.

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At Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) nuclear stations, non-reactor protection setpoints frequently have administrative limits, reportable tolerances or other station specific criteria to evaluate the as-found condition of a setpoint, calibration or operational test. Refer to ER-AA-520, Instrument Performance Trending, for additional information associated with these limits.

Instrument uncertainties included in the Allowable Value allowance:

- 1) Instrument calibration uncertainties
- 2) Instrument uncertainties during normal operation
- 3) Instrument drift

5.2.3 Operating Margin: This allowance describes the relationship between the normal process condition and the trip setpoint. It is considered good practice to evaluate this relationship in order to determine the effect of normal operating transients on the trip setpoint. The operating margin may consider instrument channel accuracy, transient analysis, "allowance for spurious trip allowance", operating experience (including as-found/as-left analysis), equipment qualification tests, vendor design specifications, engineering analysis, laboratory tests, engineering drawings, etc.

5.3 UNCERTAINTY ANALYSIS AND SETPOINT CALCULATION PROCESS

The process for determining instrument setpoints and allowable values is based on the analysis of the instrument loop accuracy and the identification of the acceptance criteria for each setpoint. This process is shown in figure 2.

5.3.1 Block Diagram the Instrument Channel and Identify Components, Modules and Calibration Blocks

The instrument channel to be analyzed should first be diagrammed to ensure that all errors and uncertainties affecting instrument channel accuracy are identified and correctly applied. The process for determining instrument channel accuracy is based on the propagation of errors and uncertainties through the instrument channel from the process to the final output, i.e. actuation or indication.

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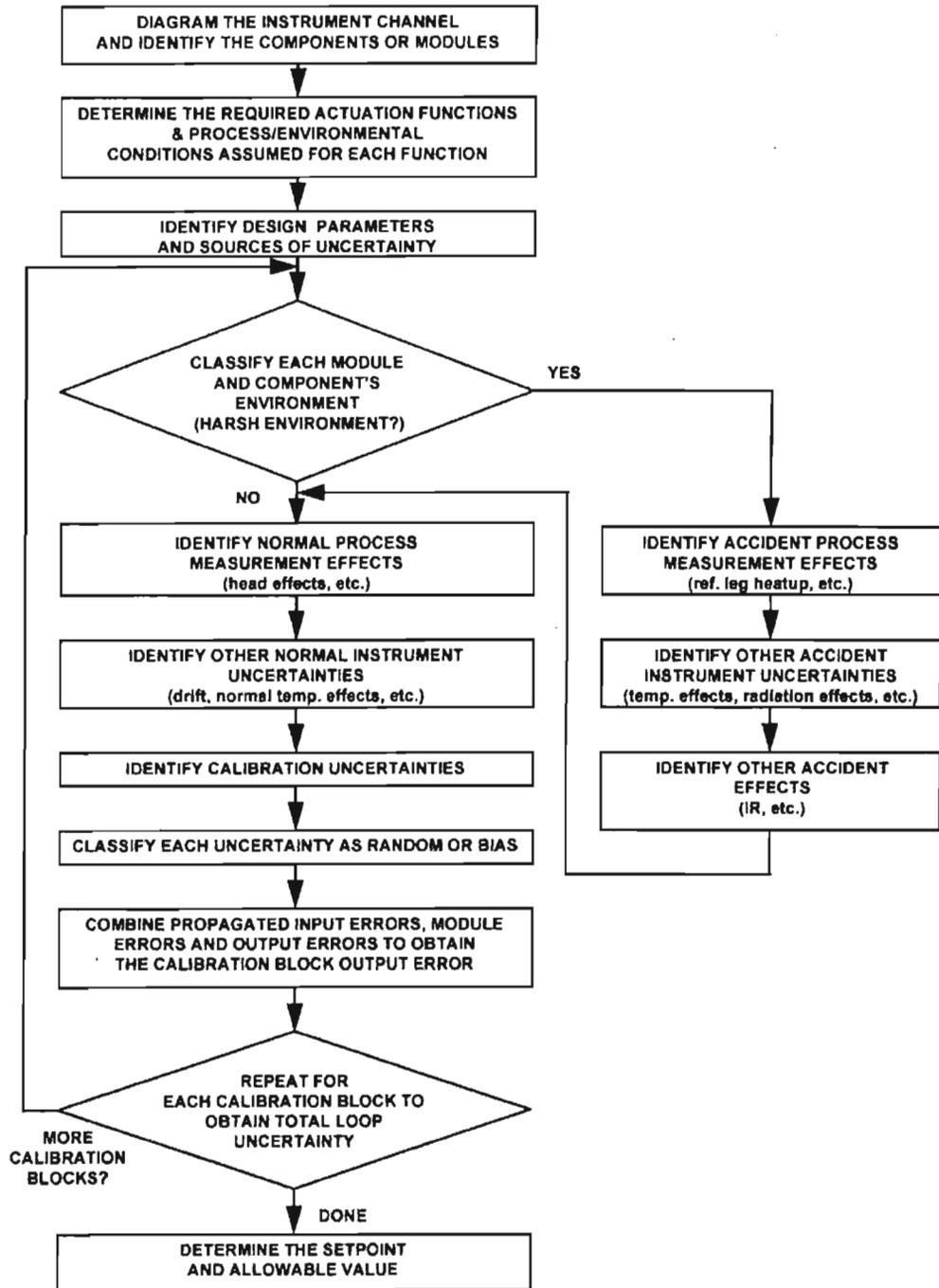


Figure 2, Setpoint Calculation Flowchart

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This process includes:

- identifying individual components and modules contained within the instrument channel, and when appropriate identifying the calibration blocks within which the components or modules are calibrated,
- propagating input errors and uncertainties through the calibration block, and
- combining the propagated errors, the specific module errors and any output errors to determine a calibration block output uncertainty.

If necessary, this calibration block uncertainty becomes one of the input uncertainties to the next calibration block.

The definition of a calibration block is the basis for this methodology. A calibration block is identified by the calibration process associated with the instrument channel to be evaluated. A calibration block is contained between the point where a test input is applied and the point at which an output is observed. The calibration block output may be digital, i.e. a bistable output, or analog, as in a measured variable or an indicated variable.

As shown in figure 3, a calibration block has:

- 1) input errors and uncertainties, including process errors, calibration errors, uncertainties associated with the input from previous modules, etc..
- 2) calibration block errors and uncertainties, including:
 - environmental conditions that affect the modules or components within the calibration block,
 - reference accuracy of each internal module or component,
 - process conditions that affect an individual module or component, e.g. static pressure error, and
 - other uncertainties associated with the individual modules or components within the module
- 3) output errors and uncertainties, including calibration errors, setting tolerance, etc.

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The total calibration block accuracy is a combination of:

- input errors/uncertainties propagated across the calibration block,
- module errors/uncertainties, some of which may have to be propagated across components within the calibration block, and
- output errors/uncertainties.

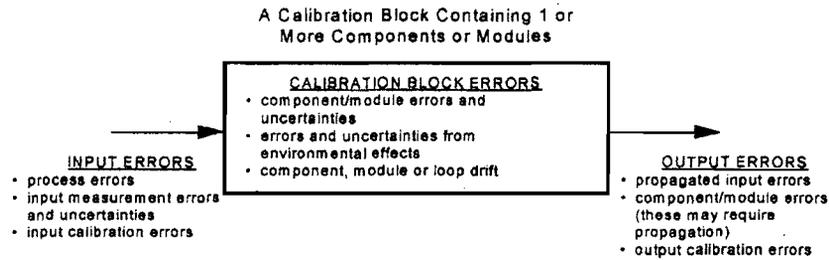


Figure 3, Input, Calibration Block and Output Errors and Uncertainties

See Appendices C and D for the equations used to combine individual errors and uncertainties when calculating total calibration block accuracy.

Some considerations when identifying a calibration block are:

- 1) A calibration block may contain 1 or more modules, or components based on the calibration methodology of the specific channel. Where a string calibration is performed as the final acceptance test, the entire string becomes the calibration block.
- 2) A calibration block can never contain just a resistor. Often a resistor is used for signal conversion. The interposing resistor may be part of the output errors of one calibration block, part of the input errors to the next calibration block or both. The calibration procedure must be carefully analyzed to ensure that the effects of these resistors are correctly incorporated into the channel or calibration block accuracy.

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5.3.2 Determine The Required Actuation Functions and Process/Environmental Conditions For Each Function

Identify the purpose of the instrument channel and setpoint to be analyzed. Determine the conditions where the setpoint is required to function and the associated environment(s) when this function is required.

5.3.2.1 Design Basis

Determine the design basis of the setpoint and the associated instrument channels. The design basis information should include:

- the function of the instrument channel
- the purpose of the setpoint
- whether the existing setpoint represents an allowable value or limiting setpoint
- what analyses are affected by the setpoint
- what limiting criteria (acceptance criteria) and assumptions regarding the setpoint are included in these analyses

5.3.2.2 Environmental Conditions

Determine the environment in which each component/module is located and the environmental conditions in which they must perform their function. Figure 4 shows a typical instrument channel layout, the point within the channel affected by various types of errors and uncertainties, and the environment for each module.

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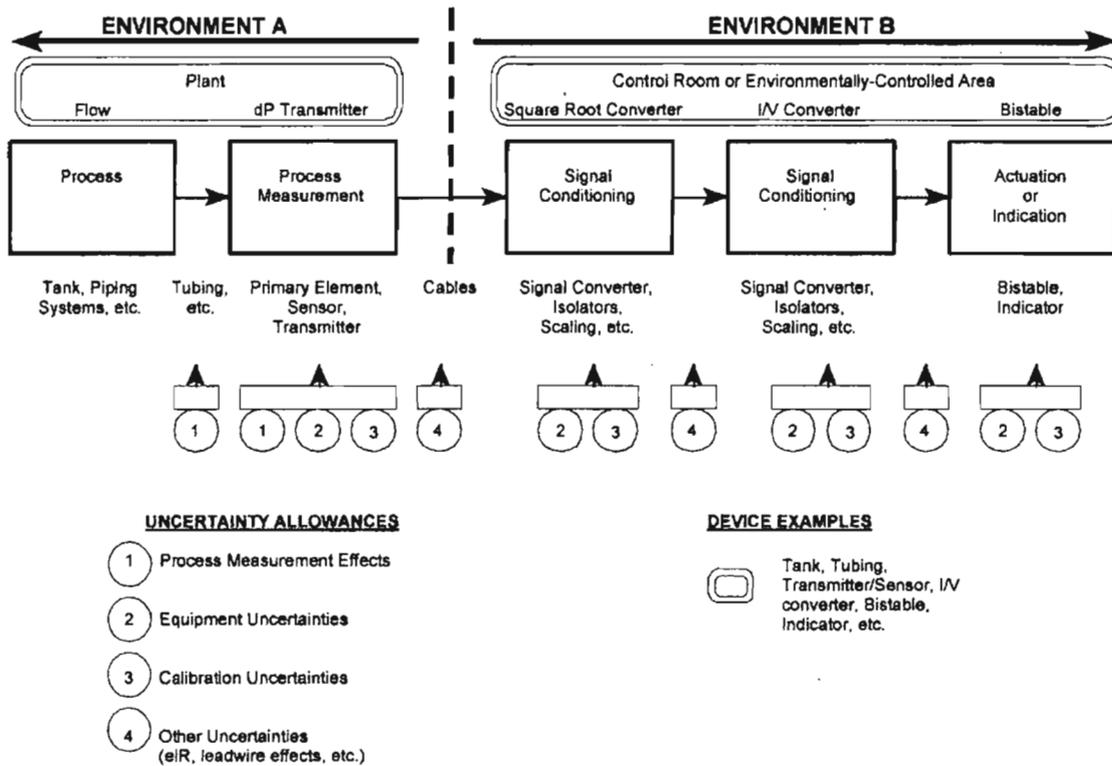


Figure 4, Typical Instrument Channel Layout

¹ ISA- RP67.04-02-2000, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation, Approved January 1, 2000.

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5.3.3 Identify Design Parameters and Sources of Uncertainty

Once the design basis for the instrument setpoint and environment is determined, identify the potential sources of errors and uncertainties that may affect the instrument channel accuracy.

See Appendix A for a discussion of the minimum list of errors and uncertainties that must be included in accordance with this standard. This minimum list is not intended to limit the types and sources of error and uncertainty associated with an instrument setpoint. Each instrument channel, method of process measurement, calibration methodology, and environment may have unique errors and uncertainties.

5.3.4 Classify Each Modules Environment

This standard requires that the station specific EQ Zones contained in the UFSAR and the station specific environmental conditions associated for each zone are to be used in evaluating all environmental effects.

5.3.5 Identify Normal/Accident Process Measurement Effects, Instrument Uncertainties, Calibration Uncertainties and Other Uncertainties, and Classify Each Uncertainty as Random, Bias, etc.

See Appendix A and Reference 3.2 for applicable error effect equations and methods for determining values of uncertainty.

5.3.6 Combine Propagated Input Errors, Module Errors and Output Errors to Yield Total Calibration Block Output Error

See Appendix B for error propagation and Appendix C for equations for the combination of errors and uncertainties.

5.3.7 Obtain Total Channel Uncertainty

See appendix C for the methodology and equations used to combine individual errors and uncertainties.

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5.3.8 Determine the Setpoint and Allowable Value

See appendix C for the methodology and equations used to determine an instrument setpoint and an associated allowable value.

5.3.9 Administrative Limits

Refer to ER-AA-520, Instrument Performance Trending, when administrative limits are required as part of the instrument loop accuracy determination.

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APPENDIX A
SOURCES OF ERROR AND UNCERTAINTY

Latest Revision indicated by a bar in right hand margin.

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This appendix discusses the sources of error that may affect instrument loop accuracy. In all cases, sound engineering judgment should be applied to account for errors not explicitly described below or as stated and verified in respective vendor documentation. Significant errors, whether or not they are described in this appendix shall also be either included in the computation of setpoint error and/or instrument loop accuracy or appropriately corrected during calibration of the instrumentation.

This appendix provides a minimum list of errors and uncertainties that shall be evaluated for each component and module when evaluating instrument channel accuracy in accordance with this standard.

1.0 PROCESS ERRORS

Process errors result from changes in the process or sensing channel from the nominal, or calibration conditions. They may also result from conditions that cannot be readily measured, e.g. turbulence or other system complexities. To account for process errors in a setpoint error calculation, it is necessary to model the process, and the effects of sensing elements on the process. For example, intrusive flow sensing devices, such as venturis, directly affect the process that they measure. Process models should account for calibration conditions, normal operation, and accident conditions. For each of these conditions, the behavior of all applicable process variables, such as temperature, pressure, and density, must be understood well enough to predict the error.

Changes in the process may result in either random or non-random errors. Non-random process errors are those that can predictably be correlated to process conditions, such as thermal expansion effects. Random errors result from uncertainties that are not predictable as to their direction, but exist as a range or limit of error around the process value.

1.1 DENSITY EFFECTS

Measurements of fluid flow, pressure, and levels are affected by the process densities. Density changes in the process and in instrument sensing lines can result in measurement errors. An example of a process measurement that is affected by density changes is the measurement of fluid flow. Fluid flow is inversely proportional to the square root of fluid density. If a flow meter is calibrated for a specific fluid density, and the density changes, then a flow measurement error that is inversely proportional to the square root of the density change will result.

1.2 FLOW ERRORS

Flow measurements are based on nominal values for the dimensions of components such as nozzles, orifices, and venturis. These devices are subject to changes in dimension due to the erosion and/or corrosion effects of the material they contain. Changes in pipe diameter, or

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bore tolerance will cause flow measurement errors and should be considered in the evaluation of instrument loop accuracy.

1.3 TEMPERATURE ERRORS

Changes in the process media temperature from the nominal or calibration values will cause process measurement errors. Pressure and differential pressure measurements are particularly susceptible to temperature induced errors. Pressure and level measurements are made by sensing the hydrostatic head pressure of a fluid. The hydrostatic head pressure of a fluid is directly proportional to the product of the fluid's height and specific weight. Since specific weight is a temperature dependent parameter, temperature changes in the process fluid will cause process measurement errors. Temperature induced process errors will affect pressure, level, and flow measurements and should be considered in the evaluation of instrument loop accuracy.

1.4 THERMAL EXPANSION ERRORS

Changes in temperature cause dimensional changes in system structures, components and instrument sensing lines. Instrument calibration is often based on specific sensing line or component installed elevations. Component elevation changes due to temperature effects will cause process measurement errors and should be considered in the evaluation of instrument loop accuracy.

An example of a thermal expansion effect on a process measurement is reactor pressure vessel growth. As the reactor is heated and pressurized to operating conditions, dimensional increases occur. Differential pressure level sensing instruments are calibrated for specific values of process tap and component elevations. These elevations may change from calibration values as the reactor is brought up to operating conditions as a result of thermal expansion.

Thermal expansion errors should be accounted for in the evaluation of instrument loop accuracy.

1.5 PIPING CONFIGURATION

Intrusive devices, i.e. nozzles, orifices, venturis and valves, as well as pipe bends, changes in pipe diameter and material cause turbulence in flow media. Flow turbulence is a source of flow measurement error. Inspection of piping and isometric drawings can provide information on the proximity of flow sensors to fittings and valves that cause turbulence. It may be possible to bound flow measurement error due to turbulence based on the upstream or downstream separation between the flow sensor and source of turbulence. Refer to References 3.2, 3.10 and 3.13 for additional information.

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2.0 REFERENCE ACCURACY (RA)

The Reference Accuracy of an instrument loop component is never zero. This would infer that there is no difference between the true value of a process and the measured value of a process. Error free measurements are physically impossible.

The error due to the Reference Accuracy of an instrument is usually given as a numerical expression, graph, or specification published by the instrument vendor.

Where independent test labs rather than the manufacturers have evaluated an instrument's performance characteristics, the test methods should be reviewed to ensure that the test results are consistent with their intended use.

The error due to instrument Reference Accuracy is classified as a normally distributed random variable.

3.0 OPERATIONAL ERRORS.

3.1 Drift (D)

Instrument drift is a change in instrument performance that occurs over a period of time that is unrelated to input, environment or load. Drift independently affects all components of an instrument loop. Ambient conditions such as temperature, radiation, and humidity do not affect the magnitude of an instrument's drift.

Specific instrument drift effect data is typically provided from:

- The instrument manufacturer
- The review of historical calibration data
- Documentation industry experience
- Environmental Test Reports

If specific values for this effect are not available from these sources, the following default values may be included when preparing the analysis for additional conservatism. The Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) default drift effect values that will be used in these cases are:

Mechanical Components: $\pm 1.0\%$ of span per refueling cycle
 Electronic Components: $\pm 0.5\%$ of span per refueling cycle

The intent of these Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) default drift effect values is to establish consistent values for this type of error for inclusion into the calculations to achieve additional conservatism when this data is not available, applicable, or published. Selection of these default drift effect values is the result of engineering review

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and judgement of industry practices, typical Reference Accuracy for these device types, and industry experience. These default drift effect values shall not be used when instrument drift effect data is available from the sources listed above.

A manufacturer's published "drift specifications" that are explicitly dependent on operational conditions, i.e. temperature, should not be misinterpreted as Drift in the instrument analysis. In these instances, the use of the word drift is inconsistent with the definition in this standard. An example of this is, "the instrument's zero drift is 10 mv/ C." The net effect of drift on the components of an actuating loop may shift the trip point in the conservative direction, the non-conservative direction, or not at all. Drift is probabilistic in nature. Therefore, the magnitude and direction of its effects are impossible to predict precisely.

Drift is classified as a symmetric random error. This classification accurately models the uncertainty in the sign of the drift error and assumes that the maximum possible drift always occurs between successive instrument surveillances. However, if an instrument surveillance occurs either before or after the manufacturer's published drift interval, then the value for drift must be adjusted to account for the differing intervals (see Eq. A1 or A2).

Where the error caused by drift is assumed to be a linear function of time, equation A1 should be used. If the engineer preparing the calculation determines that the drift effect is not a linear function, i.e. "point drift", then the basis for the drift function shall be explained in the calculation.

The following equation should be used to calculate instrument drift (D):

$$D = (1 + LF/SI)SI \times IDE \tag{Eq. A1}$$

where:

IDE = instrument drift effect that is specified by the instrument vendor, published by an independent test lab, or determined from plant historical data.

SI = instrument surveillance interval specified in the station technical specifications or other station document.

LF = test interval late factor. This is the amount of time (grace period) by which a required instrument surveillance is administratively allowed to exceed the licensed surveillance period. Surveillance intervals, grace periods and Late Factor are found in the plant technical specifications.

This method of drift error calculations should be used unless other data or vendor information is available. The drift term is considered a linear function of time unless other methods to evaluate drift are available.

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Where multiple time periods of IDE and/or SI are to be evaluated, and it can be shown or reasonably argued that the drift error during each drift period is random and independent, then the SRSS of the individual drift periods between calibrations may be used.

$$D = [IDE] [(SI+LF)/VDP]^{1/2} \tag{Eq. A2}$$

where:

VDP = vendor drift period that is specified by the instrument vendor or obtained from other testing (e.g. as-found/as-left analysis).

Example: SI+LF = 22 ½ months
 VDP = 12 months
 IDE = 1% span per 12 month period

$$D = [1\%][22 \frac{1}{2} / 12]^{1/2} = \pm 1.37\% \text{ span}$$

3.2 STATIC PRESSURE EFFECTS (eSP)

Static pressure effects are instrument errors due to a change in process pressure from the value present at the time of calibration. These effects should be considered for those devices with sensing elements that are in direct contact with the process. This effect typically applies to differential pressure sensors.

$$eSP = ISPE(\Delta SP) \tag{Eq. A3}$$

where:

ISPE = the instrument static pressure effect specified by the vendor, independent test lab or determined from plant historical data.

ΔSP = the changes in static pressure conditions from calibration conditions.

For instrumentation measuring a high static pressure process, additional scrutiny needs to be maintained when replacing or upgrading older instrumentation that may not be susceptible to effects of high static pressures due to design. The effects are repeatable and systematic, but need to be evaluated based on instrumentation being implemented; appropriate system and vendor documentation review is warranted. Inclusion of Static Pressure Span Effect and Zero Shift corrections should be considered for differential pressure (as these effects are not applicable to gauge pressure) instrumentation installations that measure processes over 500 psi. If process pressure is over 500 psi and the Static Pressure Span Effect and Zero Shift are greater than the reference accuracy of the instrumentation, then the following guidance can be used for incorporating these effects into the calibration.

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An example of how to account for these affects is documented well for Rosemount transmitters (see an example in Reference 3.24) and has been implemented in calibration procedures at Limerick and Peach Bottom (see Reference 3.25). Review the appropriate vendor documentation for specific model effects and implementation guidance.

Rosemount Static Pressure Span Effect:

Transmitters placed in service at high static pressures will display a reduction in output per unit dP input in comparison to its output at atmospheric pressure. This is known as the Static Pressure Span Effect. The magnitude of the effect is predictable for a particular model transmitter. The dP input values used in calibration at atmospheric pressure must be adjusted to compensate for this effect. If the values listed in the calibration sheet have not already been adjusted to compensate for the Static Pressure Span Effect, then engineering can utilize the following formula to determine the compensated differential pressure to be applied during calibration at atmospheric pressure.

$$dP_c = dP [1 - K (sp)]$$

where:

dP_c = compensated differential pressure to be applied during calibration at atmospheric conditions

dP = differential pressure actually experienced when in service

K = correction constant for particular model transmitter

sp = static pressure in PSIG experienced when in service

Rosemount Static Pressure Zero Shift Effect:

Transmitters placed in service at high static pressures, will display a shift in output value in comparison to its output at atmospheric pressure. This is known as the Static Pressure Zero Shift. The magnitude and direction of the shift is specific to the individual transmitter; therefore, the Static Pressure Zero Shift of each transmitter must be measured and compensated for individually. If the calibration sheet does not list the serial number of the transmitter being calibrated and indicate the output values have been adjusted to compensate for Zero Shift, then perform the following to determine the Static Pressure Zero Shift Correction Constant to be applied to the ideal output values during calibration at atmospheric pressure.

If a record of the As Found and As Left values is not required and the calibrated range includes zero differential pressure, then the Static Pressure Zero Shift can be trimmed out after the transmitter is returned to service. In that case the transmitter

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should be calibrated to the ideal values as presented in the calibration sheet. After calibration is complete, apply the same static process pressure to both sides of the measurement cell and trim the zero adjust to return the output to the ideal value for zero differential pressure. Otherwise, follow these 7 steps:

1. If the transmitter's calibrated range does not include zero differential pressure then turn the zero screw until the calibrated range includes zero. Transmitters with large amounts of zero elevation or suppression may require the jumper on the amplifier board be placed back in the mid position for this step.
2. Ensure the transmitter's span has been nominally calibrated.
3. Apply atmospheric pressure to both sides of the measurement cell (zero pressure differential).
4. Record the transmitter's output value.
5. Apply the static process pressure that will be experienced when the transmitter is in service to both sides of the measurement cell (zero pressure differential).
6. Record the transmitter's output value.
7. Calculate the Static Pressure Zero Shift Correction Constant by subtracting the value recorded in Step 6 from the value recorded in Step 4.
8. Record the transmitter serial number and Static Pressure Zero Shift Correction Constant on the calibration sheet.

3.3 PRESSURE EFFECTS (eP)

Pressure changes can cause density changes in process media. Pressure induced density changes in process media from nominal or calibration values are sources of process measurement error. Pressure changes due to environmental or accident effects can cause measurement errors in process parameters.

$$eP = IPE(\Delta P) \tag{Eq. A4}$$

where:

IPE = instrument pressure effect is determined from vendor specifications, published independent test lab data or plant historical data.

ΔP = changes in pressure from calibration conditions.

3.4 POWER SUPPLY EFFECTS (eV)

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Variations in the output of an instrument loop's power supply may cause errors in process measurement. Instrument errors due to fluctuations in the loop power supply may be estimated by:

$$eV = IPSE(\Delta V) \quad (\text{Eq. A5})$$

where:

IPSE = Instrument power supply effect is determined from vendor specifications or published independent test lab data.

ΔV = power supply stability as determined from plant data

4.0 ENVIRONMENTAL ERRORS

Changes in environmental conditions from those present at the time of calibration can cause measurement errors. Errors due to environmental fluctuations can occur during calibration, during normal operation, or during an accident and should be included in the calculation of instrument loop accuracy.

Environmental errors are classified as non-random. The following three methods may be used to specify environmental error effects.

- 1) A numerical constant that bounds the error is specified for a specific range of environmental conditions. This constant is specified by the instrument manufacturer or an independent test lab. An example of this type of error specification is:

1% of output span for ambient temperatures of 60 - 90°F.

- 2) An instrument's environmental error is calculated by evaluating a model that describes the instrument's sensitivity to specific environmental fluctuations. Environmental error models may be available from instrument manufacturers and published in the instrument specifications, or from independent test labs. An example of this type of error specification is:

$$\text{Temperature Error (eT)} = 0.75\% \text{ of the Upper Range Limit} + 0.50\% \text{ of the Calibrated Span}$$

- 3) An instrument's environmental errors may be given as a graphical specification. Figure A1 shows a graphical representation of instrument error based on empirical or calculated data gathered by the instrument manufacturer, or by an independent test lab. A graphical error specification shows instrument error as a function of environmental changes.

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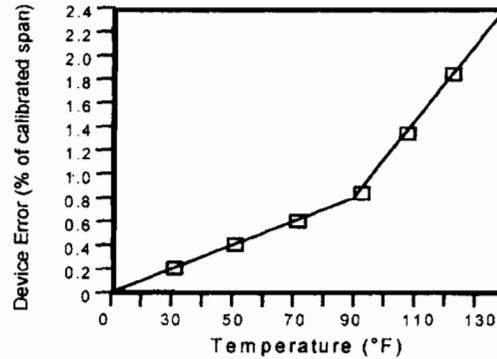


Figure A1, Graphical Specification of Device Error

4.1 TEMPERATURE EFFECTS (eT)

Temperature errors result from deviations in ambient temperature at the instrument location from the temperature at which the instrument was previously calibrated. Where a mathematical model (ITE) is available for temperature error, then the model should be evaluated for the anticipated temperature change.

$$eT = ITE(\Delta T) \tag{Eq. A6}$$

where:

ITE = the instrument temperature effect that models the measurement error as a function of the temperature changes (ΔT).

4.2 HUMIDITY EFFECTS (eH)

Humidity errors are due to changes in humidity at an instrument location from calibration or nominal values. If a model is available for humidity error, then the model should be evaluated for the anticipated humidity change.

$$eH = IHE(\Delta H) \tag{Eq. A7}$$

where:

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IHE = the instrument humidity effect that models the measurement error as a function of humidity changes (ΔH).

4.3 RADIATION EFFECTS (eR)

Radiation errors are caused by instrument exposure to ionizing radiation. If a model is available for radiation error, then the model should be evaluated for the anticipated radiation dose.

$$eR = IRE(TID) \quad (\text{Eq. A8})$$

where:

IRE = the instrument radiation effect that models the measurement error as a function of radiation dose, expressed as total integrated dose (TID).

4.4 SEISMIC EFFECTS (eS)

Seismic errors result from subjecting an instrument to high energy vibrations and accelerations. If a model is available for seismic error, then that model should be evaluated for the anticipated acceleration at the instrument location.

$$eS = ISE(ZPA) \quad (\text{Eq. A9})$$

where:

ISE = the instrument seismic effect that models the measurement error as a function of Zero Period Acceleration (ZPA) anticipated at the instrument location.

Seismic error models must take into account the instrument response due to location, mounting, orientation, and flexibility of the instrument, etc. Data for required response spectra and the associated error due to seismic effects should be obtained from the plant UFSAR, seismic test reports, and seismic structure analysis reports. The published instrument error (and its associated ZPA due to seismic effects should be compared with the required response spectrum specified for the instrument location to ensure that they are consistent. IEEE Recommended Practice For Seismic Qualification of Class 1E Equipment For Nuclear Power Generating Stations (reference 3.18) defines Required Response Spectrum (RRS) as, "The response spectrum issued by the user or his agent as part of his specifications for qualifications or artificially created to cover future applications. The RRS constitutes a requirement to be met".

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5.0 CALIBRATION ERRORS

Errors that occur in the adjustment and measurement of loop element signals due to measurement and test equipment (M&TE) are called calibration errors. Calibration errors are classified as random and include:

- M&TE reference accuracy,
- M&TE reading error,
- M&TE environmental errors,
- calibration standard reference accuracy (STD),
- calibration standard reading error, and
- setting tolerance (ST).

5.1 MEASUREMENT AND TEST EQUIPMENT (M&TE).

5.1.1 M&TE Error (RAMTE)

All calibration procedures require measurement and test equipment to monitor instrument adjustments using a specified set of conditions. Some calibration procedures require additional test components whose accuracy must be included in the determination of calibration error. M&TE error includes the reference accuracy of each device, the uncertainties resulting from the environment in which the M&TE was calibrated or used, and the uncertainty added by any component used in a calibration procedure. M&TE accuracy should be obtained from the manufacturer's published specifications unless the device has been calibrated or maintained to a different set of criteria. At Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad), the calibration facility may be directed to maintain the M&TE to an accuracy different from the manufacturer's specification. This difference should be documented in the basis for the M&TE accuracy used in the instrument channel or setpoint accuracy calculation. When assumptions are required regarding which particular M&TE device may be utilized in a test or calibration procedure, the assumed accuracy of the test equipment data should be equal to that of the least accurate instrument in the group of possible candidates.

Measurement and test equipment used during calibration procedures may be sensitive to environmental fluctuations. M&TE errors should use the largest expected change between the instrument calibration conditions and the normal environment. These extremes typically are obtained from EQ documents, e.g. the station EQ zone maps. This provides a bounding or conservative estimate of M&TE environmental error. Restricting or assuming that the calibration environment deviates less than the associated EQ zone is not desirable since it places added requirements on the IM's to document the assumed environmental condition during each calibration.

5.1.2 Reading Error (REMTE)

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Since it is unlikely that an analog gauge reading will always coincide with a graduation tick mark, the readability of the gauge scale is $\frac{1}{2}$ of the smallest division. The uncertainty in this readability, or reading error (RE), is $\pm \frac{1}{4}$ of the smallest graduation interval. For devices that have non-linear scales, the division used to determine the reading error is consistent with the desired reading.

For digital output devices, the reading error is considered to be the least significant digit (LSD) or least significant increment of the display.

5.1.3 Input M&TE Temperature Error (TEMTE)

M&TE temperature errors are determined from the vendor's expression for temperature effects (ITE) and the range of temperature fluctuations (ΔT). The temperature extremes at which the M&TE equipment was calibrated and the ambient temperature extremes in which the M&TE device is going to be used should be evaluated.

5.1.4 Calibration Standard Error (STD).

Calibration standards are used to perform periodic calibrations on M&TE. If the calibration standard is at least 4 times more accurate than the M&TE, then its error represents at most 6.25% of the M&TE error, and may be assumed to be negligible. If the calibration standard is not 4 times more accurate than the measurement and test equipment, then its error should be factored into the calculation of calibration error. Refer to NES-EIC-20.01, Standard for Evaluation of M&TE Accuracy When Calibrating Instrument Components and Channels, for additional guidance.

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5.1.5 Surveillance Interval (SI).

The surveillance interval is the period between successive instrument surveillances or calibrations. Surveillance intervals are specified in the plant technical specifications, implemented in the plant calibration procedures, or identified by station instrument calibration scheduling programs.

Station Technical Specifications may allow a grace period beyond the specified calibration frequency. The surveillance frequency is typically limited to 125% of the required SI. The grace period should be included in the determination of instrument loop accuracy. The grace period should not be included in the calculation of the Allowable Value since it results in the potential for non-conservative evaluation of operability.

5.2 SETTING TOLERANCE (ST)

Setting tolerance is the uncertainty associated with the calibration procedure allowances used by technicians in the calibration process. Programs exist at each station to ensure that instrument channels and calibrated setpoints will not be left outside of a specified setting tolerance. As a result, it is expected that 100% of the population is left within the required setting tolerance. For pre-existing instrument channels that have established calibration procedures, the setting tolerance should be incorporated into the setpoint calculation as a 3σ error estimate. For new channels, the setting tolerance should be conservatively determined to justify a 3σ confidence value.

6.0 CALCULATIONAL ERRORS

6.1 NUMERICAL PRECISION AND ROUNDING

The precision of a number is determined by the significant digits in the number. Conclusions based on a calculation or measurement depends on the number of significant digits in the result of the calculation, or measurement. Calculated results can be no more precise than the calculation input data. To prevent the propagation of rounding and truncation errors in a calculation, round only the final result.

The final result should be rounded to the number of significant digits found in the least precise input data but no less than the number of significant digits utilized in presenting the calibration setpoint or the calibration endpoints for loops that do not have setpoints. If the output is read on a DVM that displays 3 digits after the decimal point, the calculations conclusions must be rounded to no less than 3 digits after the decimal point.

This standard recommends the following method for rounding. The left-most non-zero digit in a number is the most significant digit. The right-most non-zero digit is the least significant

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digit if there is no decimal point. If there is a decimal point, the right most digit is the least significant digit. The number of digits between the most significant and least significant digits are counted as the number of significant digits associated with a calculation, or measurement. The following numbers all have 4 significant digits: 1234, 1.234, 10.10, 0.0001010, 1.000 e-4.

Round the final results of calculations to a level of precision that is consistent with the data input to the calculation. The rules for rounding are:

1. If the next digit less than the desired degree of precision is greater than 5, round up the least significant digit.

Example: 1.2347 ⇒ 1.235

2. If the next digit less than the desired degree of precision is less than 5, do not change the least significant digit.

Example: 7.8932 ⇒ 7.893

3. If the next digit less than the desired degree of precision is equal to 5, increment the least significant digit only if it is an odd number.

Examples: 3.4325 ⇒ 3.432, 3.4335 ⇒ 3.434

6.2 A-D AND D-A ERRORS

Analog-to-Digital or Digital-to-Analog conversions (A/D or D/A) errors occur whenever a continuous process is represented digitally with a fixed number of bits. The resolution of the A/D or D/A converter is a primary consideration when evaluating A/D or D/A errors. Resolution is given by:

$$\text{Resolution} = (1/2)^n(\text{signal span})$$

where 'n' is the number of bits in the A/D or D/A converter and signal span is the signal range present at the input of the A/D or D/A converter. There are several types of A/D or D/A converters, each of which has different sources of conversion error. Therefore, other A/D or D/A conversion errors must be determined on a case-by-case basis.

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7.0 INSULATION RESISTANCE ERROR (eIR)

The eIR error shall be evaluated for all instrument components and instrument modules where the actuation function is expected to operate in an abnormal or harsh environment.

Sources of data for insulation resistance should include values typical for the instrument loop under consideration, such as maximum supply voltage, nominal supply voltage, maximum loop resistance, minimum loop resistance, nominal insulation resistance (which should include conductor-to-conductor and conductor-to-ground values), and splice and terminal block insulation resistance. It may be necessary to arrive at these values through performance of generic calculations typical of several types of instrument loops. For a further effects of process measurement errors due to accident related insulation resistance degradation see Reference 3.2.

8.0 SETPOINT MARGIN (MAR)

Margin may be included in the determination of instrument loop accuracy when an additional level of confidence is desired. For example, a particular vendor's testing methodology is not considered sufficiently rigorous to justify a 2σ confidence value for one of the published performance criteria. This determination may be based on engineering judgment, evaluation of the vendor's test plan or station/industry experience with the component. For the component in this example, it is determined that no other information exists to identify an alternate confidence level. This standard recommends that the vendor data should be incorporated at the 2σ confidence level. Then an additional margin value is included in the instrument loop accuracy equation to provide additional conservatism.

NOTE: where as-found/as-left analysis or special test data is available, the component performance data should be utilized at the confidence level obtained from the statistical evaluation of the data.

For new instrument channels, an additional margin of 0.5% of the instrument measurement span, in instrument units, shall be included in order to account for unanticipated, or unknown loop component uncertainties. This margin may be deleted after sufficient calibration history exists to justify the instrument channel accuracy based on all other errors and uncertainties.

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9.0 CLASSIFICATION OF ERROR TERMS

All errors and uncertainties shown in Table A1 shall be evaluated as part of the determination of instrument loop accuracy. Where an individual error or uncertainty is 0, negligible or not applicable, the calculation shall describe why this condition is appropriate. Table 1 indicates the default classification for each type of error or uncertainty. These classifications may be changed as a result of published vendor information, other monitoring programs (e.g. as-found/as-left drift analysis), or engineering judgment. The basis for any changes to the classification of an error term shall be fully documented in the associated instrument channel or setpoint accuracy calculation.

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Table A1, Classification of Error Terms

Error Type	Symbol	Error Classification
Process Errors	PE	
Density Error		non-random, bias
Process Error (non-instrument related, e.g. temperature stratification)		random (NOTE: temperature streaming uncertainty may also include an associated bias error)
Flow Element Error		random (when calculated in accordance with reference 3.10) except for errors resulting from fouling which are bias errors
Temperature Error	eT	non-random, bias
Thermal Expansion Error		non-random, bias
Configuration or Installation Error		random (e.g. installation tolerances) or bias (e.g. as measured installation deviation)
Reference Accuracy	RA	random
Operational Errors		
Drift Error	D	random
Static Pressure Error	eSP	non-random, bias
Pressure Error	eP	non-random, bias or symmetric
Power Supply Error	eV	non-random, bias or symmetric
Environmental Errors		
Temperature Error	eT	non-random, bias or symmetric
Humidity Error	eH	non-random, bias or symmetric
Radiation Error	eR	non-random, bias or symmetric
Seismic Error	eS	non-random, bias or symmetric

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Table A1 (cont.), Classification of Error Terms

Error Type	Symbol	Error Classification
Calibration Errors		
M&TE Reference Accuracy	RAMTE	random
M&TE Reading Error	REMTE	random
M&TE Temperature Error	TEMTE	random
Calibration Standard Reference Accuracy	RASTD	random
Calibration Standard Reading Error	RESTD	random
Setting Tolerance ³	OST	random (3 σ)
Calculational Errors		
Numerical Precision and Rounding		random
A-D and D-A Error		random
Other Errors		
Insulation Resistance	eIR	non-random, bias or symmetric
Margin	MAR	non-random, bias or symmetric

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APPENDIX B
PROPAGATION OF ERROR AND UNCERTAINTIES

Latest Revision indicated by a bar in right hand margin.

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1.0 PROPAGATION OF UNCERTAINTIES THROUGH FUNCTIONAL MODULES

This purpose of this appendix is to provide the methodology and functional relations to propagate errors and uncertainties through a calibration block. This appendix provides common linear and non-linear propagation equations for both random and bias errors and uncertainties. The equations provided in this appendix may be used in engineering calculations without further derivation.

For module functions not identified in this appendix, the equivalent error function should be derived. See references 3.2 and 3.11 for further information.

2.0 SYMBOLS

Symbol	Type	Description
X, Y	input signals	Units must be consistent, e.g. % of span, mA, V, etc.
σ	random error	<p>$\sigma_x, \sigma_y \dots \sigma_n$ represent random errors associated with inputs X and Y. σ_{OUT} is the resulting composite random output error.</p> <p>Units must be consistent with the associated input signals, e.g. $\pm\%$ full span, $\pm mA$, $\pm V$, etc.</p> <p>For linear functions (e.g. fixed linear gain amp), σ_{OUT} is a normally distributed, random error since the transfer function (gain) is linear. σ_{OUT} may be combined with other normally distributed error terms using the SRSS method.</p> <p>For non-linear functions (e.g. logarithmic amplification or square root extraction), σ_{OUT} assumes sufficiently small input errors so that σ_{OUT} is a nearly normal distribution. σ_{OUT} may then be combined with other normally distributed error terms using the SRSS method.</p>
e	bias error	<p>$e_x, e_y \dots e_n$ represent bias errors associated with inputs X and Y and e_{OUT} represents the composite bias error.</p> <p>Units must be consistent with the associated input signals e.g. % full span, $\pm mA$, $\pm V$, etc.</p>

Table B1, Uncertainty Symbols

For simplification, the following examples only show the positive input and output bias error terms. Where the bias is symmetrical or assumed symmetrical (as in protection and reactor

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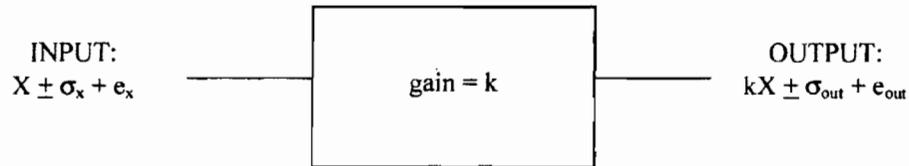
trip setpoints, and graded methodology level 1 applications), the negative output error would be identical in magnitude and opposite in sign.

Bias errors at the module output are combined by algebraically adding all of the positive biases and separately algebraically adding all of the negative biases. See appendix C for discussion of error combination.

3.0 FUNCTIONAL MODULES

3.1 LINEAR FIXED GAIN AMPLIFIER

Note: this category also applies to modules that convert process units at the input into different output process units, e.g. a transmitter where the gain might equal mA/psi), or an isolator where the gain might be mA/mA, V/V or mA/V, etc.

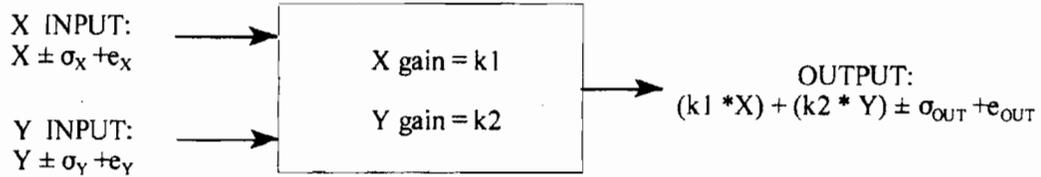


where:

$$\begin{aligned} \sigma_{OUT} &= k\sigma_x \\ e_{OUT} &= ke_x \end{aligned}$$

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3.2 SUMMING AMPLIFIER

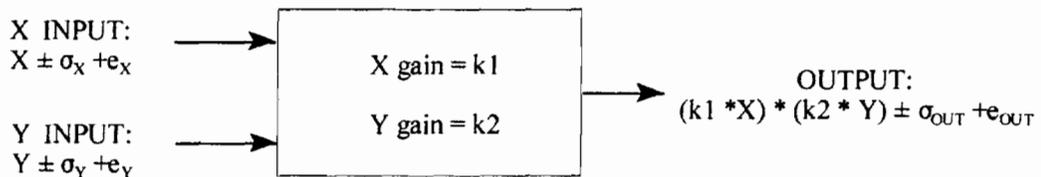


where:

$$\sigma_{OUT} = [(k1 * \sigma_X)^2 + (k2 * \sigma_Y)^2]^{1/2}$$

$$e_{OUT} = (k1 * e_X) + (k2 * e_Y)$$

3.3 MULTIPLIER



where:

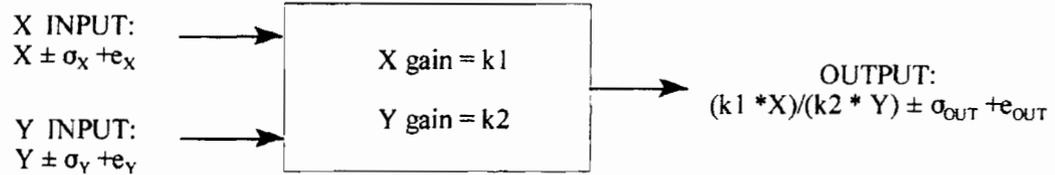
$$\sigma_{OUT} \approx (k1 * k2) [(X * \sigma_Y)^2 + (Y * \sigma_X)^2]^{1/2}$$

$$e_{OUT} \approx (k1 * k2) [(X * e_Y) + (Y * e_X)]$$

σ_{OUT} is an approximation since it is assumed that the individual input errors are small and their cross product is negligible. See reference 3.2 for the complete equation.

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3.4 DIVIDER

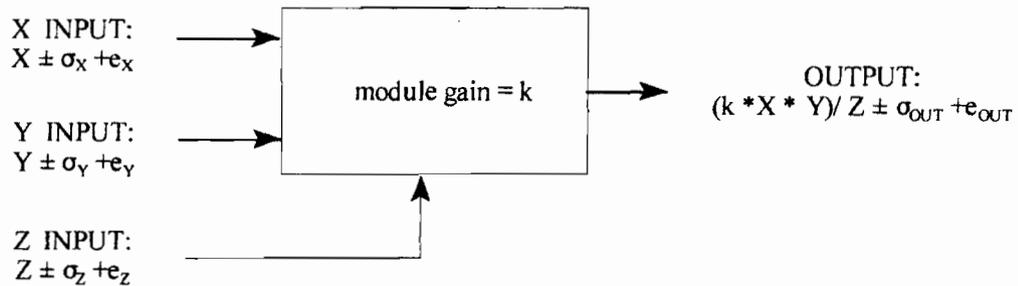


where:

$$\sigma_{OUT} \approx \frac{k1}{k2} \left[\frac{((Y \times \sigma_x)^2 + (X \times \sigma_y)^2)^{1/2}}{Y^2} \right]$$

$$e_{OUT} \approx \frac{k1}{k2} \left[\frac{(Y \times e_x) - (X \times e_y)}{Y^2} \right]$$

3.5 MULTIPLIER DIVIDER



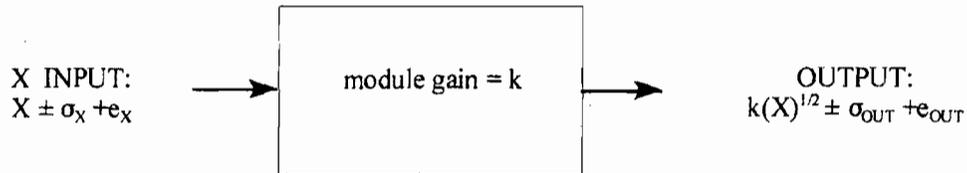
where:

$$\sigma_{OUT} \approx k \left[\left(\frac{Y}{Z} \times \sigma_x \right)^2 + \left(\frac{X}{Z} \times \sigma_y \right)^2 + \left(\frac{XY}{Z^2} \times \sigma_z \right)^2 \right]^{1/2}$$

$$e_{OUT} \approx k \left[\left(\frac{Y}{Z} \times e_x \right) + \left(\frac{X}{Z} \times e_y \right) - \left(\frac{XY}{Z^2} \times e_z \right) \right]$$

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3.6 SQUARE ROOT EXTRACTOR



where:

$$\sigma_{OUT} = \frac{k\sigma_X}{2(X)^{1/2}}$$

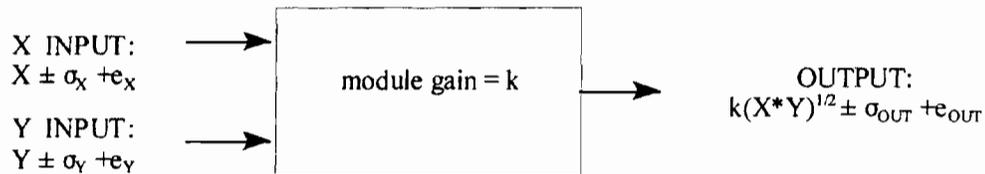
$$e_{OUT} = k[(X + e_X)^{1/2} - (X)^{1/2}]$$

$$e_{OUT} \approx \frac{ke_X}{2(X)^{1/2}}$$

for $\frac{e_X}{X} \geq 1$

for $\frac{e_X}{X} < 1$

3.7 SQUARE ROOT EXTRACTOR WITH MULTIPLIER



where:

$$\sigma_{OUT} \approx \frac{k[(Y \times \sigma_X)^2 + (X \times \sigma_Y)^2]^{1/2}}{2(XY)^{1/2}}$$

$$e_{OUT} \approx \frac{k[(Y \times e_X) + (X \times e_Y)]}{2(XY)^{1/2}}$$

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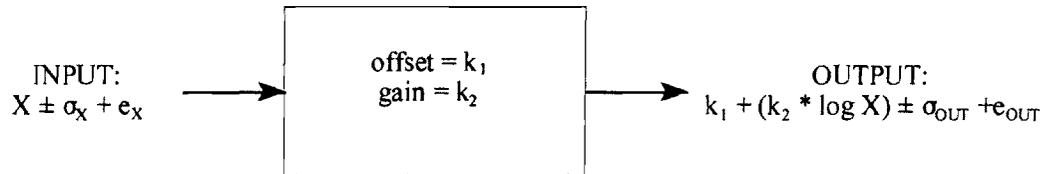
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3.8 LOGARITHMIC AMPLIFICATION



where:

$$\sigma_{OUT} \approx \left(\frac{k_2 \log e}{X} \right) \times \sigma_X$$

$$e_{OUT} \approx \left(\frac{k_2 \log e}{X} \right) \times e_X$$

4.0 MODULES WITH INPUT AND/OR OUTPUT SIGNAL OFFSETS

The functions provided in Appendix B, section 3 use normalized input and output signal values and do not explicitly indicate that either the input signal(s) or the output signal(s), or both, are offset from 0, e.g. 4-20 mA, 1-5 V. The above functions can be modified to include an offset where absolute signal values are desired. This is done by substituting $(x - x_i)$ for input X where the input offset is x_i . The output is modified in a similar manner with X_{OUT} replaced with $(x - x_0)$ and x_0 represents the output offset.

Example (square root extractor with input and output offsets)

$$\begin{aligned} \text{INPUT: } & X \pm \sigma_X + e_X \quad \Rightarrow \quad (x - x_i) \pm \sigma_X + e_X \\ \text{OUTPUT: } & k(X)^{1/2} \pm \sigma_{OUT} + e_{OUT} \quad \Rightarrow \quad k(x - x_0)^{1/2} \pm \sigma_{OUT} + e_{OUT} \end{aligned}$$

where:

$$\sigma_{OUT} = \frac{k\sigma_X}{2(x - x_0)^{1/2}}$$

$$e_{OUT} = k((x - x_0) + e_X)^{1/2} - (x - x_0)^{1/2}$$

$$e_{OUT} \approx \frac{ke_X}{2(x - x_0)^{1/2}}$$

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APPENDIX C

**EQUATIONS FOR
INSTRUMENT CHANNEL UNCERTAINTIES,
SETPOINTS AND ALLOWABLE VALUES**

Latest Revision indicated by a bar in right hand margin.

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1.0 UNCERTAINTY EQUATION

In order to provide a level of confidence that a setpoint actuation will occur prior to exceeding a performance or design basis criteria, the instrument loop accuracy must be determined. This level of confidence is dependent on determining the individual process and component errors and uncertainties, and then combining them in a consistent manner.

The combination of errors is based on statistical and algebraic methods. Errors and uncertainties are combined based on the type of error or uncertainty represented. These types are defined as:

- random, independent errors and uncertainties, which are combined using the square-root-sum-of square (SRSS) methodology.
- random, dependent or not sufficiently independent errors and uncertainties, which are combined by first algebraically adding them to form a pseudo-random composite uncertainty, then combining this uncertainty using SRSS with the other random uncertainties.
- dependent and/or non-randomly distributed errors and uncertainties, which are combined algebraically.

Accuracy, represented by the combination of errors and uncertainties, is calculated using the following equation.

$$Z = \pm[(A^2 + B^2 + C^2) + (D+E)^2]^{1/2} \pm (F) + (L) - (M) \quad \text{(Eq. C1)}$$

Where:

- Z = accuracy represented by the total uncertainty
- A, B, C = random and independent terms. The terms are zero-centered, approximately normally distributed, and indicated by a ± sign.
- D, E = random, dependent uncertainty terms that are independent of terms A, B and C
- F = 1) non-normally (abnormally) distributed uncertainties, or 2) biases with unknown sign.

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This term is used to indicate limits of error associated with uncertainties that are not normally distributed and do not have known direction. The magnitude of this term (absolute value) is assumed to contribute to the total uncertainty in a worst-case direction and is also indicated by a ± sign.

L, M = biases with known sign. These terms can impact an uncertainty in a specific direction and therefore, have a specific + or – contribution to the total uncertainty. L represents positive biases and M represents negative biases.

When the maximum and minimum total uncertainty is desired, equation C1 can be rewritten to combine all positive biases and all negative biases in separate terms.

$$Z^+ = +[(A^2 + B^2 + C^2) + (D+E)^2]^{1/2} + G \tag{Eq. C2}$$

$$Z^- = -[(A^2 + B^2 + C^2) + (D+E)^2]^{1/2} - H \tag{Eq. C3}$$

Where:

Z, A, B, C, D, E, F, L and M are defined for equation C1, and

$$G = (\Sigma|F^+|) + (\Sigma L), \text{ where } F^+ \text{ is the positive bias term sum} \tag{Eq. C4}$$

$$H = (\Sigma|F^-|) + (\Sigma|M|), \text{ where } F^- \text{ is the negative bias term sum} \tag{Eq. C5}$$

The categorization of errors and uncertainties is shown in Appendix C, Figure 1.

Random errors and uncertainties are provided using a value and a level of confidence. The combination of these errors and uncertainties MUST be evaluated at the same confidence level, e.g. 2σ, 1σ, etc.

NOTE: Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) PWR protection setpoints are calculated using the Westinghouse methodology. See the applicable Westinghouse WCAP and the individual protection setpoint calculations for a discussion of this methodology.

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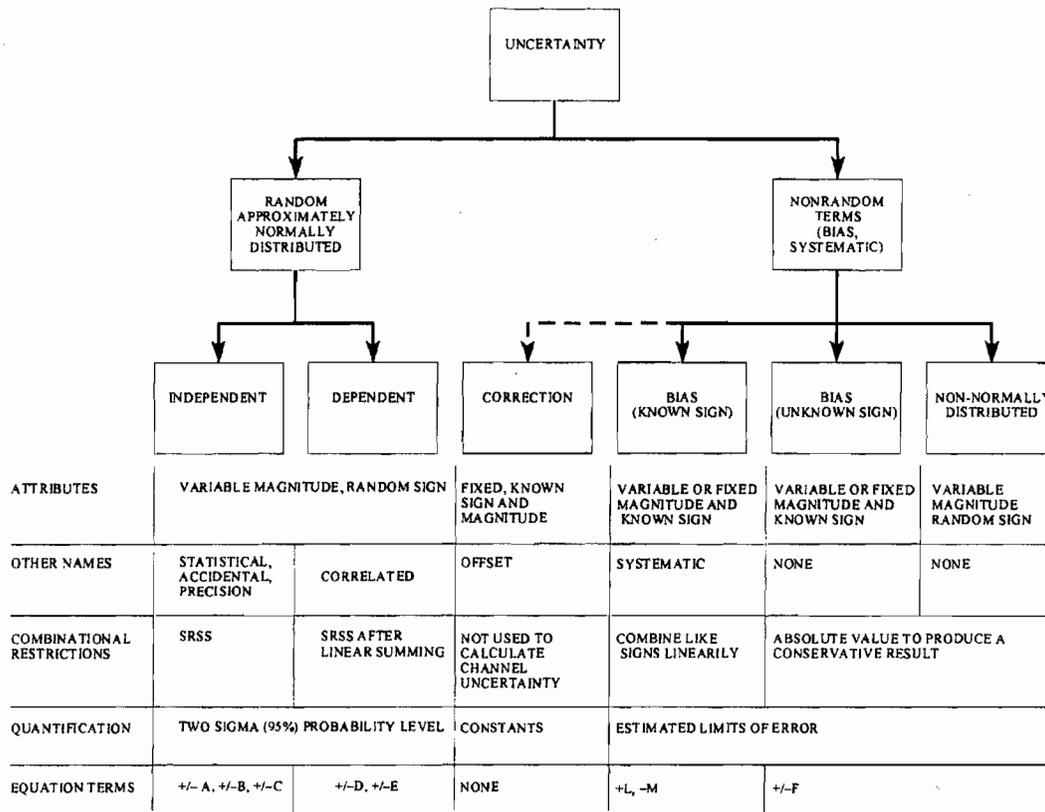


Figure C1, Uncertainty Model

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2.0 UNCERTAINTY EQUATIONS USING EXELON (BRAIDWOOD, BYRON, DRESDEN, LASALLE, AND QUAD) SYMBOLOGY

2.1 CALIBRATION ERROR

The equation for calibration error (CAL) is defined using Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) symbology:

$$CAL = \pm[(RAMTE + TEMTE)^2 + REMTE^2 + STD^2]^{1/2} \quad (\text{Eq. C6})$$

where: RAMTE = M&TE Reference Accuracy
 TEMTE = M&TE Temperature Error
 REMTE = M&TE Reading Error
 STD = Calibration Standard Error and is determined from the following equation:

$$STD = \pm[(RASTD + TESTD)^2 + RESTD^2]^{1/2} \quad (\text{Eq. C7})$$

RASTD = Calibration Standard Reference Accuracy
 TESTD = Calibration Standard Temperature Error
 RESTD = Calibration Standard Reading Error

Where both input M&TE and output M&TE are used in the calibration of a calibration block, Eq. C6 is rewritten as follows:

$$CAL = \pm[(RAMTE_{IN} + TEMTE_{IN})^2 + REMTE_{IN}^2 + STD_{IN}^2 + (RAMTE_{OUT} + TEMTE_{OUT})^2 + REMTE_{OUT}^2 + STD_{OUT}^2]^{1/2} \quad (\text{Eq. C8})$$

2.2 TOTAL ERROR

The symbols shown in Appendix A, Table 1 can be substituted into equation C1 using the applicable default error classifications. Use of this equation should be consistent with the error classifications specific to each instrument loop. For example, if the vendor supplied drift error has been determined to be a bias error, an eD term would be added to the bias errors and the σ_D term would be removed.

$$Z = \pm[\sigma_{PE}^2 + \sigma_{RA}^2 + \sigma_D^2 + CAL^2 + ST^2 + \sigma_{IN}^2]^{1/2} \pm [eSP + eP + eV + eT + eH + eR + eS + eIR + MAR] \quad (\text{Eq. C9})$$

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where: all random errors are at the same confidence level and,

- PE = Process Error
- RA = Reference Accuracy

- D = Drift
- CAL = Calibration Error
- ST = Setting Tolerance
- IN = Random input Error(s)
- eSP = Static Pressure Error
- eP - = Pressure Error
- eV - = Power Supply Error
- eT - = Temperature Error
- eH - = Humidity Error
- eR - = Radiation Error
- eS - = Seismic Error
- eIR - = Error due to current leakage through insulation resistance
- MAR = Margin (included only if applicable)

3.0 TRIP SETPOINT

The Trip Setpoint (SP) is calculated to provide a level of confidence that the setpoint function will occur prior an acceptance limit. For protection setpoints, this level of confidence is a 2σ value for random errors and the analytical limit is the associated acceptance limit.

Increasing Protection Setpoint

$$SP = AL - (Z+MAR) \tag{Eq. C10}$$

Decreasing Protection Setpoint

$$SP = AL + (Z+MAR) \tag{Eq. C11}$$

Other Increasing Setpoints

$$SP = \text{acceptance limit} - (Z+MAR) \tag{Eq. C12}$$

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Other Decreasing Setpoints

$$SP = \text{acceptance limit} + (Z + MAR) \quad (\text{Eq. C13})$$

where: SP = calculated trip setpoint
 AL = analytical limit
 Z = total uncertainty as defined in equation C9 or its equivalent
 MAR = margin, if applicable for an additional level of conservatism acceptance limit: any other limit chosen to ensure that a condition is not exceeded. Examples are: plant protection limits, personnel safety limits, equipment protection limits, radiation dose limits, EOP setpoints, etc.

4.0 ALLOWABLE VALUE

The Allowable Value is calculated to provide acceptance criteria for evaluation of operability. It is a value, which if exceeded, may mean that the instrument loop, module or component is no longer performing within the assumptions of the setpoint calculation, the design basis or the Technical Specifications. The Allowable Value is typically used to evaluate the "as-found" trip setpoint with respect to a condition of operability. The Allowable Value is typically included in the station Technical Specifications.

The Allowable Value is calculated by combining ONLY those errors that affect the "as-found" setpoint value and then adding or subtracting the combined error from the trip setpoint.

Increasing Setpoint

$$AV = SP + \text{applicable uncertainty} \quad (\text{Eq. C14})$$

Decreasing Setpoint

$$AV = SP - \text{applicable uncertainty} \quad (\text{Eq. C15})$$

where: AV = Allowable Value
 SP = Calculated Trip Setpoint
 applicable uncertainty = a value calculated from the errors and uncertainties that have been determined to effect the trip setpoint

From all of the errors and uncertainties that have been determined to affect the trip setpoint, ONLY those that effect the as-found measurement are combined using equation C9 or its equivalent. For example, for an instrument channel where the as-found trip value is determined during a quarterly functional check, a test signal is applied to the instrument rack and the bistable is observed to change state. The total uncertainty consists of the input M&TE uncertainties, the instrument channel uncertainties, any environmental effects during the functional check and the setting tolerance. None of the sensor errors affect the "as-found" setpoint value in this example, and would not be included in the applicable uncertainty for this setpoint when calculating an Allowable Value for the quarterly function check.

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5.0 EXPANDED TOLERANCES

An Expanded Tolerance is a value calculated from available instrument uncertainties that is used to evaluate an instrument's performance and its potential degradation. Refer to ER-AA-520 for calculation of Expanded Tolerances.

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APPENDIX D

**GRADED APPROACH
TO DETERMINATION OF
INSTRUMENT CHANNEL ACCURACY**

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1.0 INTRODUCTION

The Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) setpoint methodology was developed and is defined by this standard to provide the basis, consistent with ANSI/ISA-67.04.01-2000, for the determination of instrument setpoints, allowable values and instrument loop accuracy. This ISA standard defines the requirements for establishing and maintaining setpoints for nuclear safety-related instrumentation. In addition, ISA- RP67.04.02-2000 provides guidance for implementing ANSI/ISA-67.04.01-2000 and imposes rigorous requirements for instrument uncertainty calculations and setpoint determination for safety-related instrument setpoints in nuclear power plants.

ISA- RP67.04.02-2000 recognizes that the historical focus of ANSI/ISA-67.04.01-2000 was the class of setpoints associated with the analytical limits as determined in the accident analysis. These setpoints have typically been interpreted as the reactor protection (RP) and emergency safety features (ESF) setpoints. The RP and ESF setpoints are those critical to ensuring that the integrity of the multiple barriers to the release of fission products is maintained. The Recommended Practice also states that setpoints that are not part of the safety analysis and are not required to maintain the integrity of the fission product barriers may not require the same level of rigor or detail as described by the Recommended Practice. For these non-RP and non-ESF setpoints, a graduated or “graded” approach is appropriate for setpoints that:

- provide anticipatory inputs to the RP or ESF functions, but are not credited in the accident analysis or,
- support operation of, but not the initiation of, the ESF setpoints.

ISA draft Technical Report, ISA-dTR67.04.09, “Graded Approaches to Setpoint Determination”, is being prepared to provide further guidance in establishing classification schemes for setpoints and recommending an approach to translate these classification schemes into a methodology for determination of instrument loop accuracies and setpoints. The technical report requires that a “graded methodology” provide a consistent hierarchy of both rigor and conservatism for classifying, determining and subsequently maintaining setpoints.

This appendix provides a classification scheme and the associated graded methodology for the determination of instrument loop accuracy at Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) nuclear stations. The instrument loop accuracy may then be used to determine the associated instrument setpoints. The Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) “graded methodology” is summarized in Table D1.

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2.0 CLASSIFICATION

The Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) graded methodology classifies instrument setpoints into four levels. These correspond to a “level of confidence” that the setpoint will perform its function with respect to a limit or other limiting criteria. These levels range from Level 1, which provides the highest confidence, to Level 4, which may only document engineering judgment.

The following sections identify instrument channel functions and the minimum level of confidence used when determining instrument loop accuracy. Those individuals preparing and reviewing instrument loop accuracy calculations may choose to perform a particular instrument loop accuracy calculation using a higher level of confidence. This basis for this decision shall be fully documented in the instrument loop accuracy calculation.

It is not the intent of this standard to identify every instrument function encountered in a nuclear station. The following sections should provide sufficient guidance for selecting the appropriate level of confidence for those instrument functions not explicitly identified. Care should be taken to ensure that the function of the setpoint is clearly identified and that the instrument loop accuracy is determined consistent with the following levels.

2.1 LEVEL 1

This level is consistent with the definition of nuclear safety-related instrumentation in ANSI/ISA-67.04.01-2000. These instruments provide setpoints that:

- 1) Provide emergency reactor shutdown
- 2) Provide containment isolation
- 3) Provide reactor core cooling
- 4) Provide for containment or reactor heat removal
- 5) Prevent or mitigate a significant release of radioactive material to the environment or is otherwise essential to provide reasonable assurance that a nuclear power plant can be operated without undue risk to the health and safety of the public

For Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) nuclear stations, this specifically includes all reactor protection system (RPS), emergency safety features (ESF), emergency core cooling system (ECCS), primary containment isolation system (PCIS) and secondary containment (SCIS) setpoints.

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2.2 LEVEL 2

This level will include those setpoints that:

- 1) Ensure compliance with Technical Specification but are not level 1 setpoints.
- 2) Provide setpoints or limits associated with RG 1.97, category A variables.
- 3) Provide setpoints or limits associated with station emergency operating procedure (EOP) requirements.

The RG 1.97 category A variables are included in Level 2 since they provide the primary information required to permit the control room operator to take specific manually controlled actions for which no automatic control is provided and that are required for safety systems to accomplish their safety functions for design basis accident events.

Level 2 instrument loops are typically associated with those setpoints that provide the station operator with specific action values or limits used to verify plant status. This includes instrument loops that provide an indication of acceptable performance for structures, systems and components in the Technical Specifications.

Setpoints or limits contained in station EOP's that are RG 1.97 category A variables, or setpoints that provide specific action values are included in Level 2. Other EOP setpoints may be either Level 2 or 3 depending on their function.

2.3 LEVEL 3

This level will include those setpoints that:

- 1) Provide setpoints or limits associated with RG 1.97, category B, C or D variables.
- 2) Provide setpoints or limits associated with other regulatory requirements or operating commitments, e.g. OSHA, EPA, etc.
- 3) Provide setpoints or limits that are clearly associated with personnel safety or equipment protection.

The RG 1.97, category B, C and D variables are associated with contingency actions and may be included in EOP's or other written procedures.

Classification of EOP setpoints as a Level 3 setpoint shall be approved by the station EOP coordinator or other individual designated by the station operations department.

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2.4 LEVEL 4

This level will include those setpoints that:

- 1) Provide setpoints or limits not identified with the requirements in levels 1, 2 or 3 above.
- 2) Require documentation of engineering judgment, industry or station experience, or other methods have been used to set or identify an operating limit.

Level 4 shall provide documentation of all non-Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) methodologies used to establish instrument loop accuracies or instrument setpoints.

3.0 DETERMINATION OF INSTRUMENT LOOP ACCURACY

3.1 LEVELS OF CONFIDENCE

The level of confidence associated with the calculation enforces a gradation in rigor and conservatism to the instrument loop accuracy evaluation. Level 1, the highest level of conservatism, is typically associated with a 95% level of confidence that the setpoint will provide its intended function prior to limit or limiting condition. Levels 2, 3 and 4 provide decreasing levels of confidence by allowing various additions to the methodology used to calculate and combine errors and uncertainties. At Level 4, the instrument loop accuracy may not be associated with any clearly identified level of confidence other than experience.

The methodology associated with each level is shown in Table D1.

3.2 LEVEL 1

Calculation of instrument loop accuracy, instrument setpoints and allowable values in Level 1 shall use the equations in App. C. These equations use a 2σ level of confidence and require that determination of instrument loop accuracy always err on the side of conservatism.

Level 1 setpoints are consistent with ISA 67.04.01-2000 and ISA RP67.04.02-2000. in order to ensure that protective actions occur 95% of the time with a high degree of confidence before the analytical limits are reached.

3.3 LEVEL 2

Level 2 instrument loop accuracy is calculated using the equations in Appendix C with the following exceptions:

- 1) Random errors are evaluated at a 1σ level of confidence
- 2) Bias errors may be combined using SRSS in accordance with Reference 3.11

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- 3) Where it can be determined that a setpoint function is only evaluated in a single direction, either increasing or decreasing, single side of interest confidence levels may be utilized (reference 3.2, section 8.1).

3.4 LEVEL 3

Level 3 instrument loop accuracy is calculated using the equations in Appendix C, the exceptions in Level 2 and the following additional exceptions:

- 1) Uncertainties applicable to the entire instrument channel are used wherever available, e.g. channel drift and channel temperature uncertainty vs. module/component drift and module/component temperature uncertainty.
- 2) Where all terms are expected to be approximately normally distributed and the number of terms is ≥ 4 , the sum is assumed to be approximately distributed. Therefore, all terms can be combined using SRSS.
- 3) For bistables, the RA term does not require inclusion of the hysteresis/linearity components. Only the RA uncertainty OR the ST uncertainty, whichever is larger shall be used

3.5 LEVEL 4

Level 4 instrument loop accuracy may be calculated using the equations in Appendix C and include the exceptions in Level 2 and 3. For calculations associated with Level 4 instrument loops, the basis for determining the instrument loop accuracy shall be documented.

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Table D1, Graded Methodology

LEVEL	TYPICAL APPLICATION	METHODOLOGY	APPLICABLE UNCERTAINTY METHODS
1	<ul style="list-style-type: none"> • Protection setpoints • ESF/RPS/ECCS • PCIS/SCIS 	$2\sigma + \Sigma e_i$	<ul style="list-style-type: none"> • Consistent with ISA 67.04.01-2000 and ISA RP67.04.02-2000. • Ensures protective actions occur 95% of the time with a high degree of confidence before the analytical limits are reached. • Random and bias error combination: $Z = \pm[A^2 + B^2 + C^2 + (E + F)^2]^{1/2} \pm (F) + (L) - (M)$ <p>Z = resultant uncertainty, combination of random and bias uncertainties</p> <p>A,B,C = random, independent terms</p> <p>D,E = random dependent terms (independent of A,B and C)</p> <p>F = abnormally distributed uncertainties and/or bias (unknown sign)</p> <p>L,M = biases with known sign</p>
2	<ul style="list-style-type: none"> • EOP operator action setpoints • RG 1.97 Type A variables 	$\sigma + \Sigma e_i$	<ul style="list-style-type: none"> • Bias errors combined using SRSS in accordance with ASME PTC 19.1: $e_i = \pm[F^2 + L^2 + M^2]^{1/2}$ <p>where F, L and M are bias errors as shown above</p> • Single side of interest confidence interval evaluation where the evaluated setpoint is in a single direction: $Z = 0.468\sigma + \Sigma e_i$

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Table D1 (cont.), Graded Methodology

LEVEL	TYPICAL APPLICATION	METHODOLOGY	APPLICABLE UNCERTAINTY METHODS
3	<ul style="list-style-type: none"> RG 1.97 Type B, C & D variables 	$\sigma + \Sigma e_i$	<ul style="list-style-type: none"> Uncertainties applicable to the entire instrument channel are used wherever available, e.g. channel drift and channel temperature uncertainty vs. module/component drift and module/component temperature uncertainty. Single side of interest confidence interval evaluation where the evaluated setpoint is in a single direction: $Z = 0.468\sigma + \Sigma e_i$ Where all terms are expected to be approximately normally distributed, the sum is assumed to be approximately distributed for $n \geq 4$: $Z = [\sigma_n^2 + e_n^2]^{1/2}$ For bistables, the RA term does not require inclusion of the hysteresis/linearity components, therefore use the RA uncertainty OR the ST uncertainty, whichever is larger.
4	<ul style="list-style-type: none"> Documentation of setpoint accuracy (e.g. non-safety, non-tech spec compliance) Other regulatory related setpoints (consequences of non-compliance are deemed acceptable) 	as appropriate	<ul style="list-style-type: none"> Engineering Judgment shall be documented Engineering evaluation/conclusions shall be documented Vendor, Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad), or other methodologies may be utilized where appropriate

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APPENDIX E

**REACTOR WATER LEVEL
TO SENSOR dP CONVERSION**

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1.0 PURPOSE

Differential pressure transmitters are used to monitor reactor vessel water level in a BWR. Reactor vessel level is typically described by elevation from a reference level with units of "inches Reactor Water Level" or "in. RWL", while sensor dP is measured in units of pressure such as "inches water column" or "in.WC". For example; 380.87 in. WC may correspond to a range of -340 in. RWL to +60 in. RWL.

When converting between vessel level and sensor dP, changes in process conditions inside the reactor vessel and changes in environmental conditions must be accounted for. As shown in Figure E1, the sensing lines that connect the dP sensor and the reactor vessel are affected by at least 2 different environmental zones; the drywell and the reactor building. Each of these environmental zones has its own normal temperature deviations. During accident conditions, such as recirculation line break, each of these zones may experience significant temperature increases at the transmitter location or within the drywell.

This appendix will provide:

- 1) a conversion factor between "in. RWL" and the equivalent dP at the sensor as measured in "in.WC"
- 2) an equation to calculate changes in sensor dP that result from changes in the drywell and/or reactor building temperature.
- 3) a scaling conversion factor for changes to sensor dP that result from changes in process conditions.

2.0 CONVERSION OF "in. RWL" TO SENSOR dP IN "in.WC"

The differential pressure between the high and low inputs of a differential pressure transmitter is:

$$dP = P_H - P_L \quad \text{(Eq. E1)}$$

where:

- P_H = the sum of the hydrostatic head pressures at the high sensor input
- P_L = the sum of the hydrostatic head pressures at the low sensor input

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Hydrostatic pressure head is given by:

$$P = \rho g z \quad (\text{Eq. E2})$$

where:

- P = pressure
- ρ = density of the fluid (lbm/ft³)
- g = gravitational constant
- z = height of the column of fluid

Using the definition of specific weight, $\gamma = \rho g$, the equation for dP is:

$$dP = \gamma(z_2 - z_1) \quad (\text{Eq. E3})$$

Using Figure E1, we can define a conversion constant (K) as the change in reactor water level (L) for a change in sensor dP.

$$K = \frac{\delta dP}{\delta L} \quad (\text{Eq. E4})$$

Referring to Figure E1 for the associated elevations, the dP resulting from a level, L, is:

$$dP = \gamma_2(E_C - E_{PH} - E_{NL} + E_{PL}) + \gamma_3(E_{PH} - E_{PL}) - \gamma_4(E_C - L) - \gamma_1(L - E_{NL}) \quad (\text{Eq. E5})$$

An incremental change in dP, given by dP + δdP , is a result of a corresponding incremental change in level, L + δL :

$$dP + \delta dP = \gamma_2(E_C - E_{PH} - E_{NL} + E_{PL}) + \gamma_3(E_{PH} - E_{PL}) - \gamma_4(E_C - (L + \delta L)) - \gamma_1((L + \delta L) - E_{NL}) \quad (\text{Eq. E6})$$

Solving for the change in dP by subtracting equation E5 from equation E6:

$$\begin{aligned} \delta dP &= (dP + \delta dP) - (dP) \\ &= [-\gamma_4(E_C - (L + \delta L)) - \gamma_1((L + \delta L) - E_{NL})] - [-\gamma_4(E_C - L) - \gamma_1(L - E_{NL})] \\ &= \delta L(\gamma_4 - \gamma_1) \end{aligned} \quad (\text{Eq. E7})$$

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For the change in sensor dP corresponding to a 1 inch change in reactor vessel water level:

$$\delta L = 1 \text{ in. RWL}$$

From equation E4:

$$K = \frac{\delta dP}{\delta L} = (\gamma_4 - \gamma_1) \frac{\text{in. WC}}{\text{in. RWL}} \quad (\text{Eq. E8})$$

3.0 CHANGES IN SENSING LINE AND SENSOR ENVIRONMENT

Changes in sensor dP will result from changes in the drywell environment and/or changes in the reactor building environment due to changes in density of the sensing line fluid. For example:

- changes from calibrated environmental conditions to the maximum or minimum normal environmental conditions.
- changes from maximum normal environmental conditions to maximum accident conditions.

Using Figure E1, we can define the sensor dP for 2 different environments.

Environment 1

$$\begin{aligned} dP_{L1} &= [\gamma_{2-1}(E_C - E_{PH}) + \gamma_{3-1}(E_{PH} - E_X)] - [\gamma_{1-1}(E_C - L1) + \gamma_{4-1}(L1 - E_{NL}) \\ &\quad + \gamma_{2-1}(E_{NL} - E_{PL}) + \gamma_{3-1}(E_{PL} - E_X)] \\ &= \gamma_{2-1}(E_C - E_{PH} - E_{NL} + E_{PL}) + \gamma_{3-1}(E_{PH} - E_{PL}) - \gamma_{4-1}(E_C - L1) \\ &\quad - \gamma_{1-1}(L1 - E_{NL}) \end{aligned} \quad (\text{Eq. E9})$$

where:

- L1 = reactor vessel water level (in. RWL) at condition 1
- γ_{1-1} = spec. wgt. of saturated fluid in the reactor vessel at condition 1
- γ_{2-1} = spec. wgt. of fluid in that portion of the sensing lines in the drywell at drywell temperature 1
- γ_{3-1} = spec. wgt. of fluid in that portion of the sensing lines in the reactor building at reactor building temperature 1
- γ_{4-1} = spec. wgt. of saturated vapor in the reactor vessel at condition 1

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Environment 2

$$dP_{L2} = \gamma_{2-2}(E_C - E_{PH} - E_{NL} + E_{PL}) + \gamma_{3-2}(E_{PH} - E_{PL}) - \gamma_{4-2}(E_C - L2) - \gamma_{1-2}(L2 - E_{NL}) \quad (\text{Eq. E10})$$

where:

- L2 = reactor vessel water level (in. RWL) at condition 2
 γ_{1-2} = spec. wgt. of saturated fluid in the reactor vessel at condition 2
 γ_{2-2} = spec. wgt. of fluid in that portion of the sensing lines in the drywell at drywell temperature 2
 γ_{3-2} = spec. wgt. of fluid in that portion of the sensing lines in the reactor building at reactor building temperature 2
 γ_{4-2} = spec. wgt. of saturated vapor in the reactor vessel at condition 2

If we assume all changes between environment 1 and environment 2 are limited to changes in the drywell and reactor building environments:

$$\begin{aligned} L1 &= L2 \\ \gamma_{1-1} &= \gamma_{1-2} \\ \gamma_{4-1} &= \gamma_{4-2} \end{aligned}$$

The change in sensor dP from condition 1 to condition 2 is:

$$\begin{aligned} \Delta dP &= dP_{L2} - dP_{L1} \\ &= [(\gamma_{2-2} - \gamma_{2-1})(E_C - E_{PH} - E_{NL} + E_{PL})] + [(\gamma_{3-2} - \gamma_{3-1})(E_{PH} - E_{PL})] \end{aligned} \quad (\text{Eq. E11})$$

3.1 EXAMPLE

To calculate the process error due to a LOCA, we need to determine the change in sensor dP between maximum normal environmental conditions and the maximum accident environmental conditions in the drywell and reactor building. This is typically calculated at a specific reactor vessel level, e.g. one of the vessel level protection setpoints. In addition, in order to calculate a bounding change, the following assumptions apply:

- 1) Transient effects are ignored. It is assumed that the sensing lines are at thermal equilibrium with their environment.
- 2) Reactor vessel process conditions do not change; only the sensing line environments are effected by the LOCA. Obviously the reactor vessel saturation conditions will change if a scram occurs, but in this example we are looking only for the process error at the protection level setpoint.

From equation E11:

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$$\Delta dP = [(\gamma_{2a} - \gamma_{2n})(E_C - E_{PH} - E_{NL} + E_{PL})] + [(\gamma_{3a} - \gamma_{3n})(E_{PH} - E_{PL})] \quad (\text{Eq. E12})$$

where:

γ_{2n} = spec. wgt. of the fluid in that portion of the sensing lines in the drywell at the maximum normal environment.

γ_{2a} = spec. wgt. of the fluid in that portion of the sensing lines in the drywell at the maximum accident environment.

γ_{3n} = spec. wgt. of the fluid in that portion of the sensing lines in the reactor building at the maximum normal environment

γ_{3a} = spec. wgt. of the fluid in that portion of the sensing lines in the reactor building at the maximum accident environment.

Using equation E8 and equation E12, we can calculate the equivalent change in reactor vessel water level:

$$\Delta RWL = \frac{\Delta dP}{(\gamma_4 - \gamma_1)}$$

$$\Delta RWL = \frac{[(\gamma_{2a} - \gamma_{2n})(E_C - E_{PH} - E_{NL} + E_{PL})] + [(\gamma_{3a} - \gamma_{3n})(E_{PH} - E_{PL})]}{(\gamma_4 - \gamma_1)} \quad (\text{Eq. E13})$$

4.0 REACTOR WATER LEVEL SCALING

Reactor vessel level is typically provided in inches above or below some reference, e.g. top of active fuel (TAF). In order to determine the correct dP transmitter scaling we use equation E5 to determine the dP at normal process conditions and normal drywell and reactor building environments. This dP must then be converted to the equivalent dP at calibration conditions. Transmitter calibration is typically performed at cold shutdown conditions where the reactor vessel vapor space contains air and it is assumed that the vessel fluid, drywell and reactor building are at the same temperature. From equation E8, we see that the conversion from sensor dP to in. RWL is a function of the process conditions and is not effected by the sensing line environmental conditions.

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At normal process conditions:

$$\frac{dP_P}{dL_P} = \gamma_4 - \gamma_1 \quad (\text{Eq. E14})$$

At calibration conditions:

$$\frac{dP_C}{dL_C} = \gamma_{AIR} - \gamma_C F \quad (\text{Eq. E15})$$

For scaling dP values, we define a conversion factor that provides the equivalent change in reactor vessel level for a given sensor dP when we change from calibration conditions to the normal process conditions.

$$K_{S_{HP=CONSTANT}} = \frac{\text{vessel level at process conditions}}{\text{vessel level at calibration conditions}}$$

From equations E14 and E15, this is equivalent to $dP_C = dP_P$

Therefore:

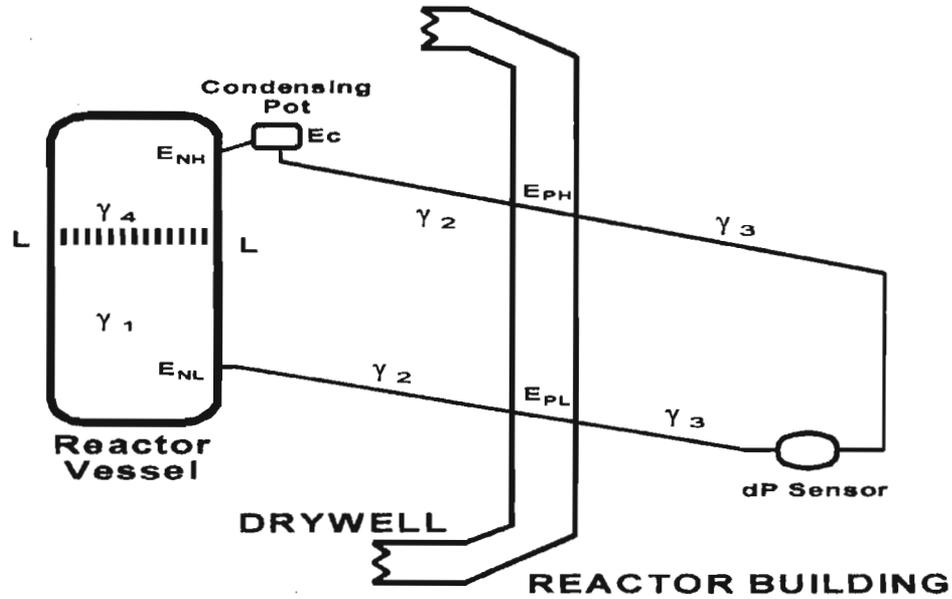
$$dL_C(\gamma_{AIR} - \gamma_C) = dL_P(\gamma_4 - \gamma_1) \quad (\text{Eq. E16})$$

$$K_S = \frac{dL_P}{dL_C} = \frac{\gamma_{AIR} - \gamma_C}{\gamma_4 - \gamma_1} \quad (\text{Eq. E17})$$

When using standard steam tables, it is convenient to rewrite equation E17 as a ratio of specific volumes. Neglecting the specific weight of air, conversion factor K_S is:

$$K_S = \frac{v_4 v_1}{v_C (v_4 - v_1)} \quad (\text{Eq. E18})$$

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- γ_1 - specific weight of the saturated fluid in the reactor vessel
- γ_2 - specific weight of the fluid in the sensing lines located in the drywell
- γ_3 - specific weight of the fluid in the sensing lines located in the reactor building
- γ_4 - specific weight for the saturated vapor in the reactor vessel
- E_{NL} - elevation of the lower nozzle
- E_{NH} - elevation of the upper nozzle
- E_C - elevation of the condensate pot
- E_{PL} - elevation of the lower penetration
- E_{PH} - elevation of the upper penetration
- E_X - elevation of the sensor
- L - Water Level (in. RWL)

Figure E1, Reactor Vessel Water Level and Sensor dP

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APPENDIX F

**TEMPERATURE EFFECTS
ON LEVEL MEASUREMENT**

Latest Revision indicated by a bar in right hand margin.

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1.0 INTRODUCTION

Differential pressure level measurement systems are typically calibrated for a specific set of operating conditions, i.e. process pressure and reference leg temperature. If either of these conditions change, an error will be introduced between the actual level and the indicated level. This is due to changes in the dP at the sensor and results from changes in fluid density and not from changes in actual level. Since this error is of known magnitude and known direction (based on the difference between the calibrated condition and the new process and/or environmental condition), it is treated as a bias error.

This appendix provides simplified formulas for estimating the effects of:

- process pressure changes (assuming that the vessel is at saturation conditions),
- environmental changes (assuming that the reference leg fluid temperature is at equilibrium with the environment), and
- both process changes and reference leg temperature changes acting simultaneously to produce a worst case bias under specified conditions.

2.0 ERROR FRACTION

When evaluating the effects of process and environmental changes on level measurement accuracy, it is convenient to consider these effects as changes from the known (or calibrated) condition. Using this concept, the level error is a function of how much the indicated level differs from the actual level. The indicated level (IND LVL) corresponds to the transmitter scaling relationship where transmitter output is a function of the dP applied to the transmitter. The scaling relationship should be based on specific process conditions and specific environmental conditions. The actual level (ACT LVL) will then deviate from the indicated level (IND LVL) as a function of the deviation of the process and environmental conditions from the calibrated conditions. This difference between indicated level and actual level is defined as the "error fraction" (E)²:

$$E = \% \text{ IND LVL} - \% \text{ ACT LVL}$$

This appendix will use units of % level, which is consistent with typical level measurement scales where indicated level ranges from 0% to 100% level. While units of level, and consequently E could be in other units, the derivations are simplified if % level is chosen.

² The term "error fraction" and the equation $E = \% \text{ IND LVL} - \% \text{ ACT LVL}$, is consistent with the steam generator level protection and EOP setpoint accuracy evaluation originally provided by Westinghouse and currently incorporated in Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) setpoint accuracy calculations for Byron and Braidwood stations.

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If E is calculated (regardless of the units of level measurement), the effects of temperature related errors on bistable or EOP setpoints can be evaluated. Table F1 can be used to determine if level bias error must be included in the instrument loop accuracy or may be ignored.

	sign of E is positive (IND LVL > ACT LVL)	sign of E is negative (ACT LVL > IND LVL)
Increasing setpoint	bias error will be conservative and may be ignored	bias error is non-conservative and must be included in the instrument loop accuracy
Decreasing setpoint	bias error is non-conservative and must be included in the instrument loop accuracy	bias error will be conservative and may be ignored

Table F1, Error Fraction Effect on Instrument Setpoints.

3.0 PROCESS FLUID DENSITY CHANGES

The following equations may be used to calculate indicated level and the error fraction resulting from process fluid density changes.

These equations assume:

- 1) saturated conditions inside the vessel The occurrence of subcooling in the downcomer region of PWR steam generators, which becomes significant above 70% RTP is typically included in instrument loop accuracy calculations, but is calculated through other mechanisms.
- 2) an actual steam generator level There is no actual level in the steam generator while generating steam. A transition zone exists between the saturated fluid and saturated vapor. The following equations calculate the actual level L as the collapsed level.
- 3) steady state process conditions Transient effects, such as rapid depressurization, are not included and would require a much more complicated analysis.
- 4) thermal equilibrium The reference leg fluid temperature is considered to be in equilibrium with the environment.

Typical condensing pot installations are located close to the vessel. This results in the H_L/H term in the following equations being sufficiently close to 1 for this term to be ignored.

3.1 FORMULAS

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For an actual level L, the indicated level will be:

$$\% \text{ IND LVL} = \left(\frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) \right) \times 100$$

where: all terms are defined in Figure F1, and
L, H and H_L are in consistent units of length (e.g. inches)

The error fraction for process fluid density changes is:

$$E = \% \text{ IND LVL} - \% \text{ ACT LVL}$$

$$\frac{E}{100} = \frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} - 1 \right)$$

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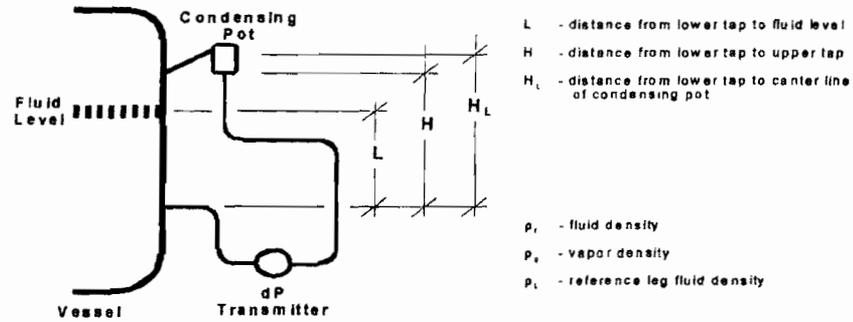
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- T_1, P_1 - temperature and pressure inside the vessel at calibrated conditions
- ρ_{f1}, ρ_{g1} - density of saturated liquid and steam at calibration conditions T_1 and P_1
- T_2, P_2 - temperature and pressure inside the vessel at some new condition
- ρ_{f2}, ρ_{g2} - density of saturated liquid and steam at the new conditions T_2 and P_2
- $T_{REF LEG}$ - temperature of the environment and reference leg fluid
- ρ_{L1} - density of reference leg liquid at $T_{REF LEG}$ and P_1 (compressed liquid)
- ρ_{L2} - density of reference leg liquid at $T_{REF LEG}$ and P_2 (compressed liquid)

Figure F1: Level Bias Error Due to Process Fluid Density Changes

3.2 DERIVATION

Calculate the transmitter 0% and 100% level for the dP at T_1 and P_1 conditions:

$$\begin{aligned}
 dP_{100\%lvl} &= \rho_{L1}gH_L - (\rho_{f1}gH + \rho_{g1}g(H_L - H)) \\
 &= gH_L(\rho_{L1} - \rho_{g1}) - gH(\rho_{f1} - \rho_{g1})
 \end{aligned}$$

$$\begin{aligned}
 dP_{0\%lvl} &= \rho_{L1}gH_L - \rho_{g1}gH_L \\
 &= gH_L(\rho_{L1} - \rho_{g1})
 \end{aligned}$$

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Calculate the transmitter dP at L% level for the dP at T₂ and P₂ conditions:

$$\begin{aligned} L\% &= (L/H) \times 100\% |v| \\ dP_{L\%|v|} &= \rho_{L2} g H_L - (\rho_{f2} g L + \rho_{g2} g (H_L - L)) \\ &= \rho_{L2} g H_L - \rho_{f2} g L - \rho_{g2} g H_L + \rho_{g2} g L \\ &= g H_L (\rho_{L2} - \rho_{g2}) - g L (\rho_{f2} - \rho_{g2}) \end{aligned}$$

Calculate the indicated level at the known dP for L% level with respect to the calibrated transmitter dP:

$$\begin{aligned} \% \text{ IND LVL} &= \frac{dP_{L\%|v|} - dP_{0\%|v|}}{dP_{100\%|v|} - dP_{0\%|v|}} \times 100 \\ &= \frac{[g H_L (\rho_{L2} - \rho_{g2}) - g L (\rho_{f2} - \rho_{g2})] - [g H_L (\rho_{L1} - \rho_{g1})]}{[g H_L (\rho_{L1} - \rho_{g1}) - g L (\rho_{f1} - \rho_{g1})] - [g H_L (\rho_{L1} - \rho_{g1})]} \times 100 \\ &= \left(\frac{-H_L (\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}) - L (\rho_{f2} - \rho_{g2})}{-H (\rho_{f1} - \rho_{g1})} \right) \times 100 \\ &= \left(\frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) \right) \times 100 \end{aligned}$$

The error fraction is:

$$E = \% \text{ IND LVL} - \% \text{ ACT LVL}$$

$$= \left(\frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) \right) \times 100 - \left(\frac{L}{H} \right) \times 100$$

$$\frac{E}{100} = \frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} - 1 \right)$$

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4.0 REFERENCE LEG HEATUP

Changes in ambient temperature will effect the density of the fluid in the reference leg. The following equation may be used to calculate the error fraction for reference leg heatup.

These equations assume:

- 1) saturated conditions inside the vessel The occurrence of subcooling in the downcomer region of PWR steam generators, which becomes significant above 70% RTP is typically included in instrument loop accuracy calculations, but is calculated through other mechanisms.
- 2) an actual steam generator level There is no actual level in the steam generator while generating steam. A transition zone exists between the saturated fluid and saturated vapor. The following equations calculate the actual level L as the collapsed level.
- 3) steady state process conditions Transient effects, such as rapid depressurization, are not included and would require a much more complicated analysis.
- 4) thermal equilibrium The reference leg fluid temperature is considered to be in equilibrium with the environment.

Typical condensing pot installations are located close to the vessel. This results in the H_L/H term in the following equations being sufficiently close to 1 for this term to be ignored.

4.1 ERROR FRACTION

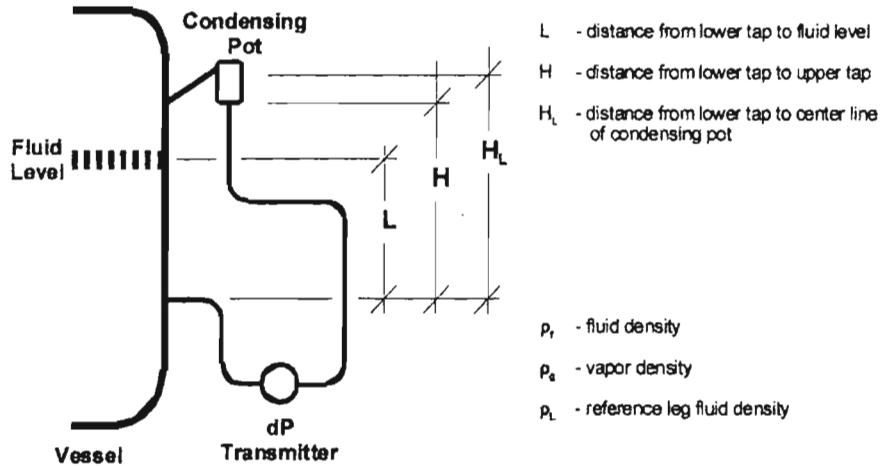
The error fraction for changes in reference leg temperature is:

$$E = \% \text{ IND LVL} - \% \text{ ACT LVL}$$

$$\frac{E}{100} = \frac{H_L}{H} \left(\frac{\rho_1 - \rho_2}{\rho_f - \rho_g} \right)$$

- where: - all terms are defined in figure F2, and
 - L, H and H_L are in consistent units of length (e.g. inches)

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- ρ_f, ρ_g - density of saturated liquid and vapor in the vessel
- T_1 - environment and reference leg temperature at the calibrated condition
- ρ_1 - density of liquid in the reference leg at calibration conditions
- T_2 - environment and reference leg temperature at the new condition
- ρ_2 - density of liquid in the reference leg at a new environmental temperature

Figure F2: Level Bias Error Due to Reference Leg Heatup

4.2 DERIVATION

Calculate the transmitter dP at 0%, 100% and L% level for the calibrated (T_1) conditions:

$$\begin{aligned}
 dP|_{100\% \text{ lvl}} &= \rho_1 g H_L - (\rho_f g H + \rho_g g (H_L - H)) \\
 &= g H_L (\rho_1 - \rho_g) - g H (\rho_f - \rho_g)
 \end{aligned}$$

$$\begin{aligned}
 dP|_{0\% \text{ lvl}} &= \rho_1 g H_L - \rho_g g H_L \\
 &= g H_L (\rho_1 - \rho_g)
 \end{aligned}$$

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Calculate the transmitter dP at 0% and 100% level for the T₂ conditions:

$$\begin{aligned} dP2_{100\%lvl} &= \rho_2 g H_L - (\rho_f g H + \rho_g g (H_L - H)) \\ &= g H_L (\rho_2 - \rho_g) - g H (\rho_f - \rho_g) \end{aligned}$$

$$\begin{aligned} dP2_{0\%lvl} &= \rho_2 g H_L - \rho_g g H_L \\ &= g H_L (\rho_2 - \rho_g) \end{aligned}$$

$$\begin{aligned} dP_L &= (L/100)(dP1_{100\%lvl} - dP1_{0\%lvl}) + dP1_{0\%lvl} \\ &= (L/100)(g H_L (\rho_1 - \rho_g) - g H (\rho_f - \rho_g) - g H_L (\rho_1 - \rho_g)) \\ &\quad + g H_L (\rho_1 - \rho_g) \\ &= g H_L (\rho_1 - \rho_g) - (LgH/100)(\rho_f - \rho_g) \end{aligned}$$

This derivation uses a different, but more realistic concept. Starting with the indicated level that we observe, the actual level is calculated by including the effect of changes in reference leg density. Since level vs. dP is a linear relationship, a ratio is used to determine the actual level. Figure F3 will help in visualizing the required ratio.

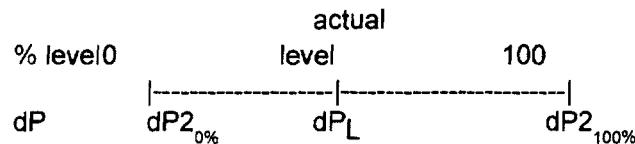


Figure F3, % Level vs. dP

$$\begin{aligned} \frac{\text{ACT LVL} - 0\%}{dP_L - dP2_{0\%}} &= \frac{100\% - 0\%}{dP2_{100\%} - dP2_{0\%}} \\ \text{ACT LVL} &= \frac{dP_L - dP2_{0\%}}{dP2_{100\%} - dP2_{0\%}} \times 100 \end{aligned}$$

The indicated level is equal to the calibrated dP, therefore:

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$$dP_L = dPI_L$$

$$\text{ACT LVL} = \frac{\left(gH_L(\rho_1 - \rho_g) - \left(\frac{LgH}{100} \right) (\rho_f - \rho_g) - gH_L(\rho_2 - \rho_g) \right)}{\left(gH_L(\rho_2 - \rho_g) - gH(\rho_f - \rho_g) - gH_L(\rho_2 - \rho_g) \right)} \times 100$$

$$= \frac{\left(H_L(\rho_1 - \rho_g - \rho_2 + \rho_g) - \frac{LH}{100}(\rho_f - \rho_g) \right)}{\left(-H(\rho_f - \rho_g) \right)} \times 100$$

$$= \left(\frac{-H_L}{H} \left(\frac{\rho_1 - \rho_2}{\rho_f - \rho_g} \right) + \frac{L}{100} \right) \times 100$$

The error fraction is:

$$E = \% \text{ IND LVL} - \% \text{ ACT LVL}$$

$$= L - \left(\frac{-H_L}{H} \left(\frac{\rho_1 - \rho_2}{\rho_f - \rho_g} \right) + \frac{L}{100} \right) \times 100$$

$$= L + \left(\frac{H_L}{H} \left(\frac{\rho_1 - \rho_2}{\rho_f - \rho_g} \right) \right) \times 100 - L$$

$$\frac{E}{100} = \frac{H_L}{H} \left(\frac{\rho_1 - \rho_2}{\rho_f - \rho_g} \right)$$

5.0 SIMULTANEOUS EFFECTS OF REFERENCE LEG HEATUP AND PROCESS FLUID DENSITY CHANGES

When process changes and environmental changes interact, e.g. LOCA or steam breaks inside containment, or where a bounding error term is desired, the following equation can be used to calculate the error fraction.

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These equations assume:

- 1) saturated conditions inside the vessel The occurrence of subcooling in the downcomer region of PWR steam generators, which becomes significant above 70% RTP is typically included in instrument loop accuracy calculations, but is calculated through other mechanisms.
- 2) an actual steam generator level There is no actual level in the steam generator while generating steam. A transition zone exists between the saturated fluid and saturated vapor. The following equations calculate the actual level L as the collapsed level.
- 3) steady state process conditions Transient effects, such as rapid depressurization, are not included and would require a much more complicated analysis.
- 4) thermal equilibrium The reference leg fluid temperature is considered to be in equilibrium with the environment.

Typical condensing pot installations are located close to the vessel. This results in the H_L/H term in the following equations being sufficiently close to 1 for this term to be ignored.

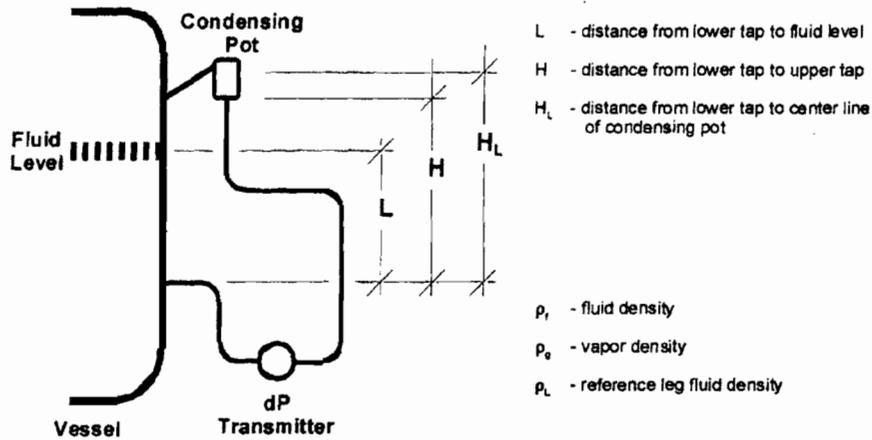
5.1 ERROR FRACTION

$$E = \% \text{ IND LVL} - \% \text{ ACT LVL}$$

$$\frac{E}{100} = \frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} - 1 \right)$$

where: - all terms are defined in figure F4, and
L, H and H_L are in consistent units of length (e.g. inches)

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- T_1, P_1 - temperature and pressure inside the vessel at calibrated conditions
- ρ_{f1}, ρ_{g1} - density of saturated liquid and steam at calibration conditions T_1 and P_1
- T_2, P_2 - temperature and pressure inside the vessel at some new condition
- ρ_{f2}, ρ_{g2} - density of saturated liquid and steam at the new conditions T_2 and P_2
- $T_{REF LEG1}$ - temperature of environment and the liquid in the reference leg
- ρ_{L1} - density of reference leg liquid at $T_{REF LEG1}$ and P_1 (compressed liquid)
- $T_{REF LEG2}$ - temperature of environment and the liquid in the reference leg
- ρ_{L2} - density of reference leg liquid at $T_{REF LEG2}$ and P_2 (compressed liquid)

Figure F4, Level Bias Error Due to Both Process Fluid Density Changes and Reference Leg Heatup

5.2 DERIVATION

Calculate the transmitter dP at 0% and 100% level for the calibrated conditions T_1, P_1 and $T_{REF LEG1}$:

$$\begin{aligned}
 dP_{100\% \text{ lvl}} &= \rho_{L1} g H_L - (\rho_{f1} g H + \rho_{g1} g (H_L - H)) \\
 &= g H_L (\rho_{L1} - \rho_{g1}) - g H (\rho_{f1} - \rho_{g1}) \\
 dP_{0\% \text{ lvl}} &= \rho_{L1} g H_L - \rho_{g1} g H_L \\
 &= g H_L (\rho_{L1} - \rho_{g1})
 \end{aligned}$$

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Calculate the transmitter dP at L% level for the new conditions T_2 , P_2 and $T_{REFLEG2}$:

$$\begin{aligned} dP_{L\%lvl} &= \rho_{L2}gH_L - (\rho_{f2}gL + \rho_{g2}g(H_L - L)) \\ &= \rho_{L2}gH_L - \rho_{f2}gL - \rho_{g2}gH_L + \rho_{g2}gL \\ &= gH_L(\rho_{L2} - \rho_{g2}) - gL(\rho_{f2} - \rho_{g2}) \end{aligned}$$

Calculate the indicated level (in % indicated level) for a $dP = dP_{L\%lvl}$ at the calibrated conditions T_1 , P_1 , and $T_{REFLEG1}$:

$$\begin{aligned} \% \text{INDLVL} &= \frac{dP_{L\%lvl} - dP_{0\%lvl}}{dP_{100\%lvl} - dP_{0\%lvl}} \times 100 \\ &= \frac{[gH_L(\rho_{L2} - \rho_{g2}) - gL(\rho_{f2} - \rho_{g2})] - [gH_L(\rho_{L1} - \rho_{g1})]}{[gH_L(\rho_{L1} - \rho_{g1}) - gL(\rho_{f1} - \rho_{g1})] - [gH_L(\rho_{L1} - \rho_{g1})]} \times 100 \\ &= \frac{H_L(\rho_{L2} - \rho_{g2} - \rho_{L1} + \rho_{g1}) - L(\rho_{f2} - \rho_{g2})}{-H(\rho_{f1} - \rho_{g1})} \times 100 \\ &= \left(\frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) \right) \times 100 \end{aligned}$$

The error fraction is:

$$E = \% \text{IND LVL} - \% \text{ACT LVL}$$

$$= \left(\frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) \right) \times 100 - \left(\frac{L}{H} \right) \times 100$$

$$\frac{E}{100} = \frac{H_L}{H} \left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H} \left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} - 1 \right)$$

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6.0 REFERENCE LEG BOILING

In addition to process and reference leg density changes, boiling could conceivable occur in the reference leg due to rapid depressurization. Boiling or other gases coming out of solution in the reference leg would result in a large level error for a short period of time.

For PWR plants, both pressurizer level and steam generator level could be effected by reference leg boiling. Analysis of chapter 15 events and containment analysis for Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) PWR stations indicate that no reference leg boiling is expected that would effect a protection setpoint. For pressurizer level setpoints, the RCS pressure is not expected to decrease below 1400 psig during a transient that prevents reference leg boiling. The accidents that rely on steam generator low level setpoints are not expected to experience depressurization at a rate that would result in reference leg boiling.

NOTE: transients that could result in hydrogen coming out of solution in the pressurizer reference leg are not currently addressed in the setpoint analyses.

For BWR plants, the possibility of reference leg boiling and reactor vessel level errors due to dissolved gasses coming out of solution has been addressed. The RVLIS/Backfill modifications have been installed in accordance with Generic Letter 92-04, Resolution of the Issues Related to Reactor Vessel Water Level Instrumentation in BWR's Pursuant to 10CFR50.54(f). Setpoint accuracy calculations and reactor vessel level scaling calculations incorporate the effects of this modification on the associated reactor protection setpoints.

7.0 REFERENCES

- 7.1 CAE-92-189/CCE-92-201/CWE-92-214, Commonwealth Edison Company, Zion/Byron/Braidwood Stations, S/G Water Level PMA Term Inaccuracies, dated 6/18/92
- 7.2 CWE-79-26, Commonwealth Edison Company, Zion Station, NRC IE Bulletin 79-21, dated 8/29/79
- 7.3 NRC IE Bulletin 79-21, Temperature Effects on Level Measurements
- 7.4 "Delta-P Level Measurement Systems", Lang, Glenn E. and Cunnigham, James P., Instrumentation, Controls and Automation in the Power Industry, vol. 34, Proceeding of the 34th Power Instrument Symposium, June 1991
- 7.5 Generic Letter 92-04, Resolution of the Issues Related to Reactor Vessel Water Level Instrumentation in BWR's Pursuant to 10CFR50.54(f)

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APPENDIX G

**DELTA-P MEASUREMENTS
EXPRESSED IN FLOW UNITS**

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1.0 INTRODUCTION

Propagation of errors and uncertainties through a non-linear device results in output errors and uncertainties that are a function of the input value. In the case of the typical flow vs. dP relationship, an approximation can be derived for the square root/square function. This appendix provides an equation that can be used to convert between errors in % dP and errors in % full scale.

Orifices, nozzles and venturies are typically provided with their flow uncertainty expressed as a % of full scale dP. This uncertainty is the same anywhere within the measured span. As an example, an orifice that has a full span of 100 in.WC and is specified to be accurate to $\pm 1\%$ full span, will have an uncertainty of ± 1 inch of water anywhere in the measured span. Since dP is a function of flow squared, this cannot be said for errors expressed in terms of flow, % flow or % flow span. The flow error will depend on the corresponding value of flow.

2.0 DERIVATION

Since dP is proportional to flow squared:

$$(F_N)^2 = dP_N \quad (\text{Eq. G1})$$

where N = Nominal Flow

Taking the partial derivative and solving for ∂F_N :

$$\frac{2F_N \partial F_N}{\partial F_N} = \frac{\partial dP_N}{(\partial dP_N)/(2F_N)} \quad (\text{Eq. G2})$$

Similarly, the error at a point (not in %) is:

$$\frac{\partial F_N}{F_N} = \frac{\partial dP_N}{2(F_N)^2} = \frac{\partial dP_N}{2dP_N}$$

and from equation G1:
$$\frac{dP_N}{dP_{MAX}} = \frac{(F_N)^2}{(F_{MAX})^2} \quad (\text{Eq. G3})$$

where: MAX = maximum flow

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The transmitter dP error is defined by:

$$\frac{\partial dP_N}{dP_{MAX}} = \% \text{ error in full scale dP (\% FS dP)} \quad (\text{Eq. G4})$$

Therefore:

$$\begin{aligned} \frac{\partial F_N}{F_N} &= \frac{\partial dP_N}{2dP_N} = \frac{dP_{MAX} \left(\frac{\%FS \text{ dP}}{100} \right)}{2dP_{MAX} \left(\frac{F_N}{F_{MAX}} \right)^2} \\ &= \frac{\%FS \text{ dP} \left(\frac{F_{MAX}}{F_N} \right)^2}{(2)(100)} \end{aligned} \quad (\text{Eq. G5})$$

The error in flow units is obtained by solving for ∂F_N :

$$\partial F_N = \frac{F_N (\%FS \text{ dP}) \left(\frac{F_{MAX}}{F_N} \right)^2}{(2)(100)} \quad (\text{Eq. G6})$$

This can be rearranged to represent the error in % nominal flow:

$$\left(\frac{\partial F_N}{F_N} \right) \times 100 = \left(\frac{\%FS \text{ dP}}{2} \right) \left(\frac{F_{MAX}}{F_N} \right)^2 \quad (\text{Eq. G7})$$

From equation G7, the error in % full span can be derived:

$$\begin{aligned} \left(\frac{\partial F_N}{F_{MAX}} \right) \times 100 &= \frac{\left(F_N (\%FS \text{ dP}) \left(\frac{F_{MAX}}{F_N} \right)^2 \right) \times 100}{(F_{MAX})(2)(100)} \\ &= \left(\frac{\%FS \text{ dP}}{2} \right) \left(\frac{F_{MAX}}{F_N} \right) \end{aligned} \quad (\text{Eq. G8})$$

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Replacing equation G8 with variables equivalent to those typically used in accuracy analysis:

$$\text{Flow Error in \% Full Scale Flow} = \left(\frac{\text{dP Error in \% Full Scale dP}}{2} \right) \left(\frac{F_{MAX}}{F_N} \right) \quad (\text{Eq. G9})$$

NOTE: full scale is equivalent to full span

Error in % nominal flow at any flow level can be obtained in the same manner from equation G7.

$$\text{Flow Error in \% Nominal Flow} = \left(\frac{\text{dP Error in \% Full Scale dP}}{2} \right) \left(\frac{F_{MAX}}{F_N} \right)^2 \quad (\text{Eq. G10})$$

3.0 APPLICABILITY

Equations G9 and G10 are used to convert between flow error and dP error. These equations are an approximation and assume that any sufficiently small portion of a curve can be replaced with a straight line. These equations show that the slope of a line segment at any point on a square root curve is: $F_{MAX} / 2F_N$. For a square root curve, this approximation provides a conservative estimate of error. Equation 9 is particularly useful when calculating instrument loop accuracy where all errors are converted to % of "full" span for consistency.

Caution should be used when using equations G9 and G10 to determine flow channel setpoints. It is important to differentiate between "full flow" and "full span". For example, full span is typically 110% to 120% of full flow to ensure that the transmitter output signal is not limited at full flow. Equation G9 is used when 100% span error is desired and the error term is to be expressed in % full span. Equation G10 is used when the equivalent error at any other flow value, e.g. 100% flow, is desired.

4.0 EXAMPLES

4.1 EXAMPLE 1: Full Flow vs. Full Span Error

The following flow loop parameters are assumed for this example.

- Full Scale Flow = 20% flow
- Nominal flow = 100% flow
- dP span = 0-500 in. WC
- Error = ±1% span
- Transmitter scaling: 0-500 in WC is equivalent to 4-20 mA

NOTE: typical orifice and nozzle span errors are provided as an error in dP span which is constant over the entire dP span.

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4.1.1 Find the error in % flow at 100% flow

From section 4.1:

$$F_{MAX} = 120\%$$

$$F_N = 100\%$$

$$\text{error in \% full scale dP} = 1\% \text{ dP span}$$

Use equation G10 for nominal flow error determination.

$$\begin{aligned} \text{Error}_{\% \text{ Nominal Flow}} &= \left(\frac{\text{dP Error in \% Full Scale dP}}{2} \right) \left(\frac{F_{MAX}}{F_N} \right)^2 \\ &= \left(\frac{1\%}{2} \right) \left(\frac{120}{100} \right)^2 \\ &= \pm 0.72\% \text{ flow at 100\% flow} \end{aligned}$$

4.1.2 Find the error at full span (120% flow).

$$F_{MAX} = 120\%$$

$$F_N = 100\%$$

$$\text{error in \% full scale dP} = \pm 1\% \text{ dP span}$$

Use equation G9 for full span error determination.

$$\begin{aligned} \text{Error}_{\% \text{ Full Scale Flow}} &= \left(\frac{\text{dP Error in \% Full Scale dP}}{2} \right) \left(\frac{F_{MAX}}{F_N} \right) \\ &= \left(\frac{1\%}{2} \right) \left(\frac{120}{100} \right) \\ &= \pm 0.6\% \text{ flow span} \end{aligned}$$

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4.2 EXAMPLE 2: Calculation of flow error using dP

The following flow loop parameters are assumed for this example.

Full span	=	120% flow
Nominal flow	=	100% flow
dP span	=	0-500 in. WC
Error	=	±1% span
Transmitter scaling:		0-500 in WC is equivalent to 4-20 mA

NOTE: typical orifice and nozzle span errors are provided as an error in dP span which is constant over the entire dP span.

4.2.1 Find the error in % flow at 100% flow

$$\text{Flow}^2 \propto \text{dP}$$

$$\frac{(\text{Flow}_{\text{MAX}} \%)^2}{\text{dP}_{\text{MAX}}} = \frac{(\text{Flow}_{\text{N}} \%)^2}{\text{dP}_{\text{N}}}$$

$$\frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(100\%)^2}{\text{dP}_{\text{N}}}$$

$$\text{dP}_{\text{N}} = 347.22 \text{ in. WC}$$

The dP error is 1% of 500 in. WC = ±5 in. WC. Therefore, at full flow (equivalent to nominal or 100% flow) the dP should be 347.22±5 in. WC. Calculating the flow error:

$$\text{Hi flow: } \frac{(\text{Flow}_{\text{MAX}} \%)^2}{\text{dP}_{\text{MAX}}} = \frac{(\text{Flow}_{\text{N}} \%)^2}{\text{dP}_{\text{N}} \pm 5 \text{ in. WC}}$$

$$\frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(\text{Flow}_{\text{N}} \%)^2}{352.22 \text{ in. WC}}$$

$$\text{Flow}_{\text{N}^+} = 100.72 \text{ \% flow}$$

$$\text{Low flow: } \frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(\text{Flow}_{\text{N}} \%)^2}{342.22 \text{ in. WC}}$$

$$\text{Flow}_{\text{N}^-} = 99.28 \text{ \% flow}$$

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Therefore the flow error is $\pm 0.72\%$ flow at full flow. This is consistent (to 2 decimal places) with the error calculated using the approximation formula in step 4.1.1.

4.2.2 Find the error in % full span at 100% flow

When using % full span to combine errors, the error at 100% flow must also be expressed in terms of % full span.

$$\begin{aligned} \text{Full flow} &= (100\% \text{ flow})(100\% \text{ span} / 120\% \text{ flow}) \\ &= 83.33\% \text{ of full span} \end{aligned}$$

From 4.2.1, the flow error is $\pm 0.72\%$ flow at full flow, which is equivalent to $100 \pm 0.72\%$ flow. Converting this to % of span:

$$(100 + 0.72)(100\% \text{ span} / 120\% \text{ flow}) = 83.93\% \text{ full span}$$

$$(100 - 0.72)(100\% \text{ span} / 120\% \text{ flow}) = 82.73\% \text{ full span}$$

The deviation from full flow as a % of span is: $83.93\% \text{ span} - 83.33\% \text{ span} = 0.6\% \text{ span}$ and $83.33\% \text{ span} - 82.73\% \text{ span} = 0.6\% \text{ span}$. Therefore, the nominal or 100% flow in terms of % full span is equivalent to $83.33 \pm 0.6\%$ full span, which is consistent with step 4.1.2.

4.3 FLOW ERROR AT LOW FLOWS

As shown in step 4.2, the approximation and the actual flow errors are expected to be relatively close when the nominal flow is close to full flow. Since errors as a % of span increase as flow decreases, the approximation becomes increasingly conservative at lower flows. Therefore, at low flows or when the exact flow error is desired, the dP method should be used to calculate flow error.

4.4 EXAMPLE 3: Error at Low flows

The flow error associated with a low flow trip at 30% flow is required. Using the same values in steps 4.1 and 4.2:

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Approximation:

$$\begin{aligned} \text{Error}_{\% \text{ Nominal Flow}} &= \left(\frac{\text{dP Error in \% Full Scale dP}}{2} \right) \left(\frac{F_{\text{MAX}}}{F_N} \right)^2 \\ &= \left(\frac{1\%}{2} \right) \left(\frac{120}{30} \right)^2 \\ &= \pm 8.0\% \text{ flow at } 30\% \text{ flow} \end{aligned}$$

$$\begin{aligned} \text{Error}_{\% \text{ Full Scale Flow}} &= \left(\frac{\text{dP Error in \% Full Scale dP}}{2} \right) \left(\frac{F_{\text{MAX}}}{F_N} \right) \\ &= \left(\frac{1\%}{2} \right) \left(\frac{120}{30} \right) \\ &= \pm 2.0\% \text{ flow span} \end{aligned}$$

Actual error:

$$\begin{aligned} \text{Flow}^2 &\propto \text{dP} \\ \frac{(\text{Flow}_{\text{MAX}} \%)^2}{\text{dP}_{\text{MAX}}} &= \frac{(\text{Flow}_N \%)^2}{\text{dP}_N} \\ \frac{(120\%)^2}{500 \text{ in. WC}} &= \frac{(30\%)^2}{\text{dP}_N} \\ \text{dP}_N &= 31.25 \text{ in. WC} \end{aligned}$$

Using a 1% span error = ± 5 in. WC:

$$\begin{aligned} \frac{(\text{Flow}_{\text{MAX}} \%)^2}{\text{dP}_{\text{MAX}}} &= \frac{(\text{Flow}_N \%)^2}{\text{dP}_N} \\ \text{Hi flow: } \frac{(120\%)^2}{500 \text{ in. WC}} &= \frac{(\text{Flow}_N \%)^2}{36.25 \text{ in. WC}} \\ \text{Flow}_{N^*} &= 32.31 \% \text{ flow} \end{aligned}$$

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$$\text{Low flow: } \frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(\text{Flow}_N \%)^2}{26.25 \text{ in. WC}}$$

$$\text{Flow}_N = 27.50 \% \text{ flow}$$

For a low flow trip setpoint, we use the error in the conservative, decreasing direction. Therefore 30.0% flow – 27.50% flow = 2.5% flow. This is considered a random error or ±2.50% flow when used in a loop accuracy calculation.

NOTE: when considering accuracy requirements, it is good engineering practice to ensure flow setpoints are never less than 25% span.

In example 3, the 30% flow setpoint is equivalent to 25% flow span. The equivalent error in % span is:

$$(30 + 2.50)(100\% \text{ span} / 120\% \text{ flow}) = 27.08\% \text{ flow span}$$

$$(30 - 2.50)(100\% \text{ span} / 120\% \text{ flow}) = 22.92\% \text{ flow span}$$

The conservative error for a decreasing setpoint is:

$$25\% \text{ span} - 22.92\% \text{ span} = \pm 2.08\% \text{ flow span.}$$

Step 4.4 shows that when errors are calculated as a “% of flow span”, the approximate and actual errors (±2.0% flow span vs. ±2.08% flow span) are relatively close even at the minimum recommended flow setpoint. The flow error as a “% flow” indicates that the approximation is conservative (±8% flow vs. ±2.5% flow). Care should be taken to ensure that the method chosen to determine flow error is sufficiently conservative with respect to the function of the flow setpoint.

CAUTION: When it is necessary to evaluate performance in terms of % flow (or gpm or mpph, etc), as in Technical Specification acceptance criteria or ISI test criteria, the use of the approximation method to calculate flow error may be excessively conservative with respect to the real accuracy of the measurement. Using the approximation to calculate flow error could result in overly conservative performance or test requirement. The result being a component, e.g. a pump, considered inoperable due to conservative acceptance criteria rather than excessively degraded performance.

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**APPENDIX H
CALCULATION OF EQUIVALENT POINTS
ON NON-LINEAR SCALES**

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1.0 INTRODUCTION

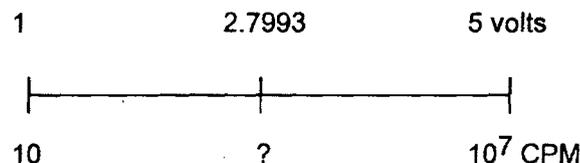
Conversion of linear information to equivalent non-linear data points can be performed using ratios. This technique can be used for all non-linear continuous functions; e.g. square root, logarithmic, etc.

For logarithmic scales, those of you who remember slide rules will quickly recognize the technique of ratioing distances. This method can be easily extended to any two scales that are equivalent. Typical instrument setpoint accuracy and instrument scaling examples include: mA to GPM, volts to source range counts, mA to DPM (decades per minute), etc. Equivalent scales are any two ranges that have a 1:1 analog relationship.

2.0 SCALE CONVERSION

The following discussion uses a logarithmic indicator scale as an example. The indicator has a 1 to 5 volt input and a 10 to 10^7 CPM scale.

First, the equivalent ranges are 1 to 5 volts and 10 to 10^7 CPM. The graphical representation below can often aid in visualizing this concept.



Next, determine the equivalent CPM to 2.7993 volts using the technique of ratios. From the above graphic, it is obvious the distances represented on the linear and logarithmic scales are identical. Most of us are familiar with analog ratios, where the ratio $(2.7993 \text{ to } 1) / (5 \text{ to } 1)$ will give us the voltage ratio. For the logarithmic ratio, one must recognize that the equivalent distances are logarithms. We use this fact to write an equation for the unknown CPM:

An alternate method to solve for log x:

$$\left(\frac{2.7993 \text{ volts} - 1 \text{ volt}}{5 \text{ volts} - 1 \text{ volt}} \right) = \left(\frac{\log x - \log 10}{\log 10^7 - \log 10} \right)$$

$$\left(\frac{1.7993 \text{ volts}}{4 \text{ volts}} \right) = \left(\frac{\log x - 1}{7 - 1} \right)$$

$$\log x = 3.69895$$

$$x = 4999.77 \approx 5000 \text{ CPM}$$

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$$\log x = 3.69895$$

$$x = 10^{3.69895} = 10^{0.69895} \times 10^3$$

$$= 4.998 \times 10^3 \approx 5000 \text{ CPM}$$

For this discussion, assume that the linear uncertainty is 2% of span. This is equivalent to:

$$2.7993 \text{ volts} \pm (2\%(5 \text{ volts} - 1 \text{ volt})) = 2.7993 \pm 0.08 \text{ volts}$$

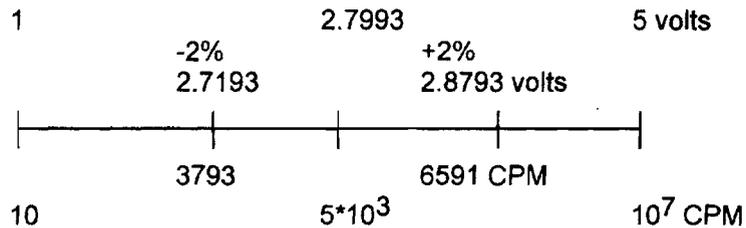
Using the ratioing technique, it becomes a simple matter to find the equivalent CPM values for 2.8793 volts and 2.7919 volts. The $\pm 2\%$ tolerance equations are provided below, followed by the completed graphic.

$$\left(\frac{2.7993 \text{ volts} - 0.8 \text{ volts}}{5 \text{ volts} - 1 \text{ volt}} \right) = \left(\frac{\log x - \log 10}{\log 10^7 - \log 10} \right)$$

$$\left(\frac{1.8793 \text{ volts}}{4 \text{ volts}} \right) = \left(\frac{\log x - 1}{7 - 1} \right)$$

$$\log x = 3.81895$$

$$x = 6590.98 \approx 6591 \text{ CPM}$$



Thus, for a linear input of 1 to 5 volts with an error of $\pm 2\%$ of span, the equivalent uncertainty range at 5000 CPM is 3793 to 6591 CPM. As with all non-linear relationships, it is important to note that the uncertainty range is dependent on the point on the non-linear scale around which the uncertainty is calculated. In other words the +1591, -1207 CPM uncertainty range is only valid at 5000 CPM.

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3.0 EXAMPLES

The following examples demonstrate some of the typical problems that can quickly be solved using this technique. A graphical representation is used to visualize the problem. One advantage of quickly sketching the problem is that incorrect relationships can be easily identified.

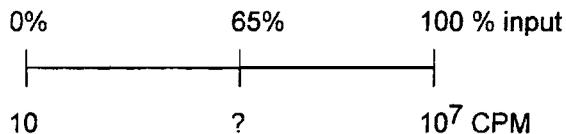
3.1 EXAMPLE 1

For an input range of 1 to 5 volts (0 to 100% span) and an output range of 10 to 10^7 CPM, find the setpoint in CPM at 65% input span. NOTE: Since 0 to 100% span is linear, there is no need to convert anything to volts.

$$\left(\frac{65\% - 0\%}{100\% - 0\%} \right) = \left(\frac{\log x - \log 10}{\log 10^7 - \log 10} \right)$$

$$(0.65(7 - 1)) + 1 = \log x$$

$$x = 79,432 \approx 7.9 \times 10^4 \text{ CPM}$$



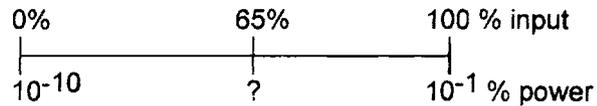
3.2 EXAMPLE 2

For an input range of 1 to 5 volts (0 - 100% span) and an output range of 10^{-10} to 10^{-1} % power, find the setpoint (in percent power) at 3.6 volts. This example is typical of nuclear instrumentation where the source and intermediate range need to be displayed in percent power.

First, calculate % power, so that we don't have to do any conversion in our ratio equation.

$$\left(\frac{3.6 - 1 \text{ volt}}{5 - 1 \text{ volt}} \right) \times 100\% \text{ span} \times \left(\frac{100\% \text{ power}}{100\% \text{ span}} \right) = 65\% \text{ power}$$

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$$\left(\frac{65\% - 0\%}{100\% - 0\%} \right) = \left(\frac{\log x - \log 10^{-10}}{\log 10^{-1} - \log 10^{-10}} \right)$$

$$0.65 = \left(\frac{\log x + 10}{-1 + 10} \right)$$

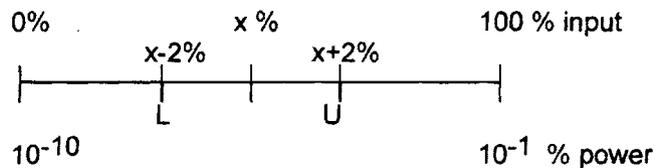
$$\log x = -4.15$$

$$x = 10^{-4.15} = 10^{0.85} \times 10^{-5}$$

$$= 7.08 \times 10^{-5} \% \text{ power}$$

3.3 EXAMPLE 3

Using the ranges in Example 2, find the $\pm 2\%$ of span tolerance for a setpoint of 7×10^{-5} % power, where 2% of span represents the input error. NOTE: Once again there is no need to convert to other input units.



First find the equivalent setpoint:

$$\left(\frac{\log(7 \times 10^{-5}) - \log 10^{-10}}{\log 10^{-1} - \log 10^{-10}} \right) = \left(\frac{x - 0\%}{100\% - 0\%} \right)$$

$$\left(\frac{-4.154902 + 10}{-1 + 10} \right) = \left(\frac{x - 0\%}{100\% - 0\%} \right)$$

$$x = 64.94553\% \text{ input span}$$

Use the following ratio to solve for the upper limit (U).

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$$\left(\frac{(64.94553 + 2) - 0\%}{100\% - 0\%} \right) = \left(\frac{\log U - \log 10^{-10}}{\log 10^{-1} - \log 10^{-10}} \right)$$

$$0.6694533 = \left(\frac{\log U + 10}{9} \right)$$

$$U = 10^{-3.974902} = 1.06 \times 10^{-4} \% \text{ power}$$

Solve for the lower limit (L).

$$U = 10^{-3.974902} = 1.06 \times 10^{-4} \% \text{ power}$$

As expected, non-linear scales result in non-symmetrical upper and lower values for an equivalent symmetrical input error. When evaluating the accuracy of a single point (e.g. bistable setpoint or EOP required actuation point), you can use the limit associated with the direction of the process change. Thus an increasing setpoint would use U and a decreasing setpoint would use L for calculating accuracy.

When calculating accuracy for a point on an indicator scale, the accuracy values are used in 2 different ways. When calibrating the indicator the calibration limits can use the specific L and U values for each cardinal point. When providing accuracy values to a plant operator or other individual that is using the indicator to monitor a plant process condition, it is usually inconvenient to list asymmetric limits. In this case it is conservative to describe accuracy as $\pm U$ or $\pm L$, whichever is larger.

In order to use the ratio technique for other non-linear functions, compare (ratio) the equivalent scalar distances of each range. Thus with square root/square relationships, such as flow (GPM, CFM, etc.) or percent of flow, the ratio is obtained by taking the square root or square of the corresponding linear value.

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APPENDIX I
NEGLIGIBLE UNCERTAINTIES

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1.0 INTRODUCTION

The errors and uncertainties listed in this appendix have historically been found to be negligible under normal operating conditions. If the individual preparing an instrument loop accuracy calculation determines that the specific conditions apply, then these errors and uncertainties do not have to be evaluated in the calculation.

2.0 NEGLIGIBLE UNCERTAINTIES**2.1 Radiation Effects**

The effects of normal radiation are small and accounted for in the periodic calibration process. Outside of containment there is not a creditable increase in radiation during normal operation. The uncertainty introduced by radiation effects on components is considered to be negligible.

If an as-found/as-left analysis has been performed based on historical calibration data, then normal radiation effects are considered to be included in the drift analysis results.

2.2 Humidity Effects

The uncertainty introduced by humidity effects during normal conditions is not typically addressed in vendor literature. Therefore humidity effects are considered to be negligible unless the manufacturer specifically mentions humidity effects in the applicable technical manual. The effects of changes in humidity on the components are considered to be calibrated out on a periodic basis. A condensing environment is regarded as an abnormal event that will require maintenance to the equipment. Humidity's below 10% are expected to occur very infrequently and are not considered.

If an as-found/as-left analysis has been performed based on historical calibration data, the humidity effect is assumed to be included in the drift analysis results.

2.3 Power Supply Effects

It is expected that regulated instrument power supplies have been designed to function within manufacturer's required voltage limits. The variations of voltage and frequency are expected to be small and the power supply voltage and frequency uncertainties are considered to be negligible with respect to other error terms.

If an as-found/as-left analysis has been performed based on historical calibration data, the power supply voltage and frequency effects are assumed to be included in the drift analysis results.

2.4 Calibration Standard Error (STD)

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The calibration standards used by the station to maintain and calibrate station M&TE are expected to be maintained to manufacturer's specifications. These calibration standards are more accurate than the station M&TE by a ratio greater than 4:1. Therefore, the effects of the calibration standard error are considered to be negligible with respect to other error terms.

2.5 Seismic/Vibration Effects

The impact of Seismic Effects in the setpoint calculation should be consistent with the Licensing Design Basis of the specific station (e.g. assuming a design Seismic Event coincident with a Design Basis Accident).

For normal errors, seismic events less than or equal to an OBE are considered to cause no permanent shift in the input/output relationship of the device. For seismic events greater than an OBE, it should be verified that the affected instrumentation is recalibrated prior to any subsequent accident to negate any permanent shift, which may result from a post seismic shift.

Unlike Seismic effects, Vibration effects may not always be calibrated out or included in the statistical drift. Consideration must be made of the "normal operating" versus "calibration" conditions. If the relative vibration conditions of these two states are not the same, then the vibration effect must be considered. This effect is not calibrated out or included in the historical calibrations data.

If an as-found/as-left analysis has been performed based on historical calibration data, the vibration effect is considered to be included in the drift analysis results, if the normal operation conditions and the calibration conditions are similar.

2.6 Lead Wire Effects

Since the resistance of a wire is equal to the resistivity times the length divided by the cross sectional area, the very small differences in the length of wires between components does not contribute any significant resistance differences between wires. Therefore, the effect of lead wire resistance differences is considered negligible, except for RTD's and thermocouples.

If a system design requires that lead wire effects be considered as a component of uncertainty, that requirement must be included in the design basis. It is assumed that the general design standard is to eliminate lead wire effects as a concern in both equipment design and installation. Failure to do so is a design fault that should be corrected.

The lead wire effects for RTD's and thermocouples must be considered separately and must be evaluated for each specific application.

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3.0 NEGLIGIBLE UNCERTAINTIES FOR RELAYS, TIMERS, LIMIT AND MECHANICAL DISPLACER-TYPE SWITCHES

3.1 Relays and Timers

Table II, Negligible Errors and Uncertainties for Relays and Timers

Error Type	Symbol	Justification
Process Errors	PE	These particular devices are not in direct contact with the process and are not subject to these types of errors or uncertainties.
Density Error		
Process Error		
Flow Element Error		
Temperature Error	eT	
Thermal Expansion Error		
Configuration or Installation Error		
Operational Errors		
Drift Error	D	Unless specifically prescribed by the Vendor, drift is assumed to be accounted for in the published Reference Accuracy for the device.
Static Pressure Error	eSP	These particular devices are not in direct contact with the process and are not subject to these types of errors or uncertainties.
Pressure Error	eP	There are no Pressure Errors associated with the function of these devices as the ambient pressure at the device location remains constant at normal atmospheric pressure.
Power Supply Error	eV	There are no Power Supply Errors associated with the function of these particular devices.
Environmental Errors		Unless specifically prescribed by the Vendor, environmental errors are assumed to be accounted for in the published Reference Accuracy for the device. Additionally, as these types of devices are typically installed in controlled environments and expected to perform their functions under normal operating conditions, the effects of these errors is considered negligible.
Temperature Error	eT	
Humidity Error	eH	
Seismic Error	eS	
Radiation Error	eR	
Other Errors		
Insulation Resistance	eIR	There are no Insulation Resistance Errors associated with the function of these particular devices
Random Input Errors		These devices function as separate modules and have no random input errors.

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3.2 Limit Switches

Table I2, Negligible Errors and Uncertainties for Limit Switches

Error Type	Symbol	Justification
Process Errors	PE	These particular devices are not in direct contact with the process and are not subject to these types of errors or uncertainties.
Density Error		
Process Error		
Flow Element Error		
Temperature Error	eT	
Thermal Expansion Error		
Configuration or Installation Error		
Operational Errors		
Drift Error	D	Unless specifically prescribed by the Vendor, drift is not applicable for these type of devices.
Static Pressure Error	eSP	These particular devices are not in direct contact with the process and are not subject to these types of errors or uncertainties.
Pressure Error	eP	There are no Pressure Errors associated with the function of these devices as the ambient pressure at the device location remains constant at normal atmospheric pressure.
Power Supply Error	eV	There are no Power Supply Errors associated with the function of these particular devices.
Environmental Errors		Unless specifically prescribed by the Vendor, environmental errors are assumed to be accounted for in the published Reference Accuracy for the device.
Temperature Error	eT	
Humidity Error	eH	
Seismic Error	eS	
Radiation Error	eR	
Other Errors		
Insulation Resistance	eIR	There are no Insulation Resistance Errors associated with the function of these particular devices
Random Input Errors		These devices function as separate modules and have no random input errors.

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3.3 Mechanical Displacer-Type Switches (Float Switches)

Table I3, Negligible Errors and Uncertainties for Mechanical Displacer-Type Switches		
Error Type	Symbol	Justification
Operational Errors		
Drift Error	D	Unless specifically prescribed by the Vendor, drift is not applicable for these type of devices.
Pressure Error	eP	There are no Pressure Errors associated with the function of these devices as the ambient pressure at the device location remains constant at normal atmospheric pressure.
Power Supply Error	eV	There are no Power Supply Errors associated with the function of these particular devices.
Environmental Errors		
Temperature Error	eT	Unless specifically prescribed by the Vendor, environmental errors are assumed to be accounted for in the published Reference Accuracy for the device.
Humidity Error	eH	
Seismic Error	eS	
Radiation Error	eR	
Other Errors		
Insulation Resistance	eIR	There are no Insulation Resistance Errors associated with the function of these particular devices
Random Input Errors		These devices function as separate modules and have no random input errors.

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APPENDIX J
GUIDELINE FOR THE ANALYSIS AND USE OF
AS-FOUND/AS-LEFT DATA

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1.0 INTRODUCTION

The analysis of the data from calibration of installed instrumentation can provide the station with several pieces of information that will allow for better prediction of instrument behavior and will provide more “accurate” data for computation of loop uncertainties.

This attachment defines a process that will be used at Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) to ensure consistency and compliance with regulatory position GL-91-04. This process will specify certain requirements, but does not provide a step-by-step methodology. Each site should develop specific methodologies, utilizing these guidelines to support their specific needs.

There are several approaches to the analysis of data and its subsequent use. Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) has adopted a general methodology similar to that presented in EPRI TR-103335, *Guidelines for Instrument Calibration Extension/Reduction Programs, Revision 1*. Refer to this document for a complete understanding of the guidelines developed in this Appendix.

This Appendix is divided into the following sections:

- 2.1 DATA COLLECTION AND POOLING
- 2.2 INITIAL ANALYSIS PROCESS
- 2.3 OUTLIER AND POOLING VERIFICATION REQUIREMENTS
- 2.4 NORMALITY
- 2.5 TIME DEPENDENCE
- 2.6 RESULTS
- 2.7 USING RESULTS
- 2.8 CONTINUING EVALUATION

Each of these sections contains a general discussion of the expected actions that will conform to TR-103335 and the guidelines to be followed for analysis at Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) sites.

2.0 ANALYSIS METHODOLOGY

2.1 DATA COLLECTION AND POOLING

2.1.1 To evaluate the performance of an instrument or group of instruments the data that is collected should consist of a sufficient number of independent samples to allow for statistical analysis of the data that could indicate drift changes. The sample should also represent a good distribution of the instruments used. In most cases, this will be the whole population. For instruments that are used extensively in the plant, a sample can be used. When collecting data, the application of each instrument must be identified to avoid application specific errors that will cause pooling of data to be an incorrect decision. Because the evaluation includes the important element of time dependency determination, the data collected should have data from different calibration intervals. If data is not from different calibration periods then the evaluation should be reviewed and/or revised when additional calibrations

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are available. The evaluation must include all of the times that the instrument has been calibrated, or checked for accuracy (i.e. surveillance testing without adjustment).

2.1.2 Selection of the Instruments to be Evaluated (Pooled) for a Given Drift Study

2.1.2.1 All instruments evaluated shall be from the same manufacturer and shall perform in an identical manner for the critical parameters that are to be analyzed. Determining which instruments meet this criterion is eschewed by the fact that many manufacturers' have different model numbers based on mounting, enclosure, etc. The differences typically have no effect on the method that the instrument uses to monitor the parameter of concern. In addition, the range of the instrument may vary without having any significant change in the measurement method. If multiple model numbers are used, the evaluations must include a discussion of the reason why the instruments are assumed identical, specifically in the critical areas of concern.

2.1.2.2 Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) has specified that the minimum targeted number of valid data points that are required to make a drift study statistically significant shall be 30 data points. The sample value of 30 is generally accepted as a minimum valid sample size. An analysis using less than this number can be performed if justification is provided in the study results. If the analysis is performed with less than thirty data points the results of the analysis should be verified after a sufficient number of points are available (>30). In most circumstances, this number should be > 30 data points. If there are more than approximately 150 data points, there is no significant improvement in the statistical rigor of the analysis.

2.1.2.3 In order to obtain the necessary number of data points required to ensure that there is variance in the calibration interval for the make/model of concern, the calibration data from multiple instruments will be needed. The following criteria for the selection of which instruments and calibration data points shall be used:

- a. All instruments that are directly associated with RPS/ESF/ECCS automatic trips and actuations shall include at least one channel's instruments.
- b. To ensure that there is a historical perspective to the data evaluated, at least four calibration intervals of data shall be collected. The four intervals provide for historical data while ensuring that the more recent calibration data is used to detect current problems. If the instrument has not been installed for that period, then the available data will be used. There may be some problems in the evaluation of the instrument over a given calibration interval.
- c. If more than 150 data points can be developed for a given analysis, then a sample of instruments can be used instead of the whole population. The selection of which instruments to include will be done on a random basis, provided Section 2.1.2.3.a requirements are maintained. The method of selection will be prepared and included in the calculation.

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2.1.3 Data Collection is the transfer of data from the calibration records to the final analysis tool. This very sensitive process will require independent verification and validation of data transferred.

2.1.3.1 A search of all preventive and corrective maintenance records shall be conducted on each instrument selected for inclusion in the study. This search shall identify every calibration and every corrective maintenance activity for the period of concern for the study. The search should go back at least four calibration intervals (i.e. at least five sets of calibration data). If there are less than eight instruments included in the study then additional historical data will need to be collected to achieve the minimum number of data points specified by Section 2.1.2.2.

The data collected should ensure that the results are not from overlapping calibration intervals.

2.1.3.2 The data from the calibrations will be entered into a spreadsheet or data base program using a format similar to Figure J1. For instruments that have multiple calibration points (transmitters, function generators, etc.) each calibration point will be entered in the spreadsheet using the percent of span as the column title. If there are discrepancies in the exact percent of span then calibration points that are within 5% of each other can be used together (e.g. 0% FS, 1% FS and 5% FS can be considered the same calibration point).

For switches, relays or other equipment where there is a single point that is calibrated the data can be entered in percent of instrument span or in process units.

Due to the diversity of software that can be used to compute this spreadsheet statistics, there may be some variation in format. The specific project or calculation shall identify the software used and justify that the data entry is in agreement with the intent of Section 4.0 of TR-103335.

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Initial Data Analysis									
Date Mo.	Yr.	Data Status	Interval Months	Tag Number	Calibration Data (mA)				
					0%	25%	50%	75%	100%
5	93	As- Found	12	LT-459	4.00	8.00	11.94	15.96	20.01
		As-Left		LT-459	4.00	8.00	11.94	15.96	20.01
5	92	As- Found	14	LT-459	4.20	8.04	12.05	16.05	20.04
		As-Left		LT-459	4.00	8.00	11.98	15.98	20.00
3	91	As- Found	11	LT-459	4.09	8.04	12.02	16.05	20.04
		As-Left		LT-459	4.09	8.04	12.02	16.05	20.04
4	90	As- Found	10	LT-459	4.06	7.92	11.95	15.98	19.95
		As-Left		LT-459	4.06	7.92	11.95	15.98	19.95
6	89	As- Found	13	LT-459	4.00	8.00	12.02	16.07	20.02
		As-Left		LT-459	4.00	8.00	12.02	16.07	20.02
5	88	As- Found	12	LT-459	4.24	8.20	12.16	16.12	20.15
		As-Left		LT-459	4.00	7.97	11.98	15.98	20.00
5	87	As- Found		LT-459	NEW	NEW	NEW	NEW	NEW
		As-Left		LT-459	4.02	7.99	11.99	16.07	20.01

Figure J1, Example Spreadsheet Data Entry

The following information is particularly valuable for the analysis:

- The date of calibration is documented. The time interval since the previous calibration is calculated in months in the *Interval* column. Depending on the data, the time interval might be calculated in days, weeks, or months.
- The as-found and as-left data are entered into the spreadsheet exactly as recorded on the instrument data sheet. The values are in milliamperes (in this case) corresponding to a range of 0% to 100% of calibrated span.
- Note that all calibration data points have been recorded. In general, it is preferable to consider and evaluate all available data. By this approach, a better understanding of instrument drift can be obtained.

For calibrations that check calibration points during ascending and descending calibration, the ascending and descending point will be kept separately for the initial evaluation.

2.1.3.3 All Data transfer will require 100% independent verification.

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2.1.3.4 Due to legibility problems, even if it is obvious that the data recorded in original records is incorrect, verbatim transcription of the data is required. If the information cannot be determined from the original record (due to legibility problems) then the data point will be left blank. Record of this omission shall be included in the analysis.

2.1.3.5 In addition to the calibration point as-found and as-left values, the calibrated span of the instrument, date of the calibration and any significant calibration anomalies are to be recorded in the spreadsheet.

2.2 INITIAL ANALYSIS PROCESS

2.2.1 From the original data, certain manipulations may be required to get the data in a form that can be evaluated across various instruments.

2.2.1.1 If the instrument loop is not a linear loop and the data has not been converted, then the raw calibration data should be converted to Linear Equivalent Full Scale (LEFS) to ensure that drift information is not masked.

2.2.1.2 If the instrument has a known span, the data should be normally converted into percent of calibrated span by dividing the raw data by the span.

If the instrument does not have a known span, the data should be left in process units or converted to percent of the setpoint.

2.2.1.3 For each calibration interval where there is an as-left value from the older calibration and an as-found value from the younger calibration, a raw drift value should be determined by subtracting the as-left value from the as-found value. The calibration interval, in days, should also be determined.

2.2.2 Once the data is in the correct format, the number of data points, the average and the sample standard deviation should be determined for each column, (reference Section 4.0 of TR-103335).

Due to the diversity of software that can be used to compute this spreadsheet statistics, there may be some variation in format. The specific project or calculation should identify the software used and justify that the data entry is in agreement with this Standard.

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2.3. OUTLIER AND POOLING VERIFICATION REQUIREMENTS

2.3.1 After the initial computation of the average and the sample standard deviation, identification of any potential outliers and the cause of these outliers will provide important information as to the behavior of the data that was evaluated.

2.3.1.1 Using a T-Test, A statistical check of the raw data against the average and the sample standard deviation shall be conducted.

Outlier Detection by the Critical values for T-Test

ASTM Standard E 178-80 provides several methods for determining the presence of outliers. The recommended method for detection of an outlier is by the T-Test. This test compares an individual measurement to the sample statistics and calculates a parameter, T, known as the extreme studentized deviate as follows:

$$T = \frac{|x_i - \bar{x}|}{s}$$

Where,

T - Calculated value of extreme studentized deviate that is compared to the critical value of T for the sample size

\bar{x} - Sample mean

x_i - Individual data point

s - Sample standard deviation

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If the calculated value of T exceeds the critical value for the sample size and desired significance level, then the evaluated data point is identified as an outlier. The critical values of T for the upper 1%, 2.5%, and 5% levels are shown in Table J1.

Outlier Analysis			
Sample Size	Upper 5 % Significance Level	Upper 2.5% Significance Level	Upper 1% Significant Level
10	2.18	2.29	2.41
20	2.56	2.71	2.88
30	2.75	2.91	3.10
40	2.87	3.04	3.24
50	2.96	3.13	3.34
75	3.10	3.28	3.50
100	3.21	3.38	3.60
125	3.28	3.46	3.68
~150	3.33	3.51	3.73

Table J1, Critical Values for T

Note that the critical value of T increases as the sample size increases. The significance of this is that as the sample size grows, it is more likely that the sample is truly representative of the population. In this case, it is less likely that an extreme observation is truly an outlier. Thus, the T-Test makes it progressively more difficult to identify a point as an outlier as the sample size grows larger. This intuitively makes sense. As the sample size approaches infinity, there should be no outliers since all the data truly is a part of the total population. For this reason, it is relatively easy to identify a larger than average data point as an outlier if the sample size is small; however, it is (and should be) harder to call a given data point an outlier if the sample size is large.

Table J1 provides outlier criteria up to a sample of 150 data points. Beyond this size, it should be even more difficult to declare an observation as an outlier. For greater than 150 data points, an outlier factor of 4 (or 4 standard deviations) is recommended in order to assure that outliers are not easily rejected from the sample.

The T-Test inherently assumes that the data is normally distributed. The significance levels in Table J1 represent the probability that a data point will be chance exceed the stated critical value. Referring to Table J1 for a sample size of 40, we would expect to have a calculated value of T greater than 2.87 about 5% of the time and a calculated value of T greater than 3.24 about 1% of the time. For safety-related calculations, testing outliers at the 2.5% significance level is required. Refer to ASTM Standard E 178-80 for further information regarding the interpretation of the T-Test.

Example, Instrument Draft Sample

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Consider the 20 instrument drift data points shown in Table J2. The data appears to be within a $\pm 2.5\%$ range with the exception of a single large data point, 5.20%. Would the T-Test identify this point as an outlier?

Instrument Drift Sample Data	
0.47%	5.20%
-0.27%	0.21%
0.03%	-0.12%
-0.28%	0.42%
0.60%	0.69%
-0.30%	-0.78%
-0.82%	0.30%
-0.28%	-0.08%
0.27%	0.03%
0.00%	-0.45%

Table J2, Instrument Draft Sample Data

The T-Test method requires the calculation of the sample mean and standard deviation before the calculated value of T can be obtained. For the above data, the sample mean and standard deviation are:

Sample mean: 0.23%
 Sample Standard deviation: 1.24%

Now, evaluate the 5.20% data point to determine if it might be an outlier. The calculation of T is as follows:

$$T = \frac{|5.20 - 0.23|}{1.24} = 4.01$$

As shown, the calculated value of T is 4.01. Compare this result to the critical values of T for this sample size is 2.56 at the 5% significant level and 2.88 at the 1% significant level (see Table J1). In either case, the calculated value of T exceeds the critical value of T and the 5.20% data point is identified as an outlier.

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If the 5.205 data point is rejected from the sample, the sample statistics would be recomputed for the 19 remaining data points with the following results:

Sample mean: -0.03%
 Sample standard deviation: 0.42%

Notice that the single outlying observation was the only reason for an apparent bias of 0.23%. The standard deviation was reduced by approximately 65% (from 1.24% to 0.42%) by elimination of this single extreme value.

2.3.1.2 For any raw drift value that exceeds the critical T-Test, an evaluation shall be performed to determine if the data point should be excluded from the final data set. In no case can more than 5% of the original data be removed. Removal of outliers from the data set should be minimized as the process is to predict actual instrument performance. Since the data is all that we have to depict that performance, whether we like it or not, we need to accept the data unless underlying information can be inferred. The outlier process cannot be repeated after an outlier or outliers have been removed within the constraints of this section.

2.3.1.3 Identification of a potential outlier in Section 2.3.1.2 does not mean that the value will be automatically excluded. Examples of when outliers should be removed include:

- a. Review of the calibration indicates that a data entry error was likely. This will normally be seen as a random value that is significantly outside the rest of the data with no explanation. This type of outlier is a rare event and should not be done routinely.
- b. Review of the data indicates that a bad calibration was performed. This will normally be seen by multiple outliers from the same calibration and a reverse drift of similar magnitude in the next calibration. In these cases, both sets of raw data should be removed.

2.3.1.4 The pattern of outliers should also be evaluated to determine if there is a bad instrument or application that is contaminating the data set.

It is permissible for this evaluation to rerun the T-Test with a smaller critical T value to force outliers. If this is done, these outliers should not be removed from the final data set.

This process will provide a number of data points that were at the extremes of the data set. If these extremes were primarily in one instruments' data or in one application area then additional evaluations need to be performed to determine if this data can be used with the rest of the data.

2.3.1.5 Bad instruments or bad applications will be detectable from the outliers that are identified. The best indication will be that the outliers will be bunched in the instrument or instruments

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used for a specific application. Other potential causes that could be identified by this process are:

- a. Variations in range or span
- b. Variations in age of calibration or equipment.

2.3.1.6 If the result of the outlier analysis indicates the potential for an application, range, age, etc. type of problem, then an analysis of the selection at that particular instrument should be conducted. Inclusion of data from any instrument can be checked by comparing this mean and variance of the instrument data to the mean and variance to the remainder of the data as explained in TR-103335 Section B.9.

2.4 NORMALITY

2.4.1 For this analysis, the assumption of normality is an integral assumption. To ensure that the data is a normal distribution or that a normal distribution is a conservative assumption, a test for normality of the data will be performed for all as-found/as-left data analysis after any outliers have been removed.

2.4.2 There are several tests for the normality of a data set. (See Appendix C of TR-103335). Exelon (Braidwood, Byron, Dresden, LaSalle, and Quad) requires at least one of the following numerical approaches be conducted before the qualitative evaluations are performed.

- Chi-Squared, χ^2 , Goodness of Fit Test. This well known test is stated as a method for assessing normality in ISA-RP67.04, Recommended Practice, *Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation*.
- WTest. This test is recommended by ANSI N15.15-1974, *Assessment of the Assumption of Normality (Employing Individual Observed Values)*, for sample sizes less than 50.
- D-Prime Test. This test is recommended by ANSI N15.15-1974, *Assessment of the Assumption of Normality (Employing Individual Observed Values)*, for moderate to large sample sizes.

2.4.3 If normality cannot be determined from a standard test then the data should be evaluated to determine if the assumption of normality is a conservative assumption. This can be done by one of the following techniques:

- Probability Plots. Probability plots (See Figure J2) provide a graphical presentation of the data that can reveal possible reasons for why the data is or is not normal. Use of a probability plot and qualitative evaluation demonstrates how close the tails of the curve approach a diagonal.

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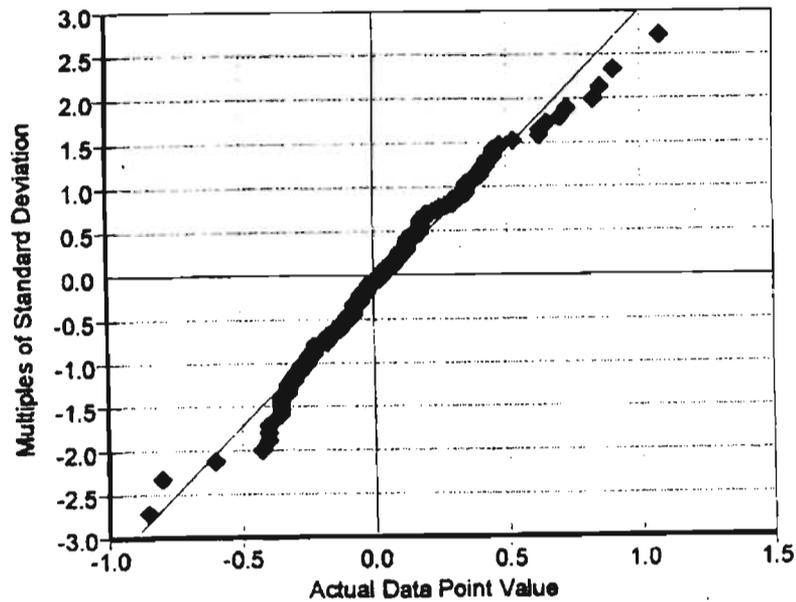


Figure J2, Typical Probability Plot for Approximately Normally Distributed Data

- Coverage Analysis. A coverage analysis (See figure J3) is used for cases in which the data fails a test for normality, but the assumption of normality can still be a conservative representation of the data.

This is performed by a visual evaluation of a histogram of the data with a normal curve for the data overlaid. In most cases instrument data will tend to have a high kurtosis (center peaked data). Since the area of concern for uncertainty analysis is in the tails of the normal curve beyond at least two standard deviations, a high kurtosis will not invalidate the conservative assumption of normality if there are not multiple data points outside the two standard deviation points.

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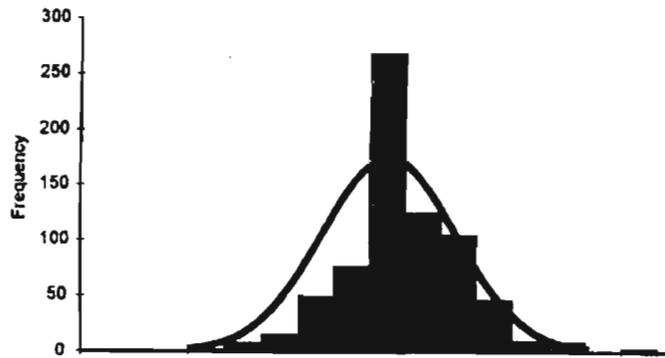


Figure J3, Coverage Analysis Histogram

2.4.4 If normality or a bounding condition of normality cannot be assumed for the data set, then depending on the distribution:

- a. A distribution free tolerance value must be determined.
- b. The size of the standard deviation will be expanded to bound the distribution.

As this is a seldom used case, this will not be discussed in this Standard. Refer to standard statistics texts for binomial and distribution free statistical method.

To determine the amount of increase needed from the tabular 95/95 value for the histogram evaluation, use the count in each bar of the histogram and ensure that greater than 95% of the data is captured. Increase the standard deviation as necessary to capture at least 95% of the data.

2.5 TIME DEPENDENCE

2.5.1 The way the resultant drift value from this as-found/as-left analysis is used is very sensitive to the determination of the time dependency.

This is particularly important for the extension of operating cycles via the NRC Generic Letter 91-04. This drift analysis requires that some decision be made on how the drift at thirty months can be determined from data that is taken over an eighteen month period.

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2.5.2 The basic and most conservative assumption that drift is linear time dependant will be used for the initial evaluation of the computed drift. However, during the development of the EPRI TR-103335, significant data was collected that indicates that drift does not follow a linear time dependent pattern and challenges this basic assumption.

To determine the existence or lack of time dependency requires evaluation of the mean of the data over the calibration interval and the variation in uncertainty over the calibration interval. The evaluation of the mean of the data over the calibration interval will identify any bias component of the instrument drift that is time dependent. The evaluation of the variation in the data over the calibration interval will identify any change in the random component of drift that is time dependent.

The following methodology is to be used to determine time dependence. Evaluation of the drift mean and its changes over time will use any combination of the following tools.

- a. Qualitative methods, which will include visual evaluation of the data on scatter plots, regression predication plots and bin mean plots.
- b. Quantitative methods, which will include regression of the significant data and the regression of the means of the bins (if there is sufficient data).

Evaluation of drift variability and its changes over time will use any combination of the following tools:

- a. Qualitative methods, which will include visual evaluation of the data on scatter plots, regression predication plots and bin standard deviation plots.
- b. Quantitative methods, which will include regression of the Absolute Value of the significant data and the regression of the standard deviation of the bins (if there is sufficient data).

2.5.2.1 First, the data will be evaluated to determine if any of the data will generate significant leverage during regression. To do this the data collected shall be placed in interval bins. The interval bins that will normally be used are:

- a. 0 to 45 days (covers most weekly and monthly calibrations)
- b. 46 to 135 days (covers most quarterly calibrations)
- c. 136 to 225 days (covers most semi-annual calibrations)
- d. 226 to 445 days (covers most annual calibrations)
- e. 446 to 650 days (covers most old refuel cycle calibrations)
- f. 651 to 800 days (covers most extended refuel cycle calibrations)
- g. 801 to 999 days
- h. > 1000 days

2.5.2.2 For each internal bin, the average (\bar{x}), sample standard deviation (σ) and data count (n) shall be computed. In addition, the average calibration interval of the data points in each bin will be computed.

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2.5.2.3 To determine the existence of time dependency, ideally the data needs to be “equally” distributed across the multiple bins. However, equal distribution in all bins would not normally occur. The minimum expected distribution that would allow this evaluation is:

- a. A bin will be considered in the final analysis if it holds more than five data points and more than ten percent of the total data count. The minimum number of data points in a bin was selected to ensure that one calibration at a point would not adversely affect evaluation of a significant amount of data at other intervals. The choice of five data points is engineering judgement and may be changed for a specific case with appropriate documentation in the specific calculation.
- b. For those bins that are to be considered the difference between bins will be less than twenty percent of the total data count. If there is a bin with significant data that does not meet this requirement, the evaluation should be done and the bin included if it can be shown to be from the same data set (a pooling test).
- c. At least two bins including the bin with the most data must be left for evaluation to occur.

The following example demonstrates the process described above.

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Example, Time Dependence Evaluation

For a given make and model of transmitter there were twelve EPN's that were looked at with historical calibrations for five calibration periods. Including corrective actions there were a total of 66 data points. The distribution of the data by bins was:

<u>Bin</u>	<u>Data Count</u>	<u>% of Total Count</u>
0 to 45 days	7	11
46 to 135 days	4	6
136 to 225 days	29	44
226 to 445 days	6	9
446 to 650 days	18	27
651 to 800 days	2	3

The 46 to 135 day and 651 to 800 day bins are thrown out due to less than five data points and the 226 to 445 day bin is thrown out do to having less than ten percent of the data. Of the remaining three bins the 446 to 650 day bin is within twenty percent of the other two bins so there will be three bins used for evaluation.

With a slight variation in the data:

<u>Bin</u>	<u>Data Count</u>	<u>% of Total Count</u>
0 to 45 days	7	11
46 to 135 days	4	6
136 to 225 days	29	44
226 to 445 days	3	5
446 to 650 days	21	32
651 to 800 days	2	3

Now the 0 to 45 day bin is greater than twenty percent from the next bin and thus only the 136 to 225 day and 446 to 650 day bins can be used for analysis.

With another slight variation:

<u>Bin</u>	<u>Data Count</u>	<u>% of Total Count</u>
0 to 45 days	7	11
46 to 135 days	3	5
136 to 225 days	33	50
226 to 445 days	6	9
446 to 650 days	15	23
651 to 800 days	2	3

The majority of the data is in the 136 to 225 day bin and that bin is greater than twenty percent from the next most populous bin. In this case the normal analysis cannot be used. Engineering evaluation of the other bins with greater than ten percent of the data should be done to determine if they can be grouped with the data from the large bin. This could be done by the pooling techniques listed above.

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2.5.2.4 Once the bins have been selected, data from selected bins and all bins between them will be entered into a regression analysis program.

The initial regression is for the data that populates all of the significant bins and the data that is between them. By eliminating the data that is in low populated bins and at the extremes of the calibration interval, leverage is minimized. This regression is to determine if the mean of the data changes over calibration interval.

A regression analysis will be performed using calibration interval as the independent variable and drift as the dependant variable. Output of the regression analysis shall be in a standard ANOVA table similar to that shown in Table J3.

DEP VAR: DOT2 N: 31 MULTIPLE R: 0.178 SQUARED MULTIPLE R: 0.032						
ADJUSTED SQUARED MULTIPLE R: .000 STANDARD ERROR OF ESTIMATE: 1.304						
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P (2 TAIL)
CONSTANT	0.848	0.740	0.000		1.146	0.266
PERIOD	-0.001	0.002	-0.178	1.000	-0.787	0.441
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	1.054	1	1.054	0.620	0.441	
RESIDUAL	32.319	29	1.701			

Table J3, Sample ANOVA Table

If the value for R^2 is greater than 0.3, then the bias component of the drift should be considered to be linearly time dependent over the range of the calibration intervals included in the analysis. The constant and slope of the drift line will be used for bias values in uncertainty analysis for this instrument make and model. The appropriate tolerance interval for the 95/95 case should also be determined for this regression. [Note: This case will only occur rarely]

If the value of R^2 is less than 0.3 but greater than 0.1 then there still can be a time dependency. To continue the evaluation use terms from the ANOVA table generated by the regression program (partial printout below) or an equivalent ANOVA table.

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Example, ANOVA Table Evaluation for Time Dependency

ANOVA				
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>
Regression	001	0.606767762	0.6067678	2.7507691
Residual	119	26.24915424	0.2205811	
Total	120	26.855922		
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P - value</i>
Intercept	0.1594012	0.087925043	1.812913	0.0723646
X Variable 1	-0.0003408	0.000205483	-1.6586443	0.0998413

Table J4, Time Dependence Evaluation ANOVA Table

From this table, the following values will give an indication of the potential for linear time dependency:

1. X Variable 1 *P-value*, if less than 0.05, would indicate a time dependency
2. ANOVA table *F* value, if it is greater than the *F*-table value for a 0.25% probability, the number of data points for the regression, and two degrees of freedom for the numerator, would indicate a time dependency.

2.5.2.5 After the initial regression test the same regression test is applied to the absolute value of the same data. This test detects the increasing variability with calibration interval but will not provide a correct mean. The same decision criteria as the first regression apply but the variable that is being evaluated is the random component of the drift. The slope of the regression will represent the variation in the standard deviation as calibration interval increases if a time dependency is determined. This variation will NOT provide a numerical value for the increase, but will indicate the trend.

2.5.2.6 If neither of the regression tests show an R^2 value greater than 0.3, then a review of the mean and standard deviation data for each bin of significance and an evaluation of qualitative plots will assist the engineer in determining time dependence.

2.5.2.7 If the R-Square value is less than 0.1, then the bias component of the drift should be considered to be time independent over the range of the calibration intervals included in the analysis. For those cases with no apparent time dependency, one additional check should be performed to identify any potential problems resulting from increasing uncertainty.

The evaluation of the mean and standard deviation of each bin of significance will provide visual trending of the mean and standard deviation with calibration interval.

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For each bin that was evaluated, plot the mean and sample standard deviation against the average calibration interval for that bin. These plots will provide visual indication of the stability of the mean and sample standard deviation for the data available. Indications of increased magnitude of the mean and/or the standard deviation with increasing or decreasing calibration interval can be qualitatively assessed.

A linear extrapolation of the expected increase in sample standard deviation and mean to the next bin outside the analyzed interval can be determined through the regression of the plotted values for the mean and standard deviation. This will provide a value for the mean and sample standard deviation, in Units/Day, for projection into the next bin.

If there are more than three bins with significant data then a regression of the mean and standard deviation values that were plotted can be used for evaluation of the linear fit of the data.

2.5.2.8 Determination of time dependency will be in two parts. One for the bias section and one for the random section of the drift term. These decisions will be based on the following decision process:

a. Bias Component

If the bias is showing a time dependency it will be deviating from its calibration as-left value of near zero drift as the calibration interval is increased. This deviation will be repeatable in only one direction (positive or negative).

- 1) If the regression of the data has an R-Square value greater than 0.3 then it is assumed that the data is time dependent.
- 2) If the R-Square is less than 0.3 but greater than 0.1 then the X Variable *t* *P*-value and the F-Value tests should be completed. If either test indicates that the regression is significant then assume time dependency unless there is a reason to disregard the tests.

One result that would be a reason for disregarding the regression test is that the result could not represent the real instrument behavior. This has shown up in several cases where the regression line has a large intercept value and then trends toward or crosses the zero drift term. This implies that the maximum drift will occur at time zero which is not the expectation of the instrument calibration process.

- 3) If the R-Square value is less than 0.1 then there is an expectation that the bias is time independent. This will be checked against the qualitative visual information to make a final determination.

Review:

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The scatter plot of all data – Include linear approximation line

The plot of the data that was regressed – Include linear approximation line

The plot of the means of each significant bin – Include linear approximation line

If the review of these plots indicates a clear trend toward an increasing value in the magnitude of the mean versus calibration interval, then engineering judgement should be used to conservatively treat the mean as a linearly time dependent bias.

- 4) The value of the bias will be either the linear extrapolated value of the time dependent regression for a time dependent bias component or the mean of the final data set for a time independent bias component.
- 5) If the value of bias is determined to be less than 0.1% FS, it will be considered negligible whether it is time independent or time dependent (computed to the maximum surveillance interval).

b. Random Component

The variation of the data about the mean is normally the larger uncertainty in drift evaluations and this value is the random component of drift. If the magnitude of this variation is a function of calibration interval then this variation can be said to be time dependent.

- 1) If the regression of the Absolute Value of the data has an R-Square value greater than 0.3 then it is assumed that the data is time dependent.
- 2) If the R-Square is less than 0.3 but greater than 0.1 then the X Variable 1 *P-value* and the F-Value tests should be completed. If either test indicates that the regression is significant then assume time dependency unless there is a reason to disregard the tests.
- 3) If the R-Square value is less than 0.1 then there is an expectation that the random uncertainty is time independent. This will be checked against the qualitative visual information to make a final determination.

Review:

The scatter plot of all data – Include linear approximation line

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The plot of the Absolute Value of the data that was regressed –
Include linear approximation line

The plot of the standard deviation of each significant bin – Include
linear approximation line

If the review of these plots indicates a clear trend toward a linear variation in
the standard deviation with calibration interval, then engineering judgement
should be used to assume time dependency for the random component of the
uncertainty.

4) The value of the random component of the drift will be either:

The linear extrapolated value of the standard deviation of the bins
plot for a time dependent random uncertainty

or

The standard deviation of the data for a time independent random
component

The interval for which this is valid is only the interval of the bins that were
analyzed.

2.5.3 If two or more bins were not identified for analysis then the value of drift from this
evaluation must determined from the data from the most populated bin. For this case the
process utilized is:

2.5.3.1 Compute the mean and sample standard deviation for the most populated bin. In addition,
compute the average calibration interval for the data in that bin.

2.5.3.2 The bias and random components of the drift are then determined by:

a. The bias component will be then mean of the data in the single bin. This bias will be
considered time independent unless a qualitative evaluation of the data would
visually indicate that it is time dependent.

Extrapolation of the bias value from this bin to other bins will be by assuming it is a
constant value throughout the range of concern for a time independent bias.

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- b. The random component will be the 95/95 tolerance value of the data. This will be assumed to be time independent.

Extrapolation to the bin either side of the single bin will require the use of the 99/95 tolerance value for additional conservatism. For extrapolation to larger calibration interval the random value will be expanded using the A2 Equation method of Appendix A Section 3.1.

2.6 RESULTS

2.6.1 The results of these as-found/as-left analyses determine a value of derived drift for the instrument make/model. This value will require the following minimum elements:

2.6.1.1 Bias – Will normally be either the mean of the final data set for time independent drift or the intercept (constant) and slope for linear time dependent drift. For time dependent drift, this cannot be from the regression of the absolute value data set but from the final data set. A mean that is less than 0.1% FS will be assumed to be zero. This is a standard value. Bias below this value has no significant effect on the loop uncertainty.

2.6.1.2 Time Dependent Drift Value – For drift that was classified as time dependent, the slope of the regression curve (Units/Day) is the dependent drift value. If this number was determined from the absolute value regression, it still should be specified.

2.6.1.3 Tolerance Value – This value will come from the regression study for time dependent drift. For time independent drift, it will be the sample standard deviation times a multiplier based on the sample size. The selection of the multiplier will be based on the required expectations. Some specific requirements are:

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99/95 – For cases where only one bin has sufficient data for analysis use this tolerance if the intent is to still assume time independent drift.

95/95 – For RPS and ECCS automatic actuations. If any instruments of the make/model are used for this then the result must be this confidence and tolerance interval.

95/75 – For other safety related instrumentation. If no instruments of this make/model are used for automatic actuations but they are used in safety related indication and alarm circuits then the tolerance value can be reduced to 75%.

75/75 – If the make/model is only used for non-safety related activities.

2.6.1.4 Valid Interval – The bounds of the calibration interval that were included in the analysis. For the above example, the first case would be 0 to 650 days and the second case would be 136 to 650 days. As extrapolation of statistical evaluations are not normally done this provides the data over the range where it should be valid. Some evaluation of the data within the bounding bins may be necessary to ensure that all of the data is not bunched at one interval. If there is bunching of data, the valid interval should be adjusted to account for this effect.

2.6.1.5 Extrapolation Margin – If the data from the analysis is to be extrapolated to either of the adjacent bins from the Valid Interval, then an additional margin will be added to the results of the evaluation.

2.6.2 The analysis should clearly indicate the make/model that it was performed for, and any functions excluded.

2.7 USING THE RESULTS

2.7.1 The data reduction has generated a “drift” value, but that number includes several uncertainties in addition to the classical drift. If the determined drift value is used in uncertainty calculations, the following uncertainties can normally be eliminated. To replace these values state that they are included in the calculated drift value and set their individual values to zero.

2.7.1.1 Reference Accuracy – The reference accuracy of the instrument is included in the calibration data and can be removed from the uncertainty calculation.

2.7.1.2 M&TE – As long as the calibration process uses the same, or more accurate, test equipment then this uncertainty is included in the calibration data and can be removed from the uncertainty calculation.

2.7.1.3 Drift – The true drift is included in the determined drift and is included in the calibration data and can be removed from the uncertainty calculation.

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2.7.1.4 Normal Environmental Effects – For the instruments that are included in the calibration, the effects of variations in radiation, humidity, temperature, vibration, etc. experienced **during the calibration** are included in the calibration data and can be removed from the uncertainty calculation. These terms cannot be removed from the uncertainty calculations if these components see different conditions or magnitudes of the parameter, such as vibration or temperature, while operating then during calibration.

2.7.1.5 Power Supply Effects – If the instruments are attached to the same power supply during calibration that is used during operation, then the affects are included in the calibration data and can be removed from the uncertainty calculation.

2.7.1.6 Setting Tolerance – If the setting tolerance is such that it is less than the determined drift then this tolerance will show up in that determined drift and can be removed from the uncertainty calculation.

If the ST is much larger than the determined drift it will not normally be used in the calibration process and will not be seen in the determined drift. In this case the ST can be combined with the determined drift using SRSS.

2.7.2 For cases were there are time dependent drifts, the time frame used for determining the drift should be the normal surveillance interval plus twenty-five percent.

Time dependent drift that is random is assumed to be normally distributed and can be combined using the Square Root Sum of the Squares method for intervals beyond the given interval for the drift as explained in Appendix A and C to this procedure.

2.7.3 Time independent drift can be assumed constant over the Valid Interval. It can also be assumed constant over the interval in the next bin if the Extrapolation Margin is applied.

2.8 CONTINUING EVALUATION

2.8.1 To maintain these evaluations current and to detect increasing drift, the process stipulated in ER-AA-520 “Instrument Performance Trending” shall be followed.

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		<p>Revision 5</p>

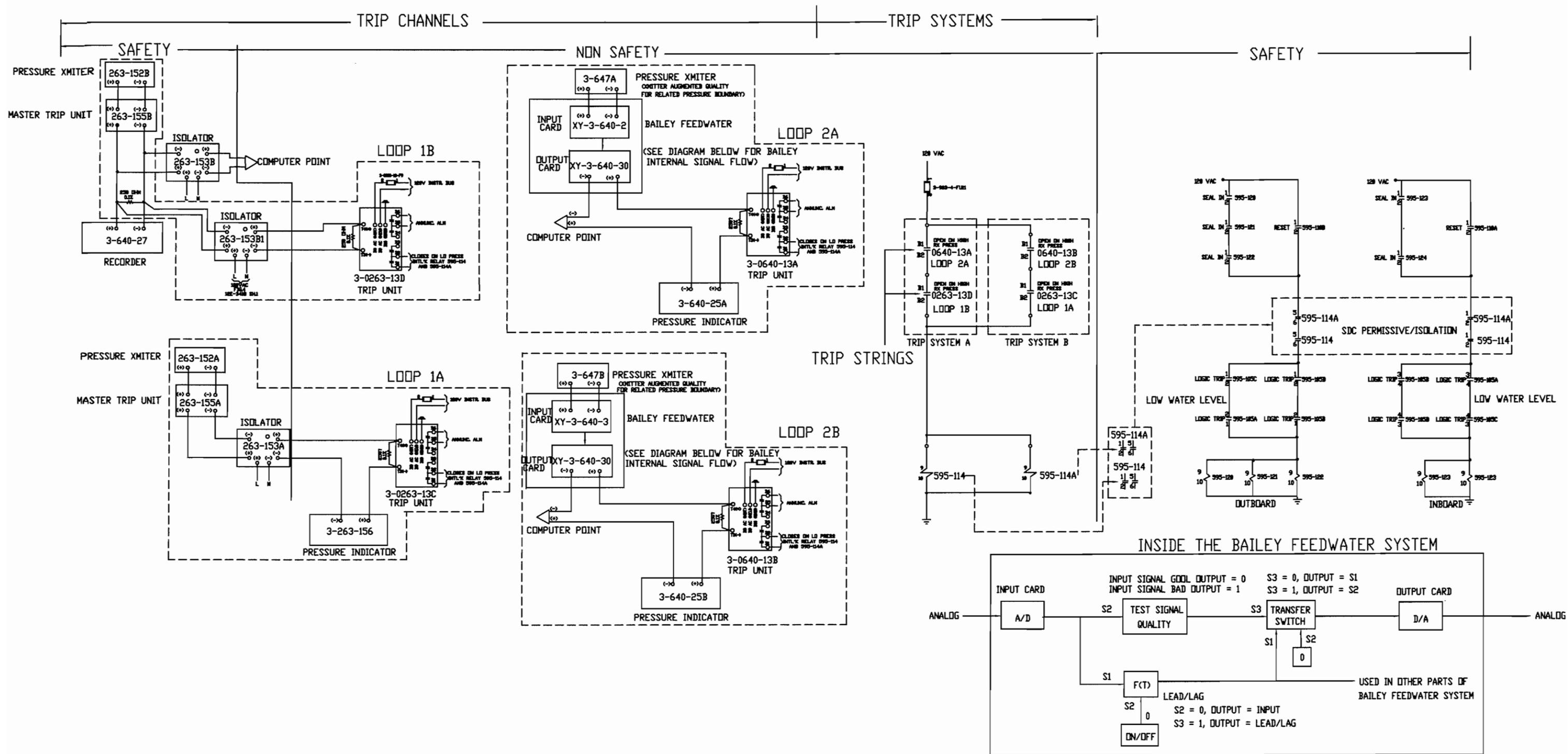
ATTACHMENT 1

Additional Information Supporting the Request for License Amendment Regarding
Shutdown Cooling System Isolation Instrumentation

ENCLOSURE 2

Sketch of the Proposed Circuit Layout for
Shutdown Cooling System Instrumentation Logic

U3(2) CONFIGURATION AFTER LAR (ONLY UNIT 3 COMPONENTS SHOWN)



ATTACHMENT 1

**Additional Information Supporting the Request for License Amendment Regarding
Shutdown Cooling System Isolation Instrumentation**

ATTACHMENT 2

Revision to Mark-up of Proposed Technical Specifications Bases Pages

BASES

BACKGROUND 5. Reactor Water Cleanup System Isolation (continued)

The Reactor Vessel Pressure-High Function is provided to isolate the SDC system. The Reactor Vessel Pressure-high function receives input from four reactor pressure channels.

provide 1 channel input
two trip systems is
ves.
valves.

6. Shutdown Cooling (SDC) System Isolation

The Reactor Vessel Water Level-Low Function receives input from four reactor vessel water level channels. Each channel inputs into one of four trip strings. Two trip strings make up a trip system and both trip systems must trip to cause an isolation of the SDC suction isolation valves. Any channel will trip the associated trip string. Only one trip string must trip to trip the associated trip system. The trip strings are arranged in a one-out-of-two taken twice logic to initiate isolation. ~~For Unit 3 the Recirculation Line Water Temperature High Function receives input from four channels, each of which provides input to both logic systems. Any channel will trip both logic systems. This is a one out of four logic for the trip system. For Unit 2 the Recirculation Line Water Temperature High Function receives input from four temperature channels. Each channel inputs into one of the four trip strings. Two trip strings make up a trip system and both trip systems must trip to cause an isolation of the SDC suction isolation valves. Any channel will trip the associated trip string. Only one trip string must trip to trip the associated trip system. The trip strings are arranged in a one-out-of-two taken twice logic to initiate isolation function. Each of the two logic systems is connected to one of the two valves on the SDC suction penetration. Only one of the logic systems isolates the SDC return penetration.~~

pressure

Each of the two logic systems is connected to one of the two valves on the SDC suction penetration. Only one of the logic systems isolates the SDC return penetration.

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APPLICABLE
SAFETY ANALYSES,
LCO, and
APPLICABILITY

primary containment
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PCIVs)," Applicable
f the safety

(continued)

The Reactor Vessel Pressure-High Function is provided to isolate the SDC system. The Reactor Vessel Pressure-High function receives input from four reactor pressure channels.

BA

APPLICABLE SAFETY ANALYSES, LCO, and APPLICABILITY (continued)

This Function isolates the Group 3 valves.

~~Shutdown Cooling (SDC) System Isolation~~

~~6.a. Reactor Vessel Pressure Recirculation Line Water Temperature High~~

~~The Recirculation Line Water Temperature High Function is provided to isolate the Shutdown Cooling System. This interlock is provided for equipment protection to prevent exceeding the system design temperature, and credit for the interlock is not assumed in the accident or transient analysis in the UFSAR.~~

~~For Unit 3 the Recirculation Line Water Temperature High signals are initiated from the high recirculation loop temperature alarm circuit. Four channels (each providing input into the trip system) of Recirculation Line Water Temperature High Function are available. Therefore only two channels (one channel from each loop) are required to be OPERABLE to ensure that no single instrument failure can preclude the isolation function. For Unit 2 the Recirculation Line Water Temperature High Isolation Function receives input from four Recirculation Line temperature channels. Each channel inputs into one of four trip strings. Two trip strings make up a trip system and both trip systems must trip to cause an isolation of the shutdown cooling (SDC) suction valves. Any channel will trip the associated trip string. Only one trip string must trip to trip the associated trip system. The trip strings are arranged in a one-out-of-two taken twice logic to initiate isolation. Therefore all four channels are required to be OPERABLE to ensure that no single instrument failure can preclude the isolation function. The Function is only required to be OPERABLE in MODES 1, 2, and 3, since these are the only MODES in which the reactor coolant temperature exceeds the system design temperature and equipment protection is needed. The Allowable Value was chosen to be low enough to protect the system equipment from exceeding its design temperature.~~

pressure

This Function isolates the Group 3 shutdown cooling valves.

(continued)

BASES

SURVEILLANCE
REQUIREMENTS

SR 3.3.6.1.2 and SR 3.3.6.1.5 (continued)

The 92 day Frequency of SR 3.3.6.1.2 is based on the reliability analyses described in References 8 and 9. The 24 month Frequency of SR 3.3.6.1.5 is based on engineering judgement and the reliability of the components.

SR 3.3.6.1.3

For Function 6.a only, there is a plant-specific program which verifies that the instrument channel functions as required, by verifying the as-left and as-found settings are consistent with those established by the setpoint methodology.

trip units provides a check of the actual . The channel must be declared inoperable if ng is discovered to be less conservative than Value specified in Table 3.3.6.1-1. If the s discovered to be less conservative than in the appropriate setpoint methodology, but the Allowable Value, the channel performance n the requirements of the plant safety er these conditions, the setpoint must be be equal to or more conservative than that in the appropriate setpoint methodology.

of 92 days is based on the reliability analyses of References 9 and 10.

SR 3.3.6.1.4 and SR 3.3.6.1.6

A CHANNEL CALIBRATION is a complete check of the instrument loop and the sensor. This test verifies the channel responds to the measured parameter within the necessary range and accuracy. CHANNEL CALIBRATION leaves the channel adjusted to account for instrument drifts between successive calibrations consistent with the plant specific setpoint methodology.

The Frequency of SR 3.3.6.1.4 is based on the assumption of a 92 day calibration interval in the determination of the magnitude of equipment drift in the setpoint analysis. The Frequency of SR 3.3.6.1.6 is based on the assumption of a 24 month calibration interval in the determination of the magnitude of equipment drift in the setpoint analysis.

(continued)