ATTACHMENT 1

Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy

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, contact the NES E/I&C group.

Rev No	Description	Prepared by	Reviewed by	Approved by
0	Initial Issue: 10/14/97	P. VandeVisse	D. Ugorcak	T. B. Thorsell
1	Revised References, Appendix A, E, I and added Appendix J	W. D. Crumpacker	D. Ugorcak	T. B. Thorsell

Latest Revision indicated by a bar in right hand margin.

	Title	
ComEd Nuclear Generation Group Nuclear Engineering Standards	Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy	STANDARD NES-EIC-20.04 Sheet 1 of 20 Revision 1

Table of Contents

List of Figures

List of Tables

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-S67.04-Part 1-1994 (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, Part II-1994 (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 ComEd 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 ComEd personnel, non-ComEd 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.

3.0 REFERENCES

3.1 ANSI/ISA-S67.04-Part I - 1994, Setpoints for Nuclear Safety-Related Instrumentation, Approved August 24, 1995

3.2 ISA-RP67.04-Part II - 1994, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation, Approved September 30, 1994, Second Printing May 1995

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 Commonwealth Edison company Procedure NEP-12-02, Preparation, Review, and Approval of Calculations, Revision 5, Issued 6/30/97

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 ComEd Nuclear Operating Division Standard NES 20.01, Standard for Evaluation of M&TE Accuracy When Calibrating Instrument Components and Channels, rev. 0, January 23, 1996

3.22 ComEd Nuclear Operating Division Standard NES 20.03, Evaluation of Instrument Performance, rev. 0, May 5, 1997

4.0 DEFINITIONS

Note: symbols in parenthesis represent the ComEd 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 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.

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 stations 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 ComEd calculations.

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 effect 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 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.

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.

5.1.4 Accuracy

Accuracy is the combination of:

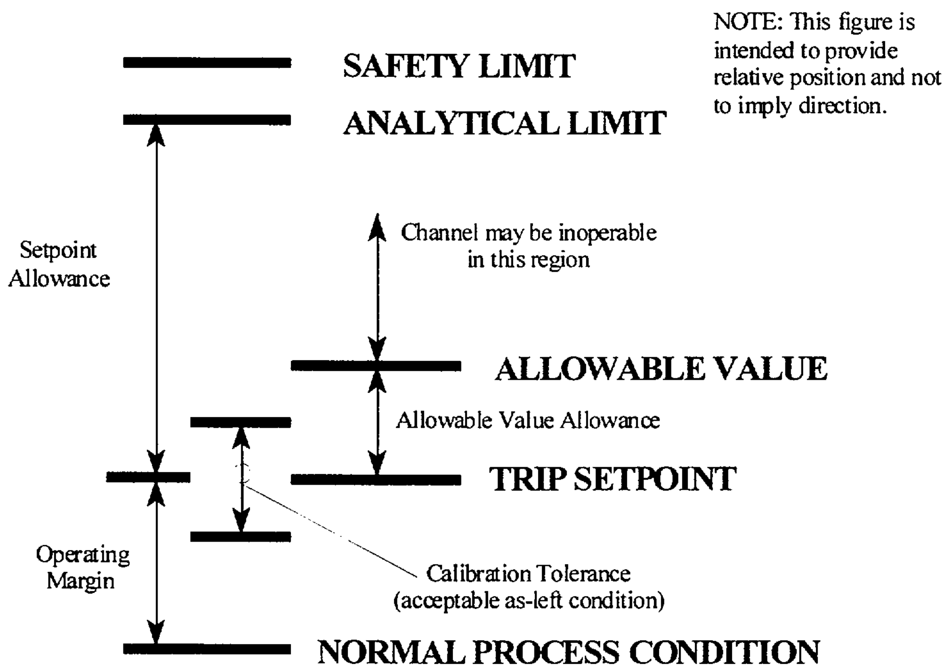
- known or expected process effects,
- known or expected instrument or instrument channel performance characteristics,
- known or expected measurement errors,
- known or expected measurement uncertainties, and
- allowances for conservatism (margin).

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 relation ship 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.



Safety Limit: A limit on an important process variable that is necessary to reasonably protect the integrity of the physical barriers that guard against the uncontrolled release of radioactivity.

Analytical Limit: The limit of a measured or calculated variable established by the safety analysis to ensure that a safety limit is not exceeded.

Trip Setpoint: The calculated trip value that will provide the necessary level of confidence that the analytical limit will not be exceeded.

Allowable Value: The criteria used for the determination of operability.

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.

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,
   - inservice 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 ComEd 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.

At ComEd 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 NES 20.03, Evaluation of Instrument Performance, 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.

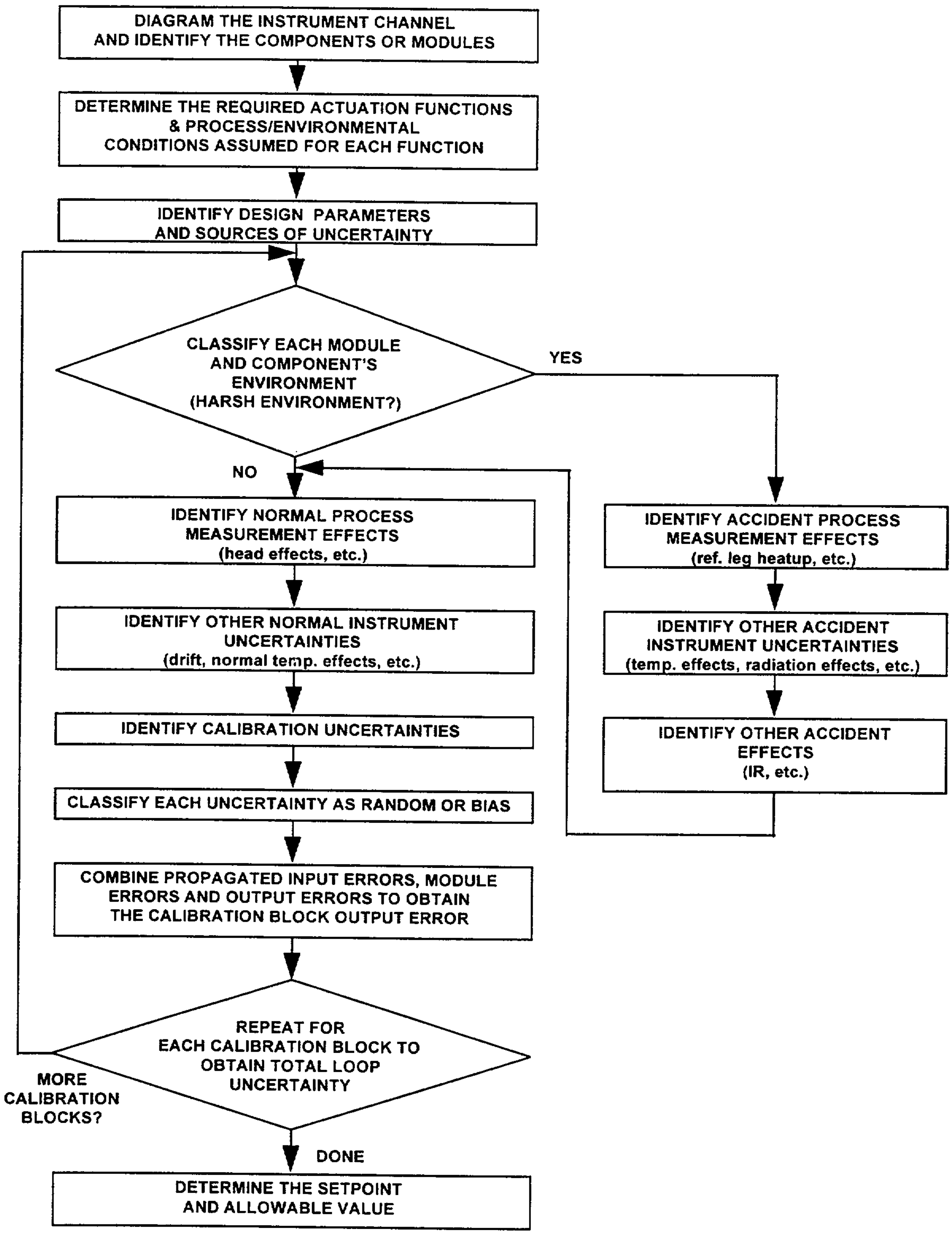


Figure 2, Setpoint Calculation Flowchart

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.

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.

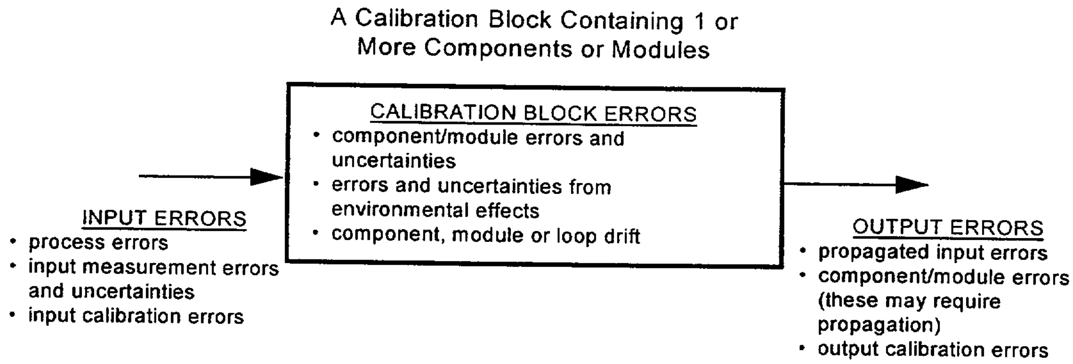


Figure 3, Input, Calibration Block and Output Errors and Uncertainties

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 <u>both</u>. The calibration procedure must be carefully analyzed to ensure that the effect of these resistors are correctly incorporated into the channel or calibration block accuracy.

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.

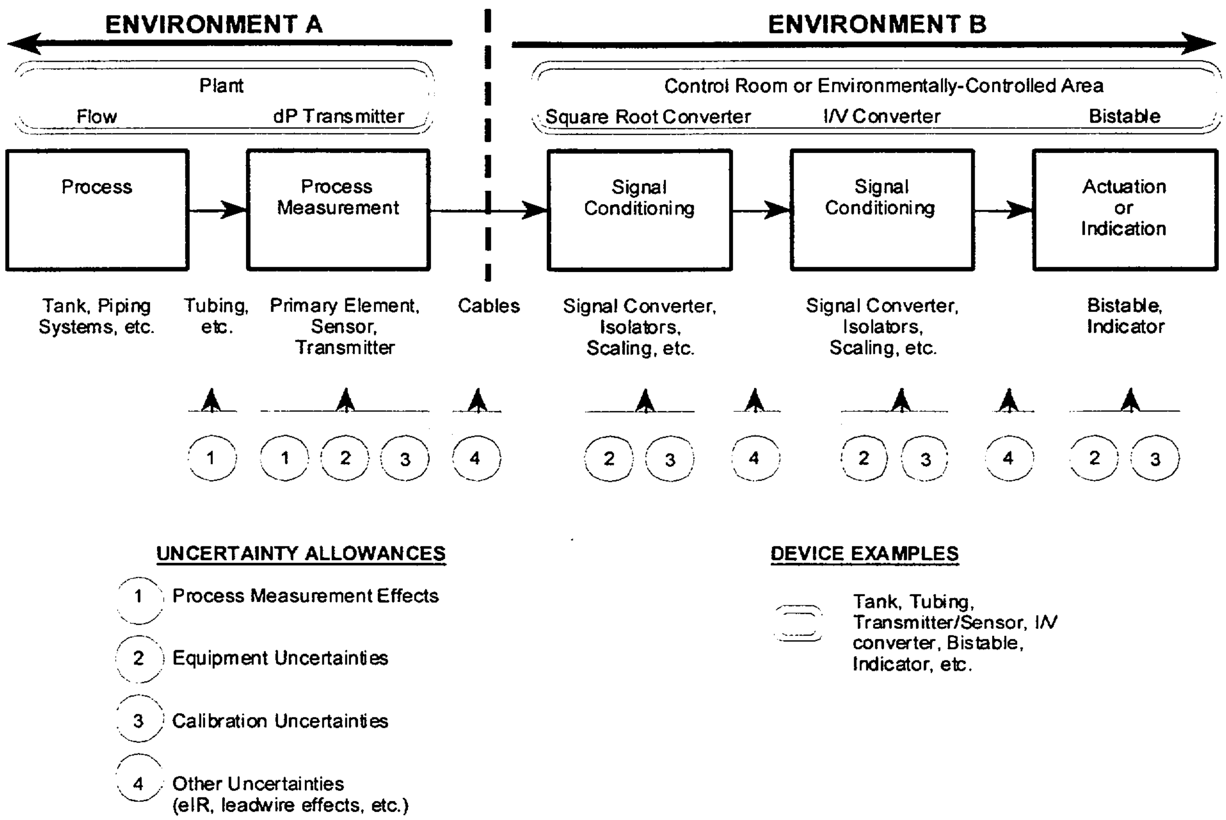


Figure 4, Typical Instrument Channel Layout

[1]

---

[1] ISA-RP67.04-Part II - 1994, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation, Approved September 30, 1994, Second Printing May, 1995.

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.

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 NES 20.03, Evaluation of Instrument Performance, when administrative limits are required as part of the instrument loop accuracy determination.

APPENDIX A

SOURCES OF ERROR AND UNCERTAINTY

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. Significant errors, whether or not they are described in this appendix shall also be included in the computation of setpoint error, or instrument loop accuracy.

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 effect 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 which 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 effected 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 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.

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 effects 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, it may be necessary to include a default value when preparing the analysis. The ComEd default drift effect values that will be used in these cases are:

Mechanical Components: ±1.0% of span per 18-month cycle
Electronic Components: ±0.5% of span per 18-month cycle

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 a 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):

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

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.

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.

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

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

$D = [1\%][22\ \tfrac{1}{2} / 12]^{1/2} = \pm 1.37\%$ 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.

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

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.

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 measurements errors in process parameters.

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

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)

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 instruments 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:

   Temperature Error (eT) = 0.75% of the Upper Range Limit + 0.50% 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.

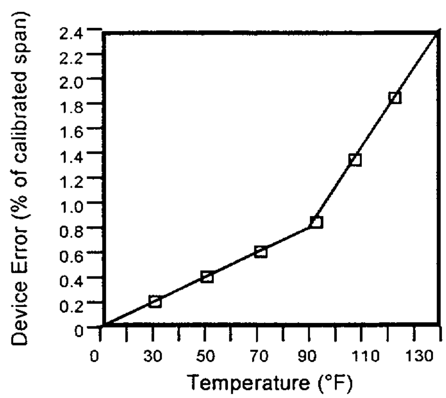


Figure A1, Graphical Specification of Device Error

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.

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

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.

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

where:
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) (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) (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".

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 ComEd, the calibration facility may be directed to maintain the M&TE to a 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)

Since it is unlikely that an analog gauge reading will always coincide with a graduation tick mark, the readability of the gauge scale is ½ of the smallest division. The uncertainty in this readability, or reading error (RE), is ± ¼ 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.

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 depend 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 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 desire 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.

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.

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.

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

Table A1 (con't), 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	ST	random (3σ)
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

APPENDIX B

PROPAGATION OF ERROR AND UNCERTAINTIES

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	σ_X, σ_Y ... σ_n represent random errors associated with inputs X and Y. σ_{OUT} is the resulting composite random output error. Units must be consistent with the associated input signals, e.g. ±% full span, ±mA, ±V, etc. 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. 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.
e	bias error	e_X, e_Y ...e_N represent bias errors associated with inputs X and Y and e_{OUT} represents the composite bias error. Units must be consistent with the associated input signals e.g. % full span, ±mA, ±V, etc.

Table B1, Uncertainty Symbols

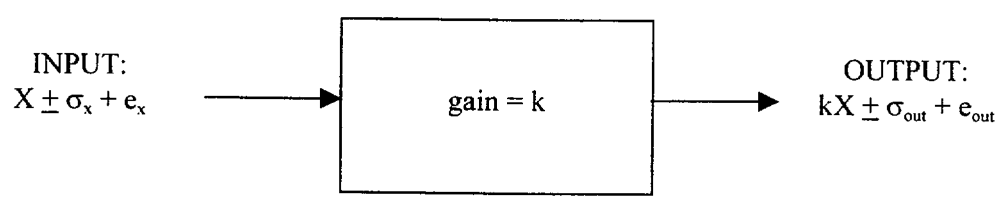
For simplification, the following examples only show the positive input and output bias error terms. Where the bias is symmetrical or assumed symmetrical (as in protection and reactor trip setpoints, and graded methodology level 1 applications), the negative output error would be identical in magnitude 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:

$\sigma_{OUT} = k\sigma_X$

$e_{OUT} = ke_X$

3.2 SUMMING AMPLIFIER

X INPUT: $X \pm F_X + e_X$ → X gain = k1

Y INPUT: $Y \pm F_Y + e_Y$ → Y gain = k2

→ OUTPUT: $(k1 * X) + (k2 * Y) \pm F_{OUT} + e_{OUT}$

where:

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

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

3.3 MULTIPLIER

X INPUT: $X \pm F_X + e_X$ → X gain = k1

Y INPUT: $Y \pm F_Y + e_Y$ → Y gain = k2

→ OUTPUT: $(k1 * X) * (k2 * Y) \pm F_{OUT} + e_{OUT}$

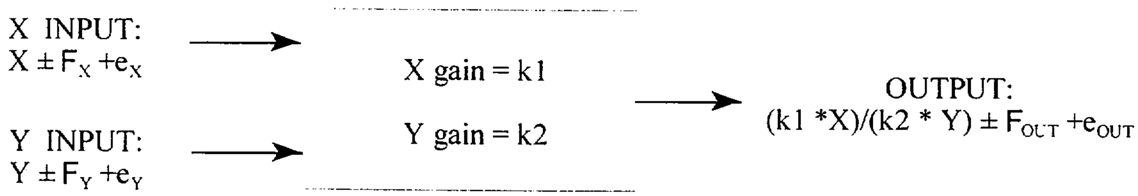
where:

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

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

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.

3.4 DIVIDER

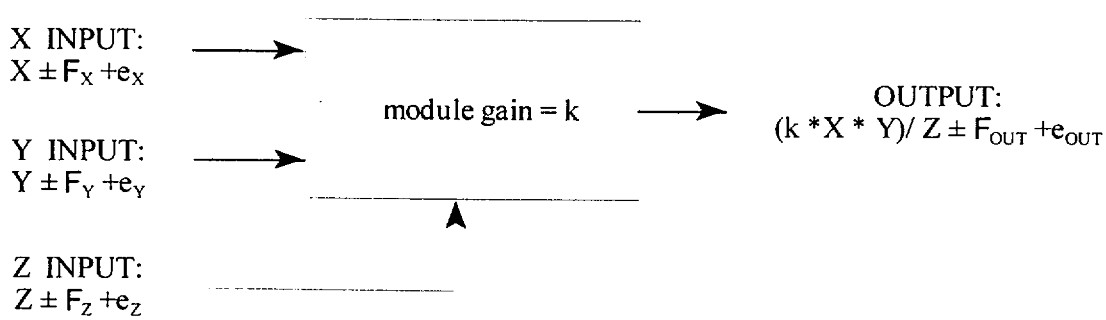


where:

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

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

3.5 MULTIPLIER DIVIDER



where:

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

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

3.6 SQUARE ROOT EXTRACTOR

X INPUT: $X \pm F_X + e_X$ → module gain = k → OUTPUT: $k(X)^{1/2} \pm F_{OUT} + e_{OUT}$

where:

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

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

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

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

$$e_{OUT} = k[(X + e_X)^{1/2} - (X)^{1/2}] \quad \text{for } \frac{e_X}{X} \geq 1$$

$$e_{OUT} \approx \frac{ke_X}{2(X)^{1/2}} \quad \text{for } \frac{e_X}{X} < 1$$

3.7 SQUARE ROOT EXTRACTOR WITH MULTIPLIER

X INPUT: $X \pm F_X + e_X$ →

Y INPUT: $Y \pm F_Y + e_Y$ →

module gain = k → OUTPUT: $k(X*Y)^{1/2} \pm F_{OUT} + e_{OUT}$

where:

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

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

3.8 LOGARITHMIC AMPLIFICATION

INPUT: $X \pm F_X + e_X$ → offset = k_1, gain = k_2 → OUTPUT: $k_1 + (k_2 * \log X) \pm F_{OUT} + e_{OUT}$

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)

INPUT: $X \pm \sigma_X + e_X \Rightarrow (x - x_I) \pm \sigma_X + e_X$

OUTPUT: $k(X)^{1/2} \pm \sigma_{OUT} + e_{OUT} \Rightarrow k(x - x_0)^{1/2} \pm \sigma_{OUT} + e_{OUT}$

where:

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

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

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

APPENDIX C

EQUATIONS FOR INSTRUMENT CHANNEL UNCERTAINTIES, SETPOINTS AND ALLOWABLE VALUES

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.

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

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.

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.

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

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

Where:

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

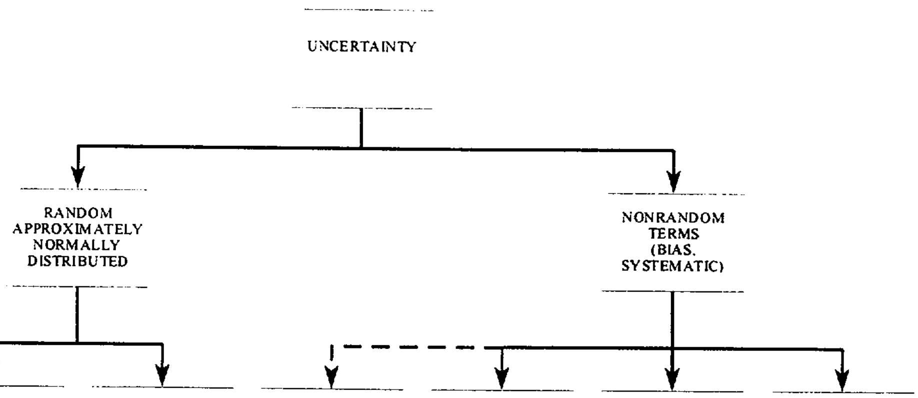
$$G = (\Sigma|F^{+}|) + (\Sigma L), \text{ where } F^{+} \text{ is the positive bias term sum} \quad \text{(Eq. C4)}$$

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

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: ComEd 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.



	INDEPENDENT	DEPENDENT	CORRECTION	BIAS (KNOWN SIGN)	BIAS (UNKNOWN SIGN)	NON-NORMALLY DISTRIBUTED
ATTRIBUTES	VARIABLE MAGNITUDE, RANDOM SIGN		FIXED, KNOWN SIGN AND MAGNITUDE	VARIABLE OR FIXED MAGNITUDE AND KNOWN SIGN	VARIABLE OR FIXED MAGNITUDE AND KNOWN SIGN	VARIABLE MAGNITUDE RANDOM SIGN
OTHER NAMES	STATISTICAL, ACCIDENTAL, PRECISION	CORRELATED	OFFSET	SYSTEMATIC	NONE	NONE
COMBINATIONAL RESTRICTIONS	SRSS	SRSS AFTER LINEAR SUMMING	NOT USED TO CALCULATE CHANNEL UNCERTAINTY	COMBINE LIKE SIGNS LINEARILY	ABSOLUTE VALUE TO PRODUCE A CONSERVATIVE RESULT	
QUANTIFICATION	TWO SIGMA (95%) PROBABILITY LEVEL		CONSTANTS	ESTIMATED LIMITS OF ERROR		
EQUATION TERMS	+/– A, +/–B, +/–C	+/–D, +/–E	NONE	+L, –M	+/–F	

Figure C1, Uncertainty Model

2.0 UNCERTAINTY EQUATIONS USING COMED SYMBOLOGY

2.1 CALIBRATION ERROR

The equation for calibration error (CAL) is defined using ComEd 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.

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

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 typically a 2σ value for random errors and the analytical limit is the associated acceptance limit.

Increasing Protection Setpoint

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

Decreasing Protection Setpoint

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

Other Increasing Setpoints

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

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, that 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 effect the "as-found" setpoint value and then adding or subtracting the combined error from the trip setpoint.

Increasing Setpoint

AV = SP + applicable uncertainty (Eq. C14)

Decreasing Setpoint

AV = SP – applicable uncertainty (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 effect 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 effect 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.

5.0 ADMINISTRATIVE LIMITS

An Administrative Limit is a value calculated from available instrument uncertainties that is used to evaluate an instrument's performance and it's potential degradation. Refer to NES-EIC-20.03 for calculation of Administrative Limits.

APPENDIX D

GRADED APPROACH TO DETERMINATION OF INSTRUMENT CHANNEL ACCURACY

1.0 INTRODUCTION

The ComEd setpoint methodology was developed and is defined by this standard to provide the basis, consistent with ANSI/ISA-S67.04-Part I, 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-Part II provides guidance for implementing ANSI/ISA-S67.04 and imposes rigorous requirements for instrument uncertainty calculations and setpoint determination for safety-related instrument setpoints in nuclear power plants.

ISA-RP67.04-Part II recognizes that the historical focus of ANSI/ISA-S67.04 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 are 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 ComEd nuclear stations. The instrument loop accuracy may then be used to determine the associated instrument setpoints The ComEd "graded methodology" is summarized in Table D1.

2.0 CLASSIFICATION

The ComEd 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-S67.04-Part I. 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 ComEd 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.

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 EOPs 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 EOPs 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.

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-ComEd 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 S67.04, Part I and ISA RP67.04, Part II. 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
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.

Table D1, Graded Methodology

LEVEL	TYPICAL APPLICATION	METHO-DOLOGY	APPLICABLE UNCERTAINTY METHODS
1	• Protection setpoints • ESF/RPS/ECCS • PCIS/SCIS	$2\sigma + \Sigma e_i$	• Consistent with ISA S67.04, Part I and ISA RP67.04, Part II. • 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: $Z = \pm[A^2 + B^2 + C^2 + (E + F)^2]^{1/2} \pm (\lvert F\rvert) + (L) - (M)$ Z = resultant uncertainty, combination of random and bias uncertainties A,B,C = random, independent terms D,E = random dependent terms (independent of A,B and C) F = abnormally distributed uncertainties and/or bias (unknown sign) L,M = biases with known sign
2	• EOP operator action setpoints • RG 1.97 Type A variables	$\sigma + \Sigma e_i$	• Bias errors combined using SRSS in accordance with ASME PTC 19.1: $e_i = \pm[F^2 + L^2 + M^2]^{1/2}$ where F, L and M are bias errors as shown above • Single side of interest confidence interval evaluation where the evaluated setpoint is in a single direction: $Z = 0.468\sigma + \Sigma e_i$

Table D1 (con't), Graded Methodology

LEVEL	TYPICAL APPLICATION	METHO-DOLOGY	APPLICABLE UNCERTAINTY METHODS
3	• RG 1.97 Type B, C & D variables	$\sigma + \Sigma e_i$	• 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≥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	• 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	• Engineering Judgment shall be documented • Engineering evaluation/conclusions shall be documented • Vendor, ComEd, or other methodologies may be utilized where appropriate

APPENDIX E

REACTOR WATER LEVEL TO SENSOR dP CONVERSION

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 effected 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:

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

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

Hydrostatic pressure head is given by:

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

where:

P = pressure
ρ = density of the fluid (lbm/ft^3)
g = gravitational constant
z = height of the column of fluid

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

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

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

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

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

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

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

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

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

$$\begin{aligned} \delta dP &= (dP + \delta dP) - (dP) \\ &= [-\gamma_4(E_C - (L + \delta L)) - \gamma_1((L + \delta L) - E_{NL})] - [-\gamma_4(E_C - L) - \gamma_1(L - E_{NL})] \\ &= \delta L(\gamma_4 - \gamma 1) \end{aligned} \qquad \text{(Eq. E7)}$$

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

$\delta L = 1$ 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

$$dP_{L1} = [\gamma_{2\text{-}1}(E_C - E_{PH}) + \gamma_{3\text{-}1}(E_{PH} - E_X)] - [\gamma_{1\text{-}1}(E_C - L1) + \gamma_{4\text{-}1}(L1 - E_{NL}) + \gamma_{2\text{-}1}(E_{NL} - E_{PL}) + \gamma_{3\text{-}1}(E_{PL} - E_X)$$

$$= \gamma_{2\text{-}1}(E_C - E_{PH} - E_{NL} + E_{PL}) + \gamma_{3\text{-}1}(E_{PH} - E_{PL}) - \gamma_{4\text{-}1}(E_C - L1) - \gamma_{1\text{-}1}(L1 - E_{NL}) \quad \text{(Eq. E9)}$$

where:

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

Environment 2

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

where:

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

$$L1 = L2$$
$$\gamma_{1\text{-}1} = \gamma_{1\text{-}2}$$
$$\gamma_{4\text{-}1} = \gamma_{4\text{-}2}$$

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

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

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:

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

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_{2a} = 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:

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

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

(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 shut-down 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.

At normal process conditions:

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

At calibration conditions:

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

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.

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

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

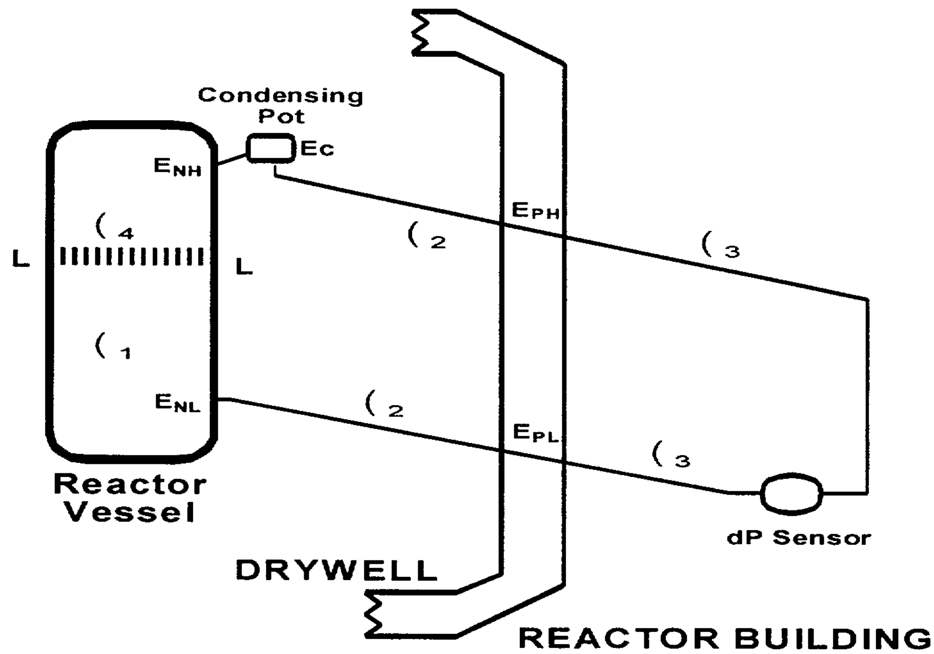
Therefore:

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

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

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:

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



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

APPENDIX F

TEMPERATURE EFFECTS ON LEVEL MEASUREMENT

1.0 INTRODUCTION

Differential pressure level measurement systems are typically calibrated for a specific set of operating conditions, i.e. processes 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)[1]:

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

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.

[1] The term "error fraction" and the equation E = % IND LVL - % ACT LVL, is consistent with the steam generator level protection and EOP setpoint accuracy evaluation originally provided by Westinghouse and currently incorporated in ComEd setpoint accuracy calculations for Byron and Braidwood stations.

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

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

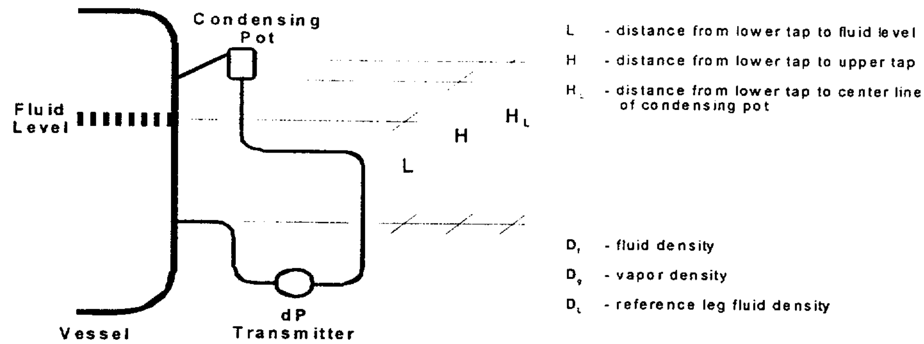
$$\%\ \text{IND LVL} = \left(\frac{H_L}{H}\left(\frac{\rho_{L1} - \rho_{L2} - \rho_{g1} + \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) + \frac{L}{H}\left(\frac{\rho_{f2} - \rho_{g2}}{\rho_{f1} - \rho_{g1}} \right) \right) \times 100$$

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 = % IND LVL - % ACT LVL

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



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:

$$dP_{100\%\,lvl} = \rho_{L1} g H_L - (\rho_{f1} g H + \rho_{g1} g (H_L - H))$$
$$= g H_L (\rho_{L1} - \rho_{g1}) - g H (\rho_{f1} - \rho_{g1})$$

$$dP_{0\%\,lvl} = \rho_{L1} g H_L - \rho_{g1} g H_L$$
$$= g H_L (\rho_{L1} - \rho_{g1})$$

Calculate the transmitter dP at L% level for the dP at T_2 and P_2 conditions:

$$L\% = (L/H) \times 100\%\ lvl$$

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

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

$$
\%\ \text{IND LVL} = \frac{dP_{L\%\,lvl} - dP_{0\%\,lvl}}{dP_{100\%\,lvl} - dP_{0\%\,lvl}} \times 100
$$

$$
= \left(\frac{[gH_L(\rho_{L2} - \rho_{g2}) - gL(\rho_{f2} - \rho_{g2})] - [gH_L(\rho_{L1} - \rho_{g1})]}{[gH_L(\rho_{L1} - \rho_{g1}) - gH(\rho_{f1} - \rho_{g1})] - [gH_L(\rho_{L1} - \rho_{g1})]} \right) \times 100
$$

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

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

The error fraction is:

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

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

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

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.

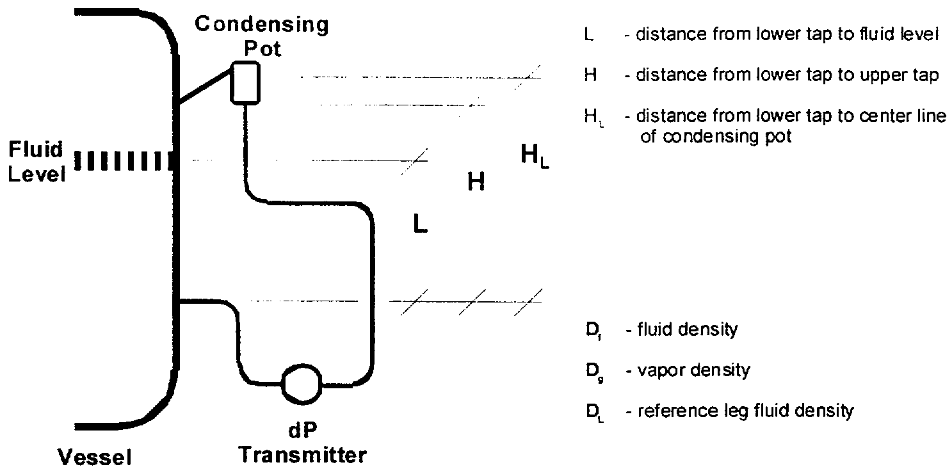
4.1 ERROR FRACTION

The error fraction for changes in reference leg temperature is:

E = % IND LVL - % 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)



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:

$$dP1_{100\%\,lvl} = \rho_l g H_L - (\rho_f g H + \rho_g g (H_L - H))$$
$$= g H_L (\rho_l - \rho_g) - g H (\rho_f - \rho_g)$$

$$dP1_{0\%\,lvl} = \rho_l g H_L - \rho_g g H_L$$
$$= g H_L (\rho_l - \rho_g)$$

Calculate the transmitter dP at 0% and 100% level for the T_2 conditions:

$$dP2_{100\%\,lvl} = \rho_2 g H_L - (\rho_f g H + \rho_g g (H_L - H))$$
$$= g H_L (\rho_2 - \rho_g) - g H (\rho_f - \rho_g)$$

$$dP2_{0\%\,lvl} = \rho_2 gH_L - \rho_g gH_L$$
$$= gH_L(\rho_2 - \rho_g)$$

$$dP_L = (L/100)(dP1_{100\%\,lvl} - dP1_{0\%\,lvl}) + dP1_{0\%\,lvl}$$
$$= (L/100)(gH_L(\rho_1 - \rho_g) - gH(\rho_f - \rho_g) - gH_L(\rho_1 - \rho_g)) + gH_L(\rho_1 - \rho_g)$$
$$= gH_L(\rho_1 - \rho_g) - (LgH/100)(\rho_f - \rho_g)$$

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.

```
                              actual
% level0                      level                  100
              |-------------------|-------------------------|
dP            dP2_0%              dP_L                  dP2_100%
```

Figure F3, % Level vs. dP

$$\frac{ACT\ LVL - 0\%}{dP_L - dP2_{0\%}} = \frac{100\% - 0\%}{dP2_{100\%} - dP2_{0\%}}$$

$$ACT\ LVL = \frac{dP_L - dP2_{0\%}}{dP2_{100\%} - dP2_{0\%}} \times 100$$

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

$$dP_L = dP1_L$$

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

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

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

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.

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.

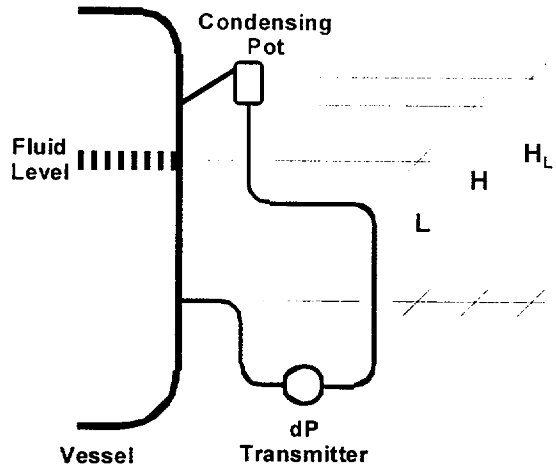
Typical condensing pot installations are located close to the vessel. This results in the H_L/H term in the following equations being sufficiently close to 1 for this term to be ignored.

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)



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 $T_{REF\ LEG1}$:

$$dP1_{100\%\ lvl} = \rho_{L1} g H_L - (\rho_{f1} g H + \rho_{g1} g (H_L - H))$$
$$= g H_L (\rho_{L1} - \rho_{g1}) - g H (\rho_{f1} - \rho_{g1})$$

$$dP1_{0\%\ lvl} = \rho_{L1} g H_L - \rho_{g1} g H_L$$
$$= g H_L (\rho_{L1} - \rho_{g1})$$

Calculate the transmitter dP at L% level for the new conditions T_2, P_2 and $T_{REF\ LEG2}$:

$$\begin{aligned} dP2_{L\%\ lvl} &= \rho_{L2} g H_L - (\rho_{f2} g L + \rho_{g2}\, g(H_L - L)) \\ &= \rho_{L2} g H_L - \rho_{f2} g L - \rho_{g2} g H_L + \rho_{g2} g L \\ &= g H_L(\rho_{L2} - \rho_{g2}) - gL(\rho_{f2} - \rho_{g2}) \end{aligned}$$

Calculate the indicated level (in % indicated level) for a dP = $dP2_{L\%\ lvl}$ at the calibrated conditions T_1, P_1, and $T_{REFLEG1}$.

$$\%\ IND\ LVL = \frac{dP_{L\%\ lvl} - dP_{0\%\ lvl}}{dP_{100\%\ lvl} - dP_{0\%\ lvl}} \times 100$$

$$= \frac{[gH_L(\rho_{L2} - \rho_{g2}) - gL(\rho_{f2} - \rho_{g2})] - [gH_L(\rho_{L1} - \rho_{g1})]}{[gH_L(\rho_{L1} - \rho_{g1}) - gH(\rho_{f1} - \rho_{g1})] - [gH_L(\rho_{L1} - \rho_{g1})]} \times 100$$

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

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

The error fraction is:

$$E = \%\ IND\ LVL - \%\ ACT\ LVL$$

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

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

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 ComEd 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 which 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 BWRs 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 BWRs Pursuant to 10CFR50.54(f)

APPENDIX G

DELTA-P MEASUREMENTS EXPRESSED IN FLOW UNITS

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 ±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:

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

where N = Nominal Flow

Taking the partial derivative and solving for ∂F_N:

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

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:

$$\frac{dP_N}{dP_{MAX}} = \frac{(F_N)^2}{(F_{MAX})^2} \qquad \text{(Eq. G3)}$$

where: MAX = maximum flow

The transmitter dP error is defined by:

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

Therefore:

$$\frac{\partial F_N}{F_N} = \frac{\partial dP_N}{2dP_N} = \frac{dP_{MAX}\left(\frac{\%FS\ dP}{100}\right)}{2dP_{MAX}\left(\frac{F_N}{F_{MAX}}\right)^2}$$

$$= \frac{\%FS\ dP\left(\frac{F_{MAX}}{F_N}\right)^2}{(2)(100)} \qquad \text{(Eq. G5)}$$

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

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

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

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

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

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

$$= \left(\frac{\%FS\ dP}{2}\right)\left(\frac{F_{MAX}}{F_N}\right) \qquad \text{(Eq. G8)}$$

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

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

(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.

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

(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.

4.1.1 Find the error in % flow at 100% flow

From section 4.1:

F_{MAX} = 120%
F_N = 100%
error in % full scale dP = 1% dP span

Use equation G10 for nominal flow error determination.

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

$$= \left(\frac{1\%}{2}\right)\left(\frac{120}{100}\right)^2$$

$$= \pm 0.72\% \text{ flow at } 100\% \text{ flow}$$

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

F_{MAX} = 120%
F_N = 100%
error in % full scale dP = ±1% dP span

Use equation G9 for full span error determination.

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

$$= \left(\frac{1\%}{2}\right)\left(\frac{120}{100}\right)$$

$$= \pm 0.6\% \text{ flow span}$$

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

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

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

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

$$\text{dP}_N = 347.22 \text{ in. WC}$$

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:

Hi flow:

$$\frac{(\text{Flow}_{MAX}\%)^2}{\text{dP}_{MAX}} = \frac{(\text{Flow}_N\%)^2}{\text{dP}_N \pm 5\,\text{in. WC}}$$

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

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

Low flow:

$$\frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(\text{Flow}_N\%)^2}{342.22 \text{ in. WC}}$$

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

Therefore the flow error is ±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.

Full flow = (100% flow)(100% span / 120% flow)
= 83.33% of full span

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

(100 + 0.72)(100% span / 120% flow) = 83.93% full span

(100 - 0.72)(100% span / 120% flow) = 82.73% full span

The deviation from full flow as a % of span is: 83.93% span - 83.33% span = 0.6% span and 83.33% span - 82.73% span = 0.6% span. Therefore, the nominal or 100% flow in terms of % full span is equivalent to 83.33±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:

Approximation:

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

$$= \left(\frac{1\%}{2}\right)\left(\frac{120}{30}\right)^2$$

$$= \pm 8.0\% \text{ flow at } 30\% \text{ flow}$$

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

$$= \left(\frac{1\%}{2}\right)\left(\frac{120}{30}\right)$$

$$= \pm 2.0\% \text{ flow span}$$

Actual error:

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

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

$$\frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(30\%)^2}{\text{dP}_N}$$

$$\text{dP}_N = 31.25 \text{ in. WC}$$

Using a 1% span error = ±5 in. WC:

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

Hi flow: $$\frac{(120\%)^2}{500 \text{ in. WC}} = \frac{(\text{Flow}_N\%)^2}{36.25 \text{ in. WC}}$$

$$\text{Flow}_{N^+} = 32.31\ \% \text{ flow}$$

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% span / 120% flow) = 27.08% flow span

(30 – 2.50)(100% span / 120% flow) = 22.92% flow span

The conservative error for a decreasing setpoint is:

25% span – 22.92% span = ±2.08% flow span.

Step 4.4 shows that when errors are calculated as a "% of flow span", the approximate and actual error (±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.

APPENDIX H

CALCULATION OF EQUIVALENT POINTS ON NON-LINEAR SCALES

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.

```
1                      2.7993                   5 volts
|--------------------------|-------------------------|
10                          ?                   10^7 CPM
```

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 to 1)/ (5 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:

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

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

$$\log\ x = 3.69895$$

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

An alternate method to solve for log x:

$$\begin{aligned}\log x &= 3.69895\\ x &= 10^{3.69895} = 10^{0.69895} \times 10^{3}\\ &= 4.998 \times 10^{3} \approx 5000 \text{ CPM}\end{aligned}$$

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

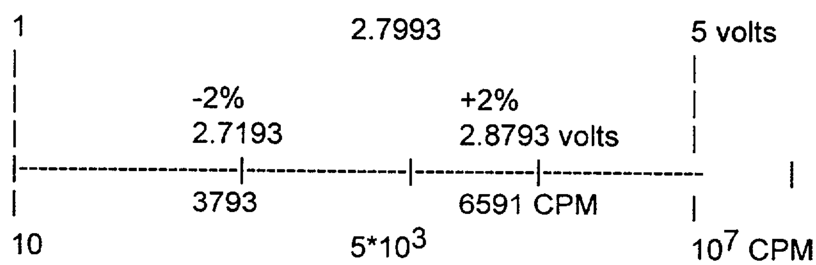
2.7993 volts ± (2%(5 volts - 1 volt)) = 2.7993 ± 0.08 volts

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

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

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

$$\begin{aligned}\log x &= 3.81895\\ x &= 6590.98 \approx 6591 \text{ CPM}\end{aligned}$$



Thus, for a linear input of 1 to 5 volts with an error of ±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.

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.

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

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

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

```
0%                    65%                 100 % input
|-------------------------|--------------------|
10                     ?                  10^7 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.

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

```
0%                  65%              100 % input
|--------------------|----------------|
10^-10               ?               10^-1 % power
```

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

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

$$\log x = -4.15$$

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

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

3.3 EXAMPLE 3

Using the ranges in Example 2, find the ±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.

```
0%                  x %                 100 % input
          x-2%              x+2%
|-------------|--------|--------|---------------|
              L                 U
10^-10                                  10^-1  % power
```

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).

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

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

$$U=10^{-3.974902}=1.06\times10^{-4}\%\ \text{power}$$

Solve for the lower limit (L).

$$U=10^{-3.974902}=1.06\times10^{-4}\%\ \text{power}$$

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 ±U or ±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.

APPENDIX I

NEGLIGIBLE UNCERTAINTIES

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, the radiation effect is 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 is considered to be calibrated out on a periodic basis. A condensing environment is regarded as an abnormal event which will require maintenance to the equipment. Humidities 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)

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

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 be resulted 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 is 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 RTDs 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 RTDs and thermocouples must be considered separately and must be evaluated for each specific application

APPENDIX J

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

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 ComEd to ensure consistency and compliance with regulatory position GL-91-04. This process will specifies 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 it's subsequent use. ComEd 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:

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 ComEd 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 make statistical significance. 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. 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 manufacturer's 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 to be identical, specifically in the critical areas of concern.

2.1.2.2. ComEd has specified that the number of valid data points that are required to make a drift study statistically significant shall be ≥ 20 data points. The value of 20 samples 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 report. To allow for the potential of an outlier, this number should be > 20 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. If the instrument has not been installed for that period of time, 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. If after the selection of instruments there is an insufficient range of calibration internals in the selected data, additional instruments shall be added to expand the range.

2.1.3 Data Collection is the transfer of data from the calibration records to the final analysis tool. This is a very sensitive process that 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 three calibration intervals (i.e. at least four sets of calibration data). If there are less than seven 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.

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.

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.

2.1.3.3 All Data transfer will require 100% independent verification.

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.

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

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% or 1% significance level is recommended. Refer to ASTM Standard E 178-80 for further information regarding the interpretation of the T-Test.

Example, Instrument Draft Sample

Consider the 20 instrument drift data points shown in Table J2. The data appears to be within a ±1% 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.

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 can 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.

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 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 remainer 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). ComEd 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 which 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.

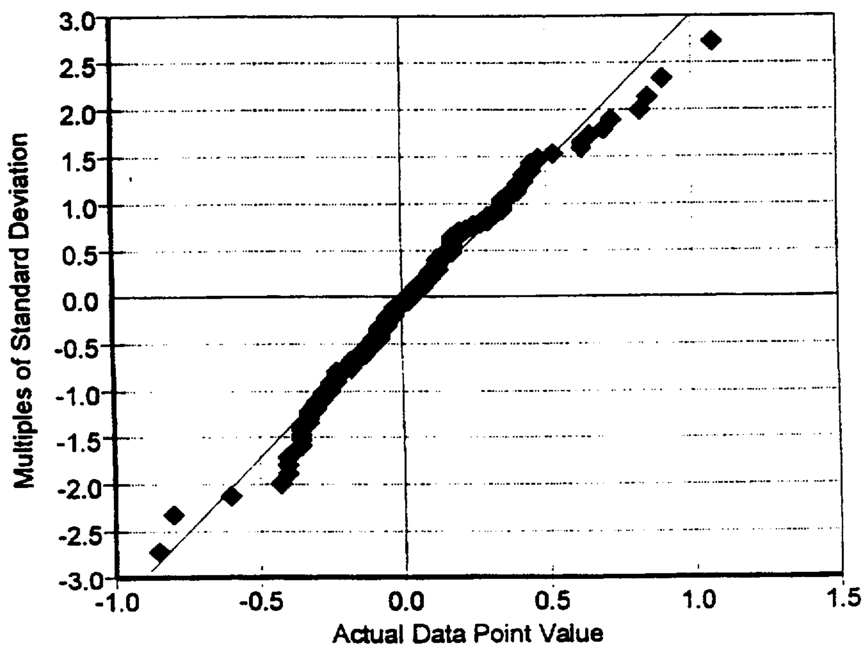


Figure J2, Typical Probability Plot for Approximately Normally Distributed Data

- 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.

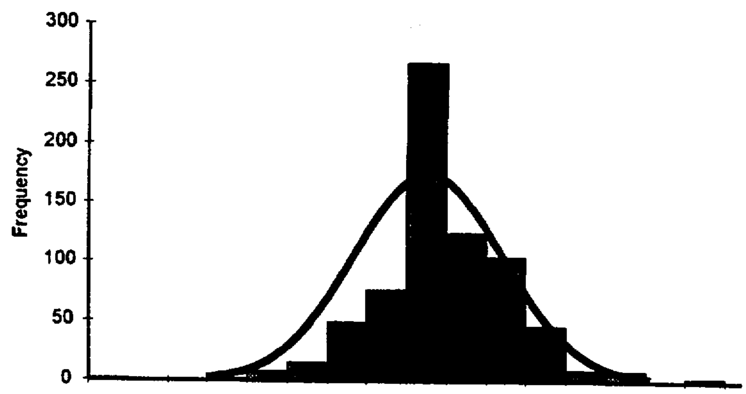


Figure J3, Coverage Analysis Histogram

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 to accomplish this activity.

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.

2.5.2 The basic assumption that drift is linear time dependant will be used for the initial evaluation of the computed drift.

The methodology to determine the existence or lack of time dependency requires evaluation of the mean of the data over calibration interval and the variation in uncertainty over calibration interval.

The following methodology has been selected by ComEd for determining time dependency.

2.5.2.1 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 ($\overline{x}$), sample standard deviation (σ) and data count (η) shall be computed. In addition, the average interval of the data points will also be computed.

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.

b. For those bins that are to be considered the difference between bins will less than twenty percent of the total data count.

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.

Example, Time Dependence Evaluation

For a given make and model of transmitter there were a total of twelve EPNs 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:

Bin	Data Count	% of Total Count
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 46 to 135 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:

Bin	Data Count	% of Total Count
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:

Bin	Data Count	% of Total Count
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.

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. 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: 21 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	19	1.701			

Table J3, Standard ANOVA Table

If the value for R^2 is greater than 0.3, then the drift appears 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 drift 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]

2.5.2.5 If the initial regression test did not find a linear time dependency, then the same regression test shall be applied to the absolute value of the same data.

The absolute value of the data is used to detect an expanding uncertainty with a sample mean near zero. Near zero sample mean exists for most drift data and thus there is a chance that the increasing uncertainty will be not detected.

2.5.2.6 If neither of the regression tests show an R^2 value greater than 0.3, then there is no time dependency for the time frame evaluated.

2.5.2.7 For those cases with no apparent time dependency, one additional check should be performed to identify any potential problems resulting from increasing uncertainty.

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 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.

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 Compute the bias (Section 2.6.1.1) and the tolerance (Section 2.6.1.3). The tolerance value is assumed to be random, allowing the use of the Square Root Sum of the sum of the Squares combination for longer time intervals.

2.5.3.3 Define the drift as either:

a. Time dependent with a bias and tolerance for the period up to the average calibration interval of the bin.

b. Time independent using the 99/95 tolerance value. Historically as-found/as-left studies have not identified any time dependency in drift. By using this expanded tolerance interval this historical information will allow expansion of time independent drift to one bin either side of the bin used for the analysis.

2.6 RESULTS

2.6.1 As a result of these as-found/as-left analyses, a value of derived drift for the instrument make/model will be determined. 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) 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 dependant 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:

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. This additional margin will be:

a. Using the value for the mean and standard deviation (Units/Day) from the process described in Section 2.5.2.7, multiply each value by the number of days that the extrapolation is required. The extrapolation cannot go beyond the next bin. All negative values for standard deviation will be set to zero.

b. Add the extrapolated value to the mean and sample standard deviation to obtain an adjusted mean and sample standard deviation. These adjusted values will be the values used for computing the results required in Sections 2.6.1.1, 2.6.1.2 and 2.6.1.3.

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.

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.

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.

2.7.2 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.

2.7.3 Time independent drift can be assumed to be constant over the Valid Interval. It can also be assumed to be 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 NSP-ER-3018 "Instrument Trending Program" shall be followed.