ATTACHMENT 4

Instrument Setpoint Calculation Methodology

TITLE: **INSTRUMENT SETPOINT CALCULATION METHODOLOGY**

SCOPE OF REVISION:

1. Adopted ISA 67.04 Part II, 1994 methodology since existing GE methodology does not provide guidance on development of As-Found and As-Left tolerances.
2. Revised Appendix L, Graded Approach to provide only one method of categorization. This was done to ensure consistency in the application of Graded Approach.
3. Provided clarification on the use of specific equations and developed section 4.5.4 to list all equations in a single location for ease of use.
4. Deleted Appendix Q "Channel Error for Indication Uncertainty" and added steps to perform Indication Loop Uncertainty into the main body of CI-01.00.
5. Removed development of LER avoidance zone and Leave alone zone since development of As-Found tolerance by the revised methodology negates the need for these values.
6. Identified which formulas to use for setpoints with Allowable Values, Setpoints without Allowable Values and for indicator/control loops.
7. Revised Appendix B to provide a sample format of a calculation and removed existing example calculations since they were not done to the revised methodology.
8. Deleted Appendix M (drift evaluation) and referenced EPRI TR-103335, Rev. 1, Statistical Analysis of Instrument Calibration Data since CPS does not statistically analyze instrument drift.
9. Revised section 5.24 to reference CI-CPS-187 instead of CI-CPS-184 for DBA influence on insulation resistance. CI-CPS-184 has been canceled. This resolves CR 1-98-03-042, Corrective Action Step #16.

INFORMATION USE

Procedure Owner: Paul Marcum Approval Date 01-04-01

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1.0 PURPOSE

1.1 The purpose of this Engineering Standard is to provide a methodology for the determination of instrument loop uncertainties and setpoints for the Clinton Power Station. The methodology described in this standard applies to uncertainty calculations for setpoint, control, and indication applications.

1.2 This document provides guidelines for the calculation of instrumentation setpoints, control, and indication applications for the Clinton Power Station.

1.3 These guidelines are applicable to all instrument setpoints. They include guidance for calculation of both Allowable Values and Nominal Trip Setpoints for setpoints included in plant Technical Specifications and calculation of Nominal Trip Setpoints for instruments not covered in the plant Technical Specifications. This document also includes guidance for determination of all input data applicable to the calculations as well as important topics concerning the interfaces with surveillance and calibration procedures and practices.

2.0 DISCUSSION/DEFINITIONS

2.1 Discussion

2.1.1 This document is structured to progress through a complete calculation process, from the most detailed level of individual device characteristics (drift, accuracy, etc.), through determination of loop characteristics, and finally to calculation of setpoints and related topics, as outlined in the following figure:

Definition of Input Data and Requirements

Calculation of Individual Device Terms (device accuracy, drift, etc.)

Combination of Individual Device Terms into Loop Terms (loop accuracy, etc.)

Calculation of Total Channel/Loop Values (Setpoint, Allowable Value, etc.)

Evaluation of Results and Resolution of Problem areas

Supporting Information

FIGURE 1. THE SETPOINT CALCULATION PROCESS

a. DETERMINE SETPOINT OR CHANNEL ERROR VALUE TO BE CALCULATED

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l. OPTIMIZE CHANNEL TO MEET REQUIREMENTS

2.1.2 Instrument setpoint uncertainty allowances and setpoint discrepancies are issues that have led to a number of operational problems throughout the nuclear industry. Historically CPS instrument loop uncertainty and setpoint determination had been based upon varying setpoint methodologies. Instrument channel uncertainty and setpoint determination had been established by two different methods depending on whether or not they applied to the Reactor Protection System and Engineered Safeguards Functions developed by GE or other safety related systems. A third methodology was used to verify that an allowance for instrument uncertainty was contained in the allowable value for Technical Specifications indicating instruments. All three methodologies were rigid in recommendation and differed in both process and application. This resulted in CPS instrument uncertainty and setpoint calculations lacking consistent definition of allowable value and improper understanding of the relationship of the allowable value to earlier setpoint methodologies, procedures, and operability criteria. Beginning with Rev. 1, this Engineering Standard is intended to provide consistency between all CPS instrument setpoint calculations by incorporating the common strengths of each historical methodology into one common method. This Standard provides a mechanism for the uniform development of new and revised CPS instrument setpoint calculations. This Standard incorporates the common strengths of each historical methodology into one common method consistent with accepted industry practice.

2.1.3 This standard provides flexibility, then, in the precise method by which a setpoint is determined, allowing for variations in calculation rigor dependent upon the significance of the function of the setpoint or operator decision point. The intent is to provide a format and systematic method, in contrast with a prescriptive method, of identifying and combining instrument uncertainties. As such, this standard provides guidelines to statistically combine uncertainties of components in a measurement and perform comparisons to ensure that there is adequate margin between the setpoint and a given limit to account for measurement error. This descriptive systematic method provides a consistent criterion for assessing the magnitude of uncertainties associated with each uncertainty component, thereby ensuring plant safety.

2.1.4 A systematic method of identifying and combining instrument uncertainties is necessary to ensure that adequate margin has been provided for safety related instrument channels that perform protective functions and for instrument channels that are important to safety. Thus ensuring that vital plant protective features are actuated at the appropriate time during transient and accident conditions. Analytical Limits have been established through the process of accident analysis, which assumed that plant protective features would intervene to limit the magnitude of a transient. Limiting Safety System Settings (LSSS) are established in accordance with 10 CFR 50.36. Ensuring that these protective features actuate as they were assumed in the accident analysis provides assurance that safety limits will not be exceeded. The methodology presented by this revision is based on the industry standard ANSI/ISA S67.04, "Setpoints for Nuclear Safety Related Instrumentation" Parts I and II(Ref. 5.3), which is endorsed by Regulatory Guide 1.105 (Ref. 5.11). Clinton Power Station (CPS) has invoked RG 1.105 for a basis for meeting the requirements of 10CFR50, Appendix A, general design criterion 13 and 20.

2.1.5 Relation to ISA Standards and Regulatory Guides

2.1.5.1 The applicable ISA Standard for setpoint calculations is ISA S67.04. That standard was prepared by a committee of the ISA, which included some representatives who also participated in preparation of the CPS Setpoint Methodology. The CPS Setpoint Methodology is consistent with ISA Standard S67.04.

2.1.5.2 There are three Regulatory Guides related to setpoint methodology; RG 1.105 (Ref. 5.11), RG 1.89 (Ref. 5.35) and RG 1.97 (Ref. 5.34). RG 1.105 covers setpoint methodology. This Setpoint Methodology complies with RG 1.105. RG 1.89 covers equipment qualification. This Setpoint Methodology does not directly address equipment qualification, beyond the basic assumption that instrumentation is qualified for its intended service. This Setpoint Methodology may be used to determine instrument errors under various conditions as part of the process of demonstrating that instruments are qualified to perform specified functions, in accordance with RG 1.89. RG 1.97 covers the topic of post accident instrumentation. This Setpoint Methodology also does not address RG 1.97. However, as is the case with RG 1.89, the methods of determining instrument performance inherent in this Setpoint Methodology may be used when demonstrating that a particular instrument channel satisfies the guidance of RG 1.97.

2.1.6 In summary, this standard, based upon ISA-S67.04, provides an acceptable method to calculate instrument loop accuracy and setpoints, and applies to NSED as well as any technical staff members involved in the modification of instrument loops at CPS. The results of an uncertainty analysis might be applied to the following types of calculations:

- Parameters and setpoints that have Analytical Limits
- Evaluation or justification of previously established setpoints
- Parameters setpoints that do not have Analytical Limits.
- Determination of instrument indication uncertainties

2.1.7 Setpoints without Analytical Limits

Many, setpoints are important for reliable power generation and equipment protection. Because these setpoints may not be derived from a safety limit threaded to an accident analysis, the basis for the setpoint calculation is typically developed from process limits providing either equipment protection or maintaining generation capacity. As defined in Appendix L, "Graded Approach to Uncertainty Analysis", the criteria in this Engineering Standard may also be used as a guide for setpoints that do not have Analytical Limits to improve plant reliability, but the calculation may not be as rigorous.

2.1.8 These guidelines are applicable to all instrument setpoints. They include guidance for calculation of both Allowable Values and Nominal Trip Setpoints for setpoints included in plant Technical Specifications, and calculation of Nominal Trip Setpoints for instruments not covered in plant Technical Specifications.

2.1.9 Indication Uncertainty (Channel Error)

Uncertainty associated with process parameter indication is also important for safe and reliable plant operation. Allowing for indication uncertainty supports compliance with the Technical Specifications and the various operating procedures. As defined in Appendix L, the methodology presented in this Engineering Standard is applicable to determining indication uncertainty.

2.1.10 Mechanical Equipment Setpoints

This Engineering Standard was developed specifically for instrumentation components and loops. This Engineering Standard does not specifically apply to mechanical equipment setpoints (i.e. safety and relief valve setpoints) or protective relay applications. However, guidance presented herein may be useful to predict the performance of other non-instrumentation-type devices.

2.1.11 Rounding Conventions

Normal rounding conventions (rounding up or down depending on the last digit in the calculated result) do not apply to error calculations or setpoints. All rounding of results should be done in the direction, which is conservative relative to plant safety (upward for error terms, away from the Analytical Limit for Allowable Values and Nominal Trip Setpoints). Additionally, all output values to calibration procedures should be in the precision required by the calibration procedure.

2.2 **Definitions**

NOTE

The following definitions are based on the methodology of NEDC-31336 (Ref. 5.1). Where the terms defined are equivalent to terms used in ISA Standard S67.04 (Ref. 5.3), the equivalence is noted.

2.2.1 AS-FOUND TOLERANCE (AFT_L): the tolerance of the As-Found error in the instrument loop (AFT_L), which requires calibration to restore the loop within the As-Left Tolerance. An as-found tolerance (AFT_i) is also developed for all devices in channel.

2.2.2 ACCURACY TEMPERATURE EFFECT (ATE): The change in instrument output for a constant input when exposed to different ambient temperatures.

2.2.3 ALLOWABLE VALUE (AV): (Technical Specifications Limit): The limiting value of the sensed process variable at which the trip setpoint may be found during instrument surveillance. Usually prescribed as a license condition. Equivalent to the term Allowable Value as used in ISA Standard S67.04

2.2.4 ANALYTICAL LIMIT (AL): The value of the sensed process variable established as part of the safety analysis prior to or at the point which a desired action is to be initiated to prevent the safety process variable from reaching the associated licensing safety limit. Equivalent to the term Analytical Limit as used in ISA Standard S67.04.

2.2.5 AS-LEFT TOLERANCE (ALT_i): This tolerance is the precision with which the technician should be able to set the device during surveillance. Additionally, if the As-Found value is within the (ALT_i) then re-calibration is not required. The As-Left Tolerance is determined by the organization responsible for defining the surveillance procedures (recommendations are provided in this document). A loop as-left tolerance (ALT_L) is also developed for all devices in channel.

2.2.6 BIAS (B): A systematic or fixed instrument uncertainty, which is predictable for a given set of conditions because of the existence of a known direction (positive or negative). See Appendix C, Section C.1.2, for additional discussion.

2.2.7 BOUNDING VALUE (BV): The extreme value of the conservatively calculated process variable that is to be compared to the licensing safety limit during the transient or accident analysis. This value may be either a maximum or minimum value, depending upon the safety variable.

2.2.8 CALIBRATION TOOL ERROR (C_i): The accuracy of the device (multimeter, etc.) being used to perform the calibration or surveillance test. Also referred to as M&TE (MTE). For typical precision equipment CPS recommends that this error term be considered to be a 3 sigma value, provided that the calibration of these devices is to NIST traceable standards and minimizes the effects of hysterisis, linearity and repeatability.

2.2.9 CALIBRATION STANDARD ERROR (CSTD): The error in the calibration of the calibrating tool. Per CPS standard CI-01.00 assumptions, this value considered negligible to the overall calibration error term and can be ignored.

2.2.10 CHANNEL CALIBRATION ACCURACY (C_L): The quality of freedom from error to which the nominal trip setpoint of a channel can be calibrated with respect to the true desired setpoint. Considering only the errors introduced by the inaccuracies of the calibrating equipment used as the standards or references and the allowances for errors introduced by the calibration procedures. The accuracy of the different devices utilized to calibrate the individual channel instruments is the degree of conformity of the indicated values or outputs of these standards or references to the true, exact, or ideal values. The value specified is the requirement for the combined accuracies of all equipment selected to calibrate the actual monitoring and trip devices of an instrument channel plus allowances for inaccuracies of the calibration procedures. Channel calibration accuracy does not include the combined accuracies of the individual channel instruments that are actually used to monitor the process variable and provide the channel trip function.

2.2.11 CHANNEL INSTRUMENT ACCURACY (A_L): The quality of freedom from error of the complete instrument channel with respect to acceptable standards or references. The value specified is the requirement for the combined accuracy's of all components in the channel that are used to monitor the process variable and/or provide the trip functions and includes the combined conformity, linearity, hysteresis and repeatability errors of all these devices. The accuracy of each individual component in the channel is the degree of conformity of the indicated values of that instrument to the values of a recognized and acceptable standard or reference device (Usually National Bureau of Standards traceable), that is used to calibrate the instrument. Channel instrument accuracy, channel calibration accuracy, and channel instrument drifts are considered to be independent variables. This definition encompasses the terms Vendor Accuracy, Hysteresis, and Repeatability defined in ISA Standard S67.04.

2.2.12 CHANNEL INSTRUMENT DRIFT (D_L): The change in the value of the process variable at which the trip action will occur between the time the nominal trip setpoint is calibrated and a subsequent surveillance test. The initial design data considers drift to be an independent variable. As field data is acquired, it may be substituted for the initial design information. This term is equivalent to the Drift Uncertainty (DR) term used in the ISA Standard S67.04.

2.2.13 CHANNEL INDICATION UNCERTAINTY (CE): This is a prediction of error in an indicator or data supply channel resulting from all causes that could reasonably be expected during the time the channel is performing its function. This term is not used in setpoint calculations.

2.2.14 CONFIDENCE LEVEL: The relative frequency that the calculated statistic is correct.

2.2.15 CONFIDENCE INTERVAL: The frequency that an interval estimate of a parameter may be expected to contain the true value. For example, 95% coverage of the true value means, that in a repeated sampling, when 95% uncertainty interval is constructed for each sample, over the long run, the intervals will contain the true value 95% of the time.

2.2.16 CPS STANDARD CI-01.00 ASSUMPTIONS: Assumptions established by the Setpoint Program that are considered to be defendable and should be used without modification to any new or revised calculation, performed under this methodology, as applicable. See Appendix I, Section I.11 for the current standard assumptions. However, it should be noted, that specific assumptions germane to the individual calculation shall follow all standard assumptions.

2.2.17 DEADBAND: The range within which the input signal can vary without experiencing a change in the output.

2.2.18 DESIGN BASIS EVENT (DBE): The limiting abnormal transient or an accident which is analyzed using the analytical limit value for the setpoint to determine the bounding value of a process variable.

2.2.19 FULL SPAN/SCALE (FS): The highest value of the measured variable that device is adjusted to measure.

2.2.20 HARSH ENVIRONMENT: This term refers to the worst environmental conditions to which an instrument is exposed during normal, transient, accident or post-accident conditions, out to the point in time when the device is no longer called upon to serve any monitoring or trip function. This term may be used in Equipment Qualification to define the qualification conditions.

From the standpoint of establishing setpoints, Harsh Environment does not apply. This distinction is made to avoid confusion between the long-term functional requirements for the devices, which includes post-trip operation, and the operational requirements during the initial period leading to the first trip.

2.2.21 HUMIDITY EFFECT (HE): Error due to humidity.

2.2.22 HYSTERESIS: An instrument's change in response as the process input signal increases or decreases (see Fig. C-5).

2.2.23 INDICATOR READING ERROR (IRE): The error applied to the accuracy with which personnel can read the analog and digital indications in an instrument loop or on M&TE. This value will normally be one quarter of the smallest division of the scale. IRE is not required IF the device ALT is rounded to the nearest conservative half-minor division. For non-linear scales the IRE may be evaluated for the area of interest. Appendix C provides in depth discussion and usage guidelines for IRE.

2.2.24 INSTRUMENT CHANNEL: An arrangement of components required to generate a protective signal, or, in the case of monitoring channels, to deliver the signal to the point at which it is monitored. Unless otherwise stated, it is assumed that the channel is the same as the loop. Equivalent to the term Instrument Channel in ISA Standard S67.04.

2.2.25 INSTRUMENT RESPONSE TIME EFFECTS: The delay in the actuation of a trip function following the time when a measured process variable reaches the actual trip setpoint due to time response characteristics of the instrument channel.

2.2.26 INSULATION RESISTANCE ACCURACY ERROR (IRA): This is the error effect produced by degradation of insulation resistance (IR), for the various cables, terminal boards and other components in the instrument loop, exclusive of other defined error terms (Accuracy, Calibration, Drift, Process Measurement Accuracy, Primary Element Accuracy). Since the effect of current leakage associated with IRA is predictable and will act only in one direction for a given loop, IRA is always treated as a bias term in calculations.

2.2.27 LICENSEE EVENT REPORT (LER): A report which must be filed with the NRC by the utility when a technical specifications limit is known to be exceeded, as required by 10CFR50.73.

2.2.28 LICENSING SAFETY LIMIT (LSL): The limit on a safety process variable that is established by licensing requirements to provide conservative protection for the integrity of physical barriers that guard against uncontrolled release of radioactivity. Events of moderate frequency, infrequent events, and accidents use appropriately assigned licensing safety limits. Overpressure events use appropriately selected criteria for upset, emergency, or faulted ASME category events. Equivalent to Safety Limit in ISA Standard S67.04.

2.2.29 LIMITING SAFETY SYSTEMS SETTING (LSSS): A term used in the Technical Specifications, and in ISA Standard S67.04, to refer to Reactor Protection System (nominal) trip setpoints and allowable values.

2.2.30 LIMITING NORMAL OPERATING TRANSIENT: The most severe transient event affecting a process variable during normal operation for which trip initiation is to be avoided.

2.2.31 LINEARITY: The ability of the instrument to provide a linear output in response to a linear input (see Fig. C-6).

2.2.32 MEAN VALUE: The average value of a random sample or population. For n measurements of X_i, where i ranging from 1 to n, the mean is given by

$$\mu = \Sigma X_i/n$$

2.2.33 MEASURED SIGNAL: The electrical, mechanical, pneumatic, or other variable applied to the input of a device.

2.2.34 MEASURED VARIABLE: A quantity, property, or condition that is measured, e.g., temperature, pressure, flow rate, or speed.

2.2.35 MEASUREMENT: The present value of a variable such as flow rate, pressure, level, or temperature.

2.2.36 MEASUREMENT AND TEST EQUIPMENT EFFECT (MTE): The uncertainty attributed to measuring and test equipment that is used to calibrate the instrument loop components. Also called Calibration Tool Error (C_i).

2.2.37 MILD ENVIRONMENT: An environment that at no time is more severe than the expected environment during normal plant operation, including anticipated operational occurrences.

2.2.38 MODELING ACCURACY: The modeling accuracy may consist of modeling bias and/or modeling variability. Modeling bias is the result of comparing analysis models used in event analysis to actual plant test data or more realistic models. Modeling variability is the uncertainty in the ability of the model to predict the process or safety variable.

2.2.39 MODULE: Any assembly of interconnecting components, which 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, which 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.

2.2.40 MODULE UNCERTAINTY (A_i): The total uncertainty attributable to a single module. The uncertainty of an instrument loop through a display or actuation device will include the uncertainty of one or more modules.

2.2.41 NOISE: An unwanted component of a signal or variable. It causes a fluctuation in a signal that tends to obscure its information content.

2.2.42 NOMINAL TRIP SETPOINT (NTSP): The limiting value of the sensed process variable at which a trip may be set to operate at the time of calibration. This is equivalent to the term Trip Setpoint in ISA Standard S67.04.

2.2.43 NOMINAL VALUE: The value assigned for the purpose of convenient designation but existing in name only; the stated or specified value as opposed to the actual value.

2.2.44 NONLINEAR: A relationship between two or more variables that cannot be described as a straight line. When used to describe the output of an instrument, it means that the output is of a different magnitude than the input, e.g., square-root relationship.

2.2.45 NORMAL DISTRIBUTION: The density function of the normal random variable x, with mean μ and variance σ^2 is:

$$n(x;\mu,\sigma)=\frac{1}{\sqrt{2\pi}\,\sigma}e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

2.2.46 NORMAL PROCESS LIMIT (NPL): The safety limit, high or low, beyond which the normal process parameter, should not vary. Trip setpoints associated with non-safety-related functions might be based on the normal process limit.

2.2.47 NORMAL ENVIRONMENT: The environmental conditions expected during normal plant operation.

2.2.48 OPERATIONAL LIMIT (OL): The operational value of a process variable established to allow trip avoidance margin for the limiting normal operating transient.

2.2.49 OVERPRESSURE EFFECT (OPE): Error due to overpressure transients (if any).

2.2.50 POWER SUPPLY EFFECT (PSE): Error due to power supply fluctuations.

2.2.51 PRIMARY ELEMENT ACCURACY (PEA): The accuracy of the device (exclusive of the sensor) which is in contact with the process, resulting in some form of interaction (e.g., in an orifice meter, the orifice plate, adjacent parts of the pipe, and the pressure connections constitute the primary element).

2.2.52 PROBABILITY: The relative frequency with which an event occurs over the long run.

2.2.53 PROCESS MEASUREMENT ACCURACY (PMA): Process variable measurement effects (e.g., the effect of changing fluid density on level measurement) aside from the primary element and the sensor.

2.2.54 RADIATION EFFECT (RE): Error due to radiation.

2.2.55 RANDOM: Describing a variable whose value at a particular future instant cannot be predicted exactly, but can only be estimated by a probability distribution function. See Appendix C, Section C.1.1, for additional discussion.

2.2.56 RANGE: The region between the limits within which a quantity is measured, received, or transmitted, expressed by stating the lower and upper range values.

2.2.57 REPEATABILITY: The ability of an instrument to produce exactly the same result every time it is subjected to the same conditions (see Figure C-4).

2.2.58 REQUIRED LIMIT (RL): A criterion sometimes applied to As-Found surveillance data for judging whether or not the channel's Allowable Value could be exceeded in a subsequent surveillance interval.

2.2.59 REVERSE ACTION: An increasing input to an instrument producing a decreasing output.

2.2.60 RFI/EMI EFFECT (REE): Error due to RFI/EMI influences (if any).

2.2.61 RISE TIME: The time it takes a system to reach a certain percentage of its final value when a step input is applied. Common reference points are 50%, 63%, and 90% rise times.

2.2.62 RPS: Reactor Protection System.

2.2.63 RTD: Resistance Temperature Detector.

2.2.64 SAFETY LIMIT (Licensing 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.

2.2.65 SAFETY-RELATED INSTRUMENTATION: Instrumentation that is essential to the following:

- Provide emergency reactor shutdown
- Provide containment isolation
- Provide reactor core cooling
- Provide for containment or reactor heat removal
- 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

Other instrumentation, such as certain Regulatory Guide 1.97 instrumentation, may be treated as safety related even though it may not meet the strict definition above.

2.2.66 SEISMIC EFFECT (SE): The change in instrument output for a constant input when exposed to a seismic event of specified magnitude.

2.2.67 SENSOR (TRANSMITTER): The portion of the instrument channel, which converts the process parameter value to an electrical signal. This is equivalent to ISA Standard S67.04.

2.2.68 SIGMA: The value specified is the maximum value of a standard deviation of the probability distribution of the parameter based on a normal distribution.

2.2.69 SIGNAL CONVERTER: A transducer that converts one transmission signal to another.

2.2.70 SPAN: The algebraic difference between the upper and lower values of a range.

2.2.71 SPAN SHIFT: An undesired shift in the calibrated span of an instrument (see Figure C-8). Span shift is one type of instrument drift that can occur.

2.2.72 SQUARE-ROOT EXTRACTOR: A device whose output is the square root of its input signal.

2.2.73 SQUARE-ROOT-SUM-OF-SQUARES METHOD (SRSS): A method of combining uncertainties that are random, normally distributed, and independent.

$$c = \pm\sqrt{a^2 + b^2}$$

2.2.74 STANDARD DEVIATION (POPULATION): A measure of how widely values are dispersed from the population mean and is given by

$$s = \sqrt{\frac{n\sum x^2 - (\sum x)^2}{n(n-1)}}$$

2.2.75 STANDARD DEVIATION (Sample): A measure of how widely values are dispersed from the sample mean and is given by

$$\sigma = \sqrt{\frac{n\sum x^2 - (\sum x)^2}{n^2}}$$

2.2.76 STATIC PRESSURE: The steady-state pressure applied to a device.

2.2.77 STATIC PRESSURE EFFECT (SPE): The change in instrument output, generally applying only to differential pressure measurements, for a constant input when measuring a differential pressure and simultaneously exposed to a static pressure. May consist of three effects:

(SPE_S) Static Pressure Span Effect (random)

(SPE_Z) Static Pressure Zero Effect (random)
(SPE_{BS}) Bias Span Effect (bias)

2.2.78 STEADY-STATE: A characteristic of a condition, such as value, rate, periodicity, or amplitude, exhibiting only a negligible change over an arbitrary long period of time.

2.2.79 STEADY-STATE OPERATING VALUE (X_o): The maximum or minimum value of the process variable anticipated during normal steady-state operation.

2.2.80 SUPPRESSED-ZERO RANGE: A range in which the zero value of the measured variable is less than the lower range value.

2.2.81 SURVEILLANCE INTERVAL: The elapsed time between the initiation or completion of successive surveillance's or surveillance checks on the same instrument, channel, instrument loop, or other specified system or device.

2.2.82 TEST INTERVAL: The elapsed time between the initiation or completion of successive tests on the same instrument, channel, instrument loop, or other specified system or device.

2.2.83 TIME CONSTANT: For the output of a first-order system forced by a step or impulse, the time constant T is the time required to complete 63.2% of the total rise or decay.

2.2.84 TIME-DEPENDENT DRIFT: The tendency for the magnitude of instrument drift to vary with time.

2.2.85 TIME-INDEPENDENT DRIFT: The tendency for the magnitude of instrument drift to show no specific trend with time.

2.2.86 TIME RESPONSE: An output expressed as a function of time, resulting from the application of a specified input under specified operating conditions.

2.2.87 TOLERANCE: The allowable variation from a specified or true value.

2.2.88 TOLERANCE INTERVAL: An interval that contains a defined proportion of the population to a given probability.

2.2.89 TOTAL HARMONIC DISTORTION (THD): The distortion present in an AC voltage or current that causes it to deviate from an ideal sine wave.

2.2.90 TRANSFER FUNCTION: The ratio of the transformation of the output of a system to the input to the system.

2.2.91 TRANSMITTER (SENSOR): A device that measures a physical parameter such as pressure or temperature and transmits a conditioned signal to a receiving device.

2.2.92 TRANSIENT OVERSHOOT: The difference in magnitude of a sensed process variable taken from the point of trip actuation to the point at which the magnitude is at a maximum or minimum.

2.2.93 TRIP ENVIRONMENT: The environment that exists up to and including the time when the instrument channel performs its initial safety (trip) function during an event.

2.2.94 TRIP UNIT: The portion of the instrument channel which compares the converted process value of the sensor to the trip value, and provides the output "trip" signal when the trip value is reached.

2.2.95 TURNDOWN RATIO: The ratio of maximum span to calibrated span for an instrument.

2.2.96 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 which have not been corrected for. The uncertainty is generally identified within a probability and confidence level.

2.2.97 UPPER RANGE LIMIT (URL): The maximum upper calibrated span limit for the device.

2.2.98 VENDOR ACCURACY (VA): A number or quantity that defines the limit that errors will not exceed when the device is used under reference operating conditions (see Figure C-3). In this context, error represents the change or deviation from the ideal value.

2.2.99 VENDOR DRIFT (VD): The drift value identified in vendor specifications or device testing (history) data.

2.2.100 ZERO: The point that represents no variable being transmitted (0% of the upper range value).

2.2.101 ZERO ADJUSTMENT: Means provided in an instrument to produce a parallel shift of the input-output curve.

2.2.102 ZERO ELEVATION: For an elevated-zero range, the amount the measured variable zero is above the lower range value.

2.2.103 ZERO SHIFT: An undesired shift in the calibrated zero point of an instrument (see Figure C-7). Zero shift is one type of instrument drift that can occur.

2.2.104 ZERO SUPPRESSION: For a suppressed-zero range, the amount the measured variable zero is below the lower range value.

2.2.105 The following Abbreviations and Acronyms are used:

AFT_i = As-Found Tolerance
A_i = Device Accuracy
AL = Analytical Limit
A_L = Loop/Channel Accuracy
ALT = As-Left Tolerance
ATE = Accuracy Temperature Effect
AV = Allowable Value
B = Bias Effect

BV = Bounding Value

BWR = Boiling Water Reactor
C_i = Calibration Device Error
CE = Channel Indication Uncertainty
CU = Channel Uncertainty
C_L = Loop/Channel Calibration Accuracy Error
CSTD = Calibration Standard Error
D = Device Drift
DBE = Design Bases Event
D_L = Loop/Channel Drift
ECCS = Emergency Core Cooling System
FS = Full Span/Scale Value
g = Acceleration of gravity
HE = Humidity Effect
IR = Insulation Resistance
IRA = Insulation Resistance Accuracy Error
IRE = Indicator Reading Error
ISA = Instrument Society of America
LER = Licensee Event Report
LOCA = Loss of Coolant Accident
LSL = Licensing Safety Limit
LSSS = Limiting Safety Systems Setting
N,n = The number of Standard Deviations (sigma values) used
NIST = National Institutes of Science and Technology
NPL = Nominal Process Limit
NTSP = Nominal Trip Setpoint
OL = Operational Limit
OPE = Overpressure Effect
PEA = Primary Element Accuracy
PMA = Process Measurement Accuracy
PSE = Power Supply Effect
RE = Radiation Effect
REE = RFI/EMI Effect
RFI/EMI = Radio Frequency/Electro-Mechanical Interference
RG = Regulatory Guide
RL = Required Limit
RPS = Reactor Protection System
RTD = Resistance Temperature Detector
SE = Seismic Effect
SL = Safety Limit
SP = Span
SPE = Static Pressure Effect
SPE_{BS} = Bias Span Effect
SPE_S = Random Span Effect
SPE_Z = Random Zero Effect
SRSS = Square root of the sum of the squares.
T = Temperature
THD = Total Harmonic Distortion
URL = Upper Range Limit
USNRC = United States Nuclear Regulatory Commission
VA = Vendor Accuracy
VD = Vendor Drift
Z = Measure of Margin in Units of Standard Deviations
ZPA = Zero Period Acceleration
σ = Sigma

3.0 RESPONSIBILITY

The Supervisor- C&I Design Engineering is responsible for the implementation of this Standard.

4.0 STANDARD

4.1 Setpoint Calculation Guidelines

The overall process for evaluating instrumentation is depicted in Figure 1, and described in the sections of this document which follow.

4.1.1 Overview

4.1.1.1 Summary of Setpoint Methodology

The Clinton Power Station (CPS) Setpoint Methodology is a statistically based methodology. It recognizes that most of the uncertainties that affect instrument performance are subject to random behavior, and utilizes statistical (probability) estimates of the various uncertainties to achieve conservative, but reasonable, predictions of instrument channel uncertainties. The objective of the statistical approach to setpoint calculations is to achieve a workable compromise between the need to ensure instrument trips when needed, and the need to avoid spurious trips that may unnecessarily challenge safety systems or disrupt plant operation.

4.1.2 Fundamental Assumptions

4.1.2.1 Treatment of Uncertainties

The first fundamental assumption of the CPS Setpoint Methodology is that all uncertainties related to instrument channel performance may be treated as a combination of bias and/or independent random uncertainties. It is assumed that, although all random uncertainties might not exhibit the characteristics of a normal random distribution, the random terms may be approximated by a random normal distribution, such that statistical methods may be used to combine the individual uncertainties. Thus, a key aspect of properly applying this methodology is to examine the various error terms of interest and properly classify each term as to whether it represents a bias or random term, and then to assign adequately conservative values to the terms.

4.1.2.2 Trip Timing

The second fundamental assumption of the CPS Setpoint Methodology is that the automatic trip functions associated with setpoints are optimized to function in their first trip during an event, the point in time when they (and they alone) are most relied upon for plant safety. Additional or subsequent trip functions are permitted to be less accurate because their importance to plant safety (relative to the importance of operator action) is less. Worst case environmental conditions, that assume failure of protective equipment, or conditions that would only exist after the point in time where manual operation action is expected are not applicable to the automatic trip functions that are expected or relied upon to occur in the early part of an event. This assumption is necessary to ensure that overly conservative environmental assumptions are not permitted to inflate error estimates, producing overly conservative setpoints, which may themselves lead to spurious trips and unnecessary challenges to safety systems. Paragraph 4.2.4.2.(d), discusses determination of trip timing.

4.1.2.3 Instrument Qualification

The third fundamental assumption of the CPS Setpoint Methodology is that safety related instrumentation has been qualified to function in the environment expected as a result of plant events. This relates to the second assumption, above. Specifically, although the setpoint is optimized for the first trip expected in an event, the instrumentation might be required to function after the first trip. In optimizing the setpoint for the first automatic function, it is expected that later automatic functions will occur, but with potentially poorer accuracy (see paragraph 4.2.4.2.(d) for further discussion on trip timing). The later automatic functions of the instrumentation can only be expected if the instrumentation has been qualified for the expected environmental conditions.

4.1.3.1 Probability Criteria

4.1.3.2 Because the CPS Setpoint Methodology is statistically based, it is necessary to establish a desired probability for the various actions associated with the setpoints. The probability target is 95%. This value has been accepted by the USNRC. Appendix C, Uncertainty Analysis Fundamentals and Reference 5.32, EPRI TR-103335, provide detail discussion of the systematic methodology.

4.1.3.3 In applying the 95% probability limit, it is important to recognize the form of the data and the objective of the calculation. For the case of test data or vendor data, the 95% probability limit corresponds to plus or minus two (2) standard deviations (i.e., 2 sigma). This represents a normal distribution with 95% of the data in the center, and 2.5% each at the upper and lower edges of the distribution. In the case of a setpoint calculation, we are usually not interested in a plus or minus situation. Instead, since the purpose of the trip setpoint is to ensure a trip only when approaching a potentially unsafe condition (one direction only). CPS is interested in a distribution in which 95% is below the trip point, and 5% is beyond the trip point, all at one end of the normal distribution. This is called a normal one-sided distribution. The point at which 5% of the cases lie beyond the trip point corresponding to 1.645 standard deviations (i.e., 1.645 sigma).

4.1.3.4 In performing the setpoint or channel error calculations it will be important that the probabilities associated with various elements of the calculation be known and properly accounted for. Scaling and the design requirements necessary for implementing process measurement will be evaluated and controlled in a device calculation.

4.1.3.4 In performing the setpoint or channel error calculations it will be important that the probabilities associated with various elements of the calculation be known and properly accounted for. Vendor and calibration data will generally be 2 or 3 sigma values. In determining channel accuracies and other errors, the data will generally be adjusted to a common 2 sigma basis. Subsequently in setpoint calculations, etc., the probability limits will be adjusted from 2 sigma to the particular probability limit of interest.

4.2 Definition of Input Data and Requirements

This section of this document provides detailed discussion of the input data and requirements that may apply to a given calculation, in terms of information on the characteristics of the instrument channel and the applicable design requirements. Additional guidance is provided in Appendix C, and in detailed Appendices, as indicated.

4.2.1 Defining Instrument channel characteristics, Overview
The instrument characteristics to be defined depend on the nature of the instrument channel. Generally, the following information should be included in the instrument channel design characteristics:

4.2.1.1 Instrument Definition
Manufacturer
Model
Range
Vendor Performance specifications
Tag Number
Instrument Channel Arrangement

4.2.1.2 Process and Physical Interfaces
Environmental Conditions
Seismic Conditions
Process Conditions

4.2.1.3 External Interfaces
Calibration Methods
Calibration Tolerances
Installation Information
Surveillance Intervals
External Contributions
Process Measurement
Primary Element
Special terms and Biases

Each of these aspects is discussed in more detail in the following Section

4.2.2 Defining Instrument Channel Characteristics

4.2.2.1 Instrument Definition

a. Manufacturer, Model, Tag Number, Instrument Arrangement

The instrument tag number, Manufacturer and model number are determined from controlled design information or by examination of the actual instruments. Instrument channel arrangement refers to the schematic layout of the channel, including both the physical layout and the electrical connections. The physical layout is important for devices that may be exposed to static head or local environmental conditions, so that the conditions can be properly accounted for in the calculations. The electrical connections are of importance because the actual manner in which the devices in a channel are connected affects the combination of error terms, particularly with regard to estimating calibration errors.

b. Instrument Range

The instrument range for each device in the instrument channel includes at least four terms.

The Upper range limit(URL) of the instrument and the calibrated span (SP) of the device. The last two, are the range of the input signal to the device, and the corresponding range of output signal produced in response to the input.

As an illustration, consider a typical channel consisting of a pressure transmitter connected to a trip unit and a signal conditioner leading to an indicator channel:

The maximum pressure range over which the transmitter is capable of operating is the URL. The process pressure range for which the transmitter is calibrated is the SP.

The output signal range of the transmitter is the electrical output(volts or milliamps) corresponding to the calibrated span.

The input to the trip unit and the signal conditioner would be the electrical input corresponding to the electrical output of the transmitter. In a similar fashion, the input and output ranges for every device in the instrument channel is defined by establishing the electrical signal that corresponds to the calibrated span of the transmitter.

c. Vendor Performance Specifications

Vendor performance specifications are the terms that identify how the individual devices in an instrument channel are expected to perform, in terms of accuracy, drift, and other errors. All error terms identified in manufacturers performance data should be considered for potential applicability to the calculation of errors. In addition, the results of plant specific or generic Equipment Qualification (EQ) programs should be considered. When EQ program data applicable to a particular application indicates different performance characteristics than that published in open vendor data, the limiting or most conservative data will be used. If additional margin is required, then the differences should be resolved. In order to assure consistency in combining errors in an instrument channel, vendor performance specifications must be expressed as a percentage of Upper Range, Calibrated Span, or the electrical input or output ranges of the devices.

4.2.2.2 Process and Physical Interfaces

a. Environmental Conditions

Up to four distinct sets of environmental conditions must be defined for a given instrument channel.

- The first of these is the set of environmental conditions that applies at the time the instruments are calibrated. Under normal conditions, the only environmental condition of interest during calibration is the possible range of temperatures. This is of interest because temperature changes between subsequent calibrations can introduce a temperature error, which becomes part of the apparent drift of the device.

- The second distinct set of environmental conditions is the plant normal conditions. These are the combination of radiation, temperature, pressure and humidity that are expected to be present at the mounting locations of each of the devices during normal plant operation under conditions where the instrument is in use. These conditions are used to estimate normal errors, particularly in the spurious trip margin evaluation.

- The third distinct set of environmental conditions to be identified is the trip environmental conditions. These are the combination of radiation, temperature, pressure and humidity expected to be present at the mounting location of each device at the point in time that the device is relied upon to perform its automatic trip function. These environmental conditions are generally those that may exist at the first trip of an automatic system, before the operator takes control of an event.

- The fourth distinct set of environmental conditions that may be needed is the long-term post-accident environmental conditions. These conditions do not apply to most setpoints, but may apply for evaluations of channel error for post-accident monitoring and long-term core cooling (or similar) functions.

4.2.2.2 (cont'd)

- In all cases, it should be noted that the environmental conditions of importance are those seen by all the devices in the instrument channel. This includes equipment, which connects to the instrument, such as instrument lines. For example, instrument lines, which pass through multiple areas (particularly the Drywell) will experience static head variations due to the temperature effects on the fluid in the lines (see Process Measurement Accuracy of Appendix C).

b. Seismic Conditions

- Seismic conditions ("g" loads) apply to setpoints associated with events that may occur during or after an earthquake. Depending on the type of instrument (and the manufacturer's definition of how seismic loads affect the devices) two different seismic conditions may be of interest. These are the seismic loads that may occur prior to the time the instrument performs its function, and the seismic loads that may be present while the instrument is performing its function. In general, the seismic loading of interest is the Zero Period Acceleration at the point the instrument is mounted.

c. Process Conditions

As discussed in Appendix C, three sets of process conditions may be of importance for most instrument channels.

- The first of these is the calibration conditions that may be present at the time the device is calibrated. This is generally of interest for devices such as differential pressure transmitters, which are calibrated at zero static pressure, but then operated when the reactor is at normal operating pressure. The change in static pressure conditions must be known and accounted for in calibration and/or channel error calculations.
- The second set of process conditions of interest is the set of worst case conditions that may be imposed on the instrument from within the process. Certain types of pressure transmitters, for example, are subject to overpressure errors if subjected to pressures above a specified value.

- The third set of process conditions of interest is the conditions expected to be present when the instrument is performing its function. Conceivably, this can be more than one set of conditions. These process conditions determine the errors that may exist when the instruments are calibrated at different process conditions, and may also affect the magnitude of Process Measurement Accuracy and Primary Element Accuracy terms in the setpoint or channel error calculations.

4.2.2.3 External (outside world) Interfaces

a. Calibration Methods and Tolerances

Calibration methods and tolerances are of importance because they have an effect on many aspects of the setpoint or channel error evaluations. They determine the channel calibration error, and may also be used to determine As-Found and As-Left tolerances. Calibration tolerances can be identified in a number of different ways. If the plant operating personnel have evaluated their calibration procedures and established an overall channel calibration error for each channel, then this information may be used directly in setpoint calculations. If not the following information should be obtained, so that the channel calibration error can be determined:

1. A list of the instruments used to calibrate the channel.
2. A calibration diagram, showing the locations in the instrument channel where calibration signals are input or measured, the type and accuracy of instruments used at each location, and values of calibration signals.
3. If known, accuracy of the NIST or equivalent Calibration standards used to calibrate devices such as pressure gauges used in the calibration.
4. If established, As-Left and As-Found tolerances used in calibration of each of the devices.

b. Installation Information

Installation information of interest includes the installed instrument arrangement, including all connections to the process, instrument line routings, panel and rack locations and elevations, etc. Elevations and instrument line routings are important for determining head corrections, Process Measurement Accuracy and Primary Element Accuracy, and other effects associated with instrument physical arrangement.

c. Surveillance Intervals

The surveillance interval associated with each device in the instrument channel should be determined from the plant surveillance documents. In general, the surveillance interval assumed for the setpoint or channel error calculations should be the longest normal surveillance interval of any device in the channel (e.g., 18 months, due to the transmitter). In cases where the calibration interval can be delayed, the maximum interval should be used (e.g., CPS Technical Specifications allow for calibration intervals to be delayed for up to 125% of the required interval, or (18 months) • 1.25 = 22.5 months). However, for devices in the instrument channel that are calibrated on a shorter interval, inaccuracies need not be extrapolated to the maximum interval. Refer to Section 4.3.2 for more detail.

d. External Error Contributions

The final step in determining instrument channel characteristics is to determine whether the instrument channel of interest may be subject to any additional error contributions beyond those normally associated with the instruments themselves. If any of these effects may apply to a particular channel, data necessary to define the effect must be obtained. Potential External Error Contributions may include:

- Process Measurement Accuracy (PMA)
- Primary Element Accuracy (PEA)
- Indicator Reading Error (IRE)
- Insulation Resistance Accuracy (IRA)
- Unique error terms

4.2.3 Instrument Channel Design Requirements

Design requirements applicable to the instrument channel should be defined, including, as applicable:

4.2.3.1 Regulatory Requirements

- Technical Specifications
- Safety Analysis Reports
- NRC Safety Evaluation Reports
- 10CFR50 (particularly Appendix R)
- Regulatory Guides 1.89, 1.97 and 1.105

4.2.3.2 Functional Requirements

- Instrument function
- Analytical and Safety Limits
- Operational Limits
- Function Times
- Requirements imposed by plant procedures, Emergency Operating Procedures (EOPs), etc.
- For indicator or computer channels, allowable channel error (CE)

Each of these aspects is discussed below.

4.2.4 Defining Instrument Channel Design Requirements

4.2.4.1 Regulatory Requirements

a. Technical Specifications

Technical Specifications requirements are of importance for setpoints and instrument channels covered within the Technical Specifications. Requirements of importance are Surveillance intervals, Allowable Values and Nominal Trip Setpoints specified in the Technical Specifications. Existing values in the Technical Specifications should be reviewed, even for new setpoint calculations, because it is usually desirable to preserve the existing Technical Specifications values if they can be supported by the setpoint calculations. Thus, the Technical Specifications values (particularly the Allowable Value and Nominal Trip Setpoint) are used in evaluating the acceptability of calculation results, and may also be used in the evaluation of As-Found and As-Left Tolerances and determination of Required Limits (if used).

b. Safety Analysis Reports, NRC, SERs, 10CFR50, Regulatory Guides

While the Technical Specifications are the key documents to examine for regulatory commitments or requirements, the balance of the plant licensing documentation may contain commitments or agreements reached with the NRC, as well as system specific requirements that may affect setpoint calculations. Normally, all such commitments or requirements should also be reflected in the applicable plant specifications and documents. However, the licensing documentation should be considered in assuring commitments are known.

4.2.4.2 Functional Requirements

a. Instrument Function

Instrument functional requirements are normally contained in system Design Specifications, Design Specification Data Sheets, Instrument Data Sheets and similar documents. The functional requirements to be determined should not only include the purpose of the setpoint, but also the plant operating conditions or operating modes under which the trip is required to be operable, and identification of the most severe conditions under which the trip should be avoided. The plant operating conditions under which a trip must be operable should be correlated to the licensing basis events so that the questions of trip environment, absence or presence of seismic loads, etc., can be answered.

b. Analytical and Safety Limits

- The Licensing Safety Limit (LSL) is the value of a safety parameter that must not be violated in order to assure plant safety. In the case of a safety situation for which there is an accident or transient analysis, the safety limit is the limit that the analysis is intended to support. For situations where there is no transient analysis, such as the pressure limit for a section of pipe. The Safety Limit or Nominal Process Limit (NPL) would be the limit assumed in design (the Design pressure and Temperature of the pipe, for example).

- The Analytical Limit (AL) is a slightly different concept. The Analytical Limit is the value at which the trip is assumed to occur, as part of the analyses, which prove that the Safety Limit is satisfied. For the example of pipe pressure, if there is a stress analysis, which assumes that a particular event is terminated, by instrument action, at or before a certain pressure is reached. The pressure at which the instrument is assumed to react, to terminate the event, is the Analytical Limit for that event, even if it is different than the Design Pressure of the piping.

- The section of this document dealing with the actual setpoint calculations gives more specific guidance on how to select the Analytical Limit to be used.

c. Operational Limits (OL)

Operational Limits are the values of the measured parameter which may occur during plant operation, and at which it would be undesirable to have a trip occur. Usually, there is one limiting Operational Limit for a given setpoint. In certain cases, such as High Drywell Pressure, there may be no credible operating condition, short of the design basis accident (which requires a trip). In such situations, there would be no Operational Limit.

d. Function Times

- Function times should be identified for every instrument channel requiring either a setpoint calculation or channel error calculation. The function time is important because it is used to determine the worst rational environmental conditions for use in determining instrument error. Caution should be exercised in determining function times. This is because the function time selected for a particular case can have a very large impact on instrument error calculations, and this in turn can have a significant impact on the setpoint, and the risk of spurious trip. That is, over-conservative function times lead to over-conservative setpoints and higher spurious trip risk. Since spurious trips can themselves lead to safety system challenges, the ultimate result of over-conservative function times can be a situation, which is counter productive to overall safety.

- In determining the function time for a particular setpoint, attention should be given to the conditions under which the operator depends most on the automatic actions triggered by the setpoint. For example, in the case of a reactor water level signal intended to start the ECCS system in the event of a Loss of Coolant Accident. The operator depends most on the automatic function during the first 10 minutes of the event, before reactor power is significantly reduced and before the operator has had an opportunity to take control of the situation. During this early period of a LOCA, the core is not yet uncovered and therefore no core damage and major radioactive release would be expected. The operator could reset the water level trip devices after the event, but since the reactor would then be shutdown, and rapidly changing water levels would no longer be credible, the need for trip accuracy would be considerably reduced. Thus, it is appropriate to base the trip setpoint on the conditions existing in the first 10 minutes, without assuming core damage (it should be noted, however, that environmental conditions used for Equipment Qualification might indicate otherwise, since they assume failures).

Note: All setpoints, controls or indications need only be evaluated to the worst environmental conditions present at the time their function is required.

e. Requirements Imposed by Plant Procedures (EOPs, etc.) As defined in Appendix L, plant operating procedures, particularly Emergency Operating Procedures, should be considered in defining the functions of instruments. This is particularly important in connection with the topic of instrument function times, since the Plant Procedures define the extent that the operator may depend on the instrumentation, and the events for which this dependence is most important. Engineering judgment must be exercised in evaluating the effect of operating procedures. For example, while a particular procedure may require the operator to reset a particular trip device, the reset requirement does not necessarily imply that the instrument must react as accurately in a subsequent trip. Thus, the first trip, prior to the operator taking control, may still be the appropriate basis for the setpoint calculation. Engineering judgment and a good understanding of the design bases of the plant must be applied to identifying the impact of Plant Procedures on the functional requirements applicable to the instrumentation.

f. Allowable Channel Error (CE)

As defined in Section 2.2, Channel Error Indication Uncertainty, for certain types of channels, particularly indicator channels and channels which supply signals to computers and data collection systems, there may be requirements on the maximum allowable error in the channel. Such requirements may be imposed by the purpose of the indicating functions (such as a Plant procedure requirement), or by the use that is made of the data. The manner in which the instrument data is used should be evaluated to determine if there are any inherent limits on acceptable channel error, independent of the setpoint calculation.

4.2.5 Data Collection

All data collected should be referenced to its source (document number, title, and revision level) and recorded in the Input, Output, or Reference Section of the calculation, so that the basis for the setpoint or channel error calculations will be traceable to the proper plant documents.

4.3 Determining Individual Device Error Terms

4.3.1 Determining Individual Device Accuracies

As defined in Section 2.2, the overall accuracy error for any individual device is developed by combining all the individual error contributions identified by vendor performance specifications or device qualification tests. As a means of assuring consideration of all terms, it is useful to view the accuracy error of the device in terms of the factors that might cause the device to exhibit errors. That is, what external or internal effects might affect the performance of the device? The answer to this question is straight forward: Device accuracy may be influenced by the inherent precision of the internal components, plus errors caused by each and every external (environmental) influence on the device. Specifically, the following potential causes of accuracy error should be considered for any given device:

a. Vendor Accuracy (VA)
b. Accuracy Temperature Effect (ATE)
c. Overpressure Effect (OPE)
d. Static Pressure Effect (SPE)
e. Seismic Effect (SE)
f. Radiation Effect (RE)
g. Humidity Effect (HE)
h. Power Supply Effect (PSE)
i. RFI/EMI Effect (REE)

The identification of these potential effects is not intended to indicate that they apply to all devices. First of all, some suppliers of instrumentation provide a single value of accuracy error, which may already include all or many of the external environmental effects listed above (within some bounding environment specified by the vendor). Guidance and information for some common devices is provided in Appendix A and C to this document, additionally, Appendix L, Graded Approach to Uncertainty Analysis, provides guidance in terms of rigor in which elements of device uncertainty should be considered during a calculation.

Following identification of potential effects, each of the error terms should be examined to determine if it may be treated as a random term, or whether dependencies may exist which would include systematic or bias error as described in Appendix C, Sections C.1.1 and C.1.2.

Once all the accuracy error contributions for a particular instrument are identified, they should be combined using the SRSS method to determine total device accuracy. In performing the SRSS combination, the individual level of confidence of each term (sigma level) should be accounted for such that the resultant device accuracy error is a 2 sigma value. Refer to Section C.4 for cases where instruments are calibrated together as a rack.

$$A_i = \pm N((VA_i/n)^2 + (ATE_i/n)^2 + (OPE_i/n)^2 + (SPE_i/n)^2 + (SE_i/n)^2 + (RE_i/n)^2 + (HE_i/n)^2 + (PSE_i/n)^2 + (REE_i/n)^2)^{1/2}$$

$\pm$ Any bias term associated with the above random errors (2σ)

Where the values of 'n' are the sigma values associated with each individual effect (i.e., 1, 2, 3) and N is 2 for a 2 sigma value of A_i.

Generally, two accuracy terms are required for setpoint calculations; accuracy under normal plant operating conditions (A_{iN}) and accuracy under the conditions for which the circuit will be required to trip($A_{I\ Accident/seismic}$).

The Setpoint Program Coordinator can provide sample calculations.

4.3.2 Determining Individual Device Drift

Drift for individual devices are determined in a manner similar to that of accuracy.

Vendor Drift (VD): Refer to Section 2.2 for definition.

The Vendor Drift term should be adjusted to the surveillance interval for that device. In accordance with References 5.1 and 5.3 this adjustment is made by multiplying the value of VD by the square root of the ratio of the surveillance interval (M) to the drift interval associated with the vendor data.
Example (six month drift interval specification):

$$VD_M = (M/6)^{1/2} VD_{6\text{-month}}$$

Refer to Appendix I, Standard Assumptions for sigma value.

Further information on drift for specific types of commonly used instruments, is provided in Appendix A.

Several cautions should be noted concerning drift calculations, specifically:

The functional life of the device must exceed the assumed surveillance interval. This is because the extrapolation of drift to longer surveillance intervals fundamentally assumes the instrument is qualified for, and expected to perform normally for, the intended length of service. The drift allowance is intended to account for natural long-term variations in the performance of a basically 'healthy' instrument, not instrument failures.

Drift calculations should be consistent with observed performance. Surveillance testing (As-Found and As-Left data) gives an indication of apparent drift. The surveillance test data is not pure drift; since it is masked by accuracy, calibration errors and other contributors as described in Section C.3.4. However, calculation models exist to permit evaluating drift performance. Conversely, good apparent performance in surveillance testing may be used to justify improvements in assumed drift values used in setpoint or channel error calculations. This is a very important consideration, since the setpoint calculation methods assume drift is a random variable, such that drift for longer intervals is determined using the SRSS method. The USNRC may require that drift assumptions be validated based on field data (the use of field data to validate drift assumptions is discussed in Appendices A and C).

4.3.3 Determining Device Calibration Tolerances

Four key considerations have been introduced in other sections of these guidelines concerning calibration tolerances. These are:

a. As Found Tolerance (AFT_i): Refer to Section 2.2 for definition.
b. As-Left Tolerance (ALT_i): Refer to Section 2.2 for definition.
c. The Calibration Tool Error (C_i): Refer to Section 2.2 for definition and Appendix H for guidance.
d. The Calibration Standard Error (CSTD): Refer to Section 2.2 for definition. Per Standard Assumptions in Appendix I, Section I.11, this value is considered negligible.

The first two of these terms are arbitrary. That is, AFT is typically calculated as shown below, however it can be rounded in a conservative manner to force a more limiting value in order to preserve an existing setpoint (See Section 4.4.5 for Loop AFT). ALT is up to personnel establishing calibration and surveillance procedures to establish these values. Once established, they should be used in the setpoint and channel error calculations. Generally, ALT is set to VA, however ALT will be considered a 2 sigma value. In the absence of other guidance, this methodology recommends that the terms be established as follows:

$$AFT_i = \pm (N)((ALTi/n)^2 + (C_i/n)^2 + (D_i/n)^2)^{1/2} \qquad (2\sigma)$$

$$ALT_i = \pm VA_i \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

Refer to Section 2.2 for definitions and Sections C.3.16 & C.3.17 for additional guidance.

Typically ALT was established in calibration procedures equal to VA. However, per Sections 2.2.5 and 4.2.2.3, the ALT established in plant procedures should be used. If, in order to preserve a setpoint, a smaller tolerance is needed, then plant personnel should be contacted for concurrence prior to using in calculation. If, the ALT established in calibration procedures is smaller than VA, then the calculation should use VA, so that plant personnel could relax the tolerance, if desired.

NOTE: The AFT and ALT values should be converted to the engineering units required by the calibration procedure and rounded to the precision of the M&TE equipment used. In cases where values are established for indication, the values should consider the readability of the device and round to the next ½ minor division.

These guidelines have been established because they permit surveillance procedure error bands, which are consistent with the types of errors that may be present during calibration.

4.4 Determining Loop/Channel Values

4.4.1 Determining Loop Accuracy (A_L)

Loop Accuracy must be determined in such a way as to be compatible with the various setpoint and channel error calculations. Loop Accuracy shall be determined to a level of confidence corresponding to 2 Standard Deviations (2σ).

In order to determine Loop Accuracy, the accuracy of all devices in the loop must be determined (with a known or assumed sigma value associated with each), adjusted to a common sigma value (2), and then combined to produce the value of Loop Accuracy. All bias effects related to any of the devices shall be separated from the random portion of the accuracy data and will be dealt with separately, such that the individual device accuracy values may be assumed to be approximately random, independent, and normally distributed.

All individual device errors shall be determined on the basis of the environmental conditions (normal, trip, post accident, etc.) applicable to the event (and function time) for which the Loop Accuracy applies.
Once the individual device accuracy errors have been identified and characterized to a common sigma value (2), they are combined by the SRSS method to find the Loop Accuracy.

$$A_L = \pm(A_1^2 + A_2^2 + \ldots + A_i^2)^{1/2} \pm \text{any bias terms} \qquad (2\sigma)$$

Normally, two distinct values of loop accuracy must be determined using the equation above. These are the normal loop accuracy ($A_{L(normal)}$) and the accuracy under accident or seismic conditions or both ($A_{L(accident/seismic)}$).
Two important cautions must be noted concerning Loop Accuracy. First, the devices included in Loop Accuracy must be consistent with the signal path of interest (i.e., every device from the signal source to the point at which the setpoint trip is produced or the channel output utilized). Secondly, the term 'devices' is not intended to restrict the calculation to hardware, or to include hardware that is treated uniquely elsewhere in the setpoint calculations. 'Devices' may include software.

4.4.1.1 The following devices are typically included in Loop Accuracy:

(1) Transmitters

(2) Trip Units

(3) Signal Conditioners/Multiplexers/Network Resistors

(4) Software errors associated with signal processing

(5) Anything which introduces a random, non-time dependent error are included, in the signal from source to point of use, unless handled elsewhere in setpoint calculations.

4.4.1.2 The following are exceptions, which are normally not included in determination of loop accuracy:

(1) Process measurement errors (PMA) and the errors of the Primary Element (PEA) are treated separately.

(2) Errors due to Insulation Degradation (IRA) are treated separately.

4.4.2 Determining Loop AS-Left Calibration Tolerances (ALT_L)

Refer to Section 2.2 for definition and Section 4.3.3 for component As-Left Tolerance (ALT_i).

Loop As-Left Tolerance (ALT_L) is calculated by combining the individual component As-Left tolerances (ALT_i). Once the calculated Loop As-Left Tolerance has been determined by the SRSS of component As-Left Tolerances, this value should be compared to existing calibration procedure Loop As-Left Tolerances. If feasible, it is desired to retain existing procedural Loop As-Left Tolerances. Selection and use of existing procedural As-Left Tolerances is desired since these values already consider readability of test equipment.

If the procedural Loop As-Left tolerance is retained, this value shall be used in the development of C_L and AFT_L and listed in the calculation results summary. Likewise, if the calculated loop As-Left tolerance is selected, this value shall be used in the development of C_L and AFT_L and will be listed in the calculation results summary. If selecting the calculated Loop As-Left Tolerance, consideration should be given to the readability of the test equipment. The selected As-Left tolerance shall be considered a 2 σ value.

If it is desired to implement an ALT_L less than the existing procedural ALT_L, I&C Maintenance should be contacted for concurrence.

NOTE: The ALT_L value shall be converted to the engineering units required by the calibration procedure and rounded to the precision of the M&TE equipment used. In cases where values are established for indication, the values should consider the readability of the device and round to the next ½ minor division.

The formula is shown as follows:

$$ALT_L = \pm(N)[(ALT_1/n)^2 + (ALT_2/n)^2 + \ldots + (ALT_i/n)^2]^{1/2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

4.4.3 Loop Calibration Error (C_L)

Loop Calibration Errors may be established by the organization responsible for calibration. Generally, Loop Calibration Error shall be calculated as 2 Sigma confidence level as shown in Section 4.4.3.1.

There are three basic components of Loop Calibration error, see Section 2.2 for definitions. These are the following:

a. ALT_i

b. C_i,

c. CSTD,

It is important to note that C_i and CSTD are controlled by 100% testing per procedure CPS 1512.01, Reference 5.14. For these reasons it is assumed that the C_i and CSTD values represent 3 sigma values.

4.4.3.1 The process of determining Loop Calibration Error is performed in two steps. The first step is to review the loop diagram and calibration procedures to determine what calibration tools are used and how many times each are used in establishing the calibration of the loop. This is a function of the plant specific calibration procedures. Typically, the calibration of a particular loop containing a transmitter and trip unit involves the use of only one pressure source and the alarm indication at the ATM. Once the device usage is determined, the loop calibration tool error is determined by combining the errors by SRSS. In the above example, there would be 4 terms in the SRSS calculation (ALT_i for each instrument, and a C_i and CSTD value for the pressure source gauge).

$$C_L = \pm N \left(\Sigma(ALT_i/n)^2 + \Sigma\ (C_i/n)^2 + \Sigma\ (CSTD/n)^2\right)^{1/2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

Further discussion on M&TE is provided in Appendix H.

4.4.4 Determining Loop Drift (D_L)

Loop Drift must be determined in such a way as to be compatible with the various setpoint and channel error calculations.

In order to determine Loop Drift, the drift of all devices in the loop must be determined (with a known or assumed sigma value associated with each) and then combined to produce the value of Loop Drift. Any bias effects related to any of the devices shall be separated from the drift data and dealt with separately, such that the individual device drift values may be assumed to be approximately random, independent, and normally distributed.

All individual device drifts must be determined on the basis of the environmental conditions applicable to the initial and subsequent surveillance tests and device calibrations (generally, temperature variations between subsequent calibrations).

$$D_L = \pm N(D_1^2/n + D_2^2/n + \ldots + D_i^2/n)^{1/2} \pm \text{any bias terms} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

Two important cautions must be noted concerning Loop Drift. First, the devices included in Loop Drift must be consistent with the signal path of interest (i.e., every device from the signal source to the point at which the setpoint trip is produced or the channel output utilized). Secondly, the term 'devices' is not intended to restrict the calculation to hardware, or to include hardware that is treated uniquely elsewhere in the setpoint calculations.

4.4.4.1 The following devices are typically included in Loop Drift:

(1) Transmitters

(2) Trip Units

(3) Signal Conditioners/Multiplexers/Network resistors (if these devices exhibit drift)

(4) Anything, which introduces a time dependent change in the signal from source to point of use.

4.4.5 Determining Loop As-Found Calibration Tolerances (AFT_L)

Key considerations have been introduced in other sections of these guidelines concerning individual loop errors used to calculate AFT_L. These are:

1. Loop Calibration Error (C_L): Defined in Section 2.2 and calculated in Section 4.4.3.

2. Loop Drift Error (D_L): Defined in Section 2.2 and calculated in Section 4.4.4.

To calculate AFT_L, loop calibration equipment and drift tolerances should be combined using the SRSS methodology. AFT_L is calculated as follows:

$$AFT_L = \pm (N)((C_L/n)^2 + (D_L/n)^2)^{1/2} \qquad (2\sigma)$$

NOTE: The AFT_L value shall be converted to the engineering units required by the calibration procedure and rounded to the precision of the M&TE equipment used. In cases where values are established for indication, the values should consider the readability of the device and round to the next ½ minor division.

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

This provides assurance, that the loop is functional and the AV is protected.

These guidelines have been established because they permit surveillance procedure error bands, which are consistent with the types of errors that may be present during calibration.

4.4.6 Determining Process Measurement Accuracy and Primary Element Accuracy (PMA/PEA)

Per definition in Section 2.2 and discussion in Appendix C, Process Measurement Accuracy (PMA) and Primary Element Accuracy (PEA) are generalized terms used in channel error calculations and setpoint calculations to account for measurement errors which lie outside the normal calibration bounds of the channel. For example, consider the case of venturi flow meter connected to a differential pressure transmitter and trip unit. The normal surveillance testing of the instrument channel would concern itself with the transmitter and trip unit. The flow meter might have been calibrated by some sort of test, but it is not part of the instrument channel. On the other hand, it very definitely is part of the measurement process.

The use of PMA and PEA in the channel evaluation is a matter of engineering judgment. These two categories are defined as a means of reminding the engineer to account for everything that affects the performance of the instrument loop. Since both PMA and PEA are treated identically in the setpoint and channel error calculations, it is not important which effects are assigned to each value, as long as the effects are assigned in such a way that there is a proper separation/combination of independent and dependent effects. This point is best illustrated by a few examples. Keep the definitions (Section 2.2) of the terms in mind:

The following paragraphs illustrate various instrument systems and application of these two definitions.

4.4.6.1 Flow Measurement

As discussed in Appendix E, Flow Measurement Uncertainty Effects, consider a flow measurement system consisting of a flow meter, such as a venturi, instrument lines connecting the flow meter to a differential pressure transmitter, and the transmitter itself. The device in contact with the process is the flow meter itself. The flow meter is therefore the Primary Element. There is some fundamental error or uncertainty in the differential pressure at the instrument line connections on the meter, due to the design of the flow meter, as-built dimensions, etc. This error may consist of both a bias term and a random component. These random and bias errors are both components of Primary Element Accuracy (PEA).

The connection between the flow meter (primary element) and the transmitter (sensor) is made using instrument lines. The density of the fluid in these lines will vary with ambient temperatures on the spaces through which these lines are routed. These density changes will affect the pressure transmitted from the primary element to the sensor. This affect can be considered negligible if the sensing lines of a differential pressure transmitter are routed together and can be proven affected by the same ambient temperature. These errors inherent in the use of the instrument lines are Process Measurement Accuracy.

4.4.6.2 Water Level Measurement

Refer to Appendix F, Level Measurement Temperature Effects, and consider a water level measurement system, particularly in a BWR, may consist of a condensing chamber, sensing lines (variable and reference leg) and differential pressure transmitters. In a manner similar to that in paragraph 4.4.6.1 we would normally classify the elevation uncertainty associated with the condensing chamber as PEA. The errors due to ambient temperature fluctuations, and their effects on instrument line fluid density, would be considered to be PMA.

4.4.6.3 Temperature Measurement

A typical temperature measurement system may consist of a temperature detector, such as a thermocouple or resistance temperature detector, and a temperature switch. In this case, the temperature detector could be treated as a sensor, much in the same fashion as a pressure detector. However, the temperature detector is generally not calibrated with the channel. For this reason, the errors of the temperature detector are usually treated as PEA. There is no PMA in this case.

4.4.6.4 General Guidance

In general, PMA and PEA are shown in the calculations being random independent variables. Therefore, random effects assigned to PEA and PMA should be independent of each other. However, if they are determined to be a bias, then they will be dealt with separately. The boundaries between PMA and PEA are a matter of convenience and judgment. The most important factor is that all potential error sources arising anywhere in the process, from the true variable desired to be measured all the way to the sensor in the instrument channel, must be considered in error calculations, as PMA, PEA, or as some other error term.

4.4.7 Determining Other Error Terms

The fundamental objective of the calculation of setpoints or channel errors is to incorporate all reasonably expected error sources, as well as any that are part of the licensing commitments applicable to the plant. As part of the design or calculation process, the responsible engineer should consider whether additional error terms should be considered. The following paragraphs discuss several potential error sources. It is up to the responsible engineer to determine whether these are applicable, and, if applicable, to define the error values.

4.4.7.1 Indicator Reading Error (IRE)

As defined in Section 2.2 and further discussed in Appendix C, Section C.3.13, if a particular channel error calculation is intended to define the potential errors in data which is manually recorded, based on reading indicator or gauges, the error in reading the scale on the indicator must be considered. This error must be established on a case basis. In general, it is a question of the scale divisions, scale curvature, etc (See Section 4.3.3 for discussion on AFT and ALT).

4.4.7.2 Resistors, Multiplexers, etc.

The signal processing hardware is not the only source of significant error in some types of instrument channels. Channels that supply signals to computer inputs, recorders, etc., sometimes setup to measure the voltage drop across a resistor in the circuit. The resistor accuracy (1%, for example) may introduce a significant error into the voltage measurement. Similar signal transmission devices, such as multiplexers, may introduce errors, which must be considered.

4.4.7.3 Software Errors

With the increased use of instrument channels which provide data to microprocessors and computers, where that data is manipulated then used to trigger some action or provide data, the software used becomes important. Software that influences the use of data introduces errors, which should be considered for applicability.

4.4.7.4 Degradation of Insulation Resistance Accuracy Error (IRA)
References 5.22, 5.23, 5.24, may provide a bounding IRA value to use, if the device is identified by these calculations. However, if a more precise IRA value for the identified devices is needed or a non identified device requires IRA to be established, then the guidance, provided in Appendix D shall be used. It determines the Effect of Insulation Resistance (IR) on Uncertainty, under certain accident conditions, particularly steam environments, where the insulation resistance of cables, terminal blocks and other devices may be reduced, producing larger than expected leakage currents, which degrade signals. This error (IRA) is defined in Section 2.2. The applicability of IRA depends on both the accident environment and the time of function. Many reactor protection setpoints, which are intended to prevent accident consequences, are not subject to IRA because of timing considerations. IRA, on the other hand, may significantly affect certain post-accident monitoring functions. These type errors are generally determined as part of equipment qualification programs.

4.4.8 Channel Error Calculation

As defined in Section 2.2, Channel Error Indication Uncertainty, Channel Error is determined when there are requirements for channel uncertainty, independent of a Safety Related Setpoint. Typically, there are three situations where Channel Error is of interest. These are (1) Non-Safety Related Setpoints, (2) when the channel serves as an indicator/recorder/control function and where the accuracy must be known (RG 1.97 indicators, information for operators, etc.), and (3) channels which supply information to data collection systems, computer systems, etc.

The channel error is determined by:

CE = ±(1.645/N)(SRSS OF RANDOM TERMS) ± BIAS TERMS

Typically calculated and shown as below:

$$CU = \pm N(PMA^2 + PEA^2 + A_L^2 + (C_L/n)^2 + (D_L/n)^2)^{1/2} \pm B \quad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

And

$$CE = \pm(1.645/N)(CU^2 + IRE^2)^{1/2} \pm \text{Bias Terms}$$

Note: An (1.645/N) adjustment to channel error is applicable to non-safety setpoints and required indicator readings that have a limit approached in one direction (single sided interest).

4.4.8.1 The RANDOM TERMS that should be considered include the following:

(1) Loop Accuracy (A_L) under the worst environmental conditions applicable to the channel function

(2) Loop Calibration Error (C_L)

(3) Loop Drift (D_L)

(4) Process Measurement Accuracy (PMA)

(5) Primary Element Accuracy (PEA)

(6) Indicator Reading Error (IRE) if applicable.

(7) Any other random terms expected to be present for the indicator and or computer channel function (such as software errors)

Refer to definitions in Section 2.2.

4.4.8.2 The BIAS TERMS that should be considered include:

(1) Any bias associated with Process Measurement or the Primary Element (PMA/PEA)

(2) The bias component of Insulation Resistance Accuracy Error (IRA)

(3) The bias portion of readout errors (IRE).

(4) The bias portion of any other unique terms known to exist (including drift and software bias).

4.4.9 Setpoints with no Analytical Limit or Allowable Value

In some cases it is necessary to determine setpoints when there are no Tech. Spec. Allowable Values or Analytical Limits. As discussed in section 2.2.46, the NPL is a limit, high or low, beyond which the normal process parameter should not vary.

$$NTSP_{(INC)} = NPL - CE$$

$$NTSP_{(DEC)} = NPL + CE$$

Note: An (1.645/N) adjustment should be made when calculating CE for non-safety setpoints and required indicator readings (single sided interest).

4.4.10 Determining Analytical Limits (AL)

Analytical Limits are used in calculating the Nominal Trip Setpoint and Allowable Value (if required). Methods of calculating Analytical Limits are not within the scope of these guidelines. However, the process by which the designer determines an Analytical Limit is of interest.

Per Section 2.2, the Analytical Limit is "the value of the sensed process variable established as part of the safety analysis, prior to or at the point which a desired action is to be initiated to prevent the safety process variable from reaching the associated licensing safety limit".

NEDC-31336, Reference 5.1, includes a discussion of the source of the Analytical Limits applicable to the set of key setpoints for which direct credit is taken in the Safety Analysis Report. For setpoints not discussed in Reference 5.1, the following guidelines are provided for determining Analytical Limits:

a. The first step for determination of an Analytical Limit is to determine the purpose of the particular setpoint. That is, what event is the setpoint intended to mitigate, prevent or initiate?

b. Once the event of interest is identified, determine what assumptions have been made in the system design or analysis regarding the setpoint. These assumptions may be explicit in the design or implicit.

c. The value of the sensed process variable, which corresponds to the design assumptions for that event is the Analytical Limit.

The key question is what value of the sensed variable corresponds to the design assumptions. This correspondence may be indirect. For example, a setpoint intended to isolate a line on a high flow would have a design basis in terms of flow rate. Whereas the Analytical Limit and setpoint calculations would be done in terms of the differential pressure across the flow measurement device, corresponding to the flow rate at which the isolation is assumed to occur. As another example, consider a setpoint intended to limit pressurization of a pipe. In this case, the Analytical Limit may be the design pressure of the pipe, but not always. If the stress analysis of the pipe assumes some peak pressure in the pipe different from the design pressure, the assumed peak pressure corresponding to the event for which the setpoint is intended, less any transient overshoot, would be the Analytical Limit. When in doubt, the organization that provided the design bases and/or analyses of the system or component should be consulted to ensure proper identification of the Analytical Limit. Trip setpoints associated with non-safety related functions are typically based on the process limit, High or Low, beyond which normal process parameter should not vary. This limit is defined as the Normal Process Limit(NPL).

4.4.11 Allowable Value Calculation (AV)

If the setpoint in question is contained in Technical Specifications and is required to have an Allowable Value, the Allowable Value (AV) should be calculated using either equation depending on the direction of process variable change when approaching the Analytical Limit. The first equation is for process variables, which increase to trip, and the second equation is for process variables, which decrease to trip.

$AV_{(INC)}$ = AL −(1.645/N)(SRSS OF RANDOM TERMS)−BIAS TERMS

$AV_{(DEC)}$ = AL +(1.645/N)(SRSS OF RANDOM TERMS)+BIAS TERMS

Or, as further described by Sections 4.4.11.1 and 4.4.11.2:

$AV_{(INC)} = AL - ((1.645/N)((PMA^2 + PEA^2 + A_L^2)^{1/2} \pm B))$

$AV_{(DEC)} = AL + ((1.645/N)((PMA^2 + PEA^2 + A_L^2)^{1/2} \pm B))$

Where N represents the number of standard deviations with which the value is calculated to (normally 2 standard deviations).

Note: An (1.645/N) adjustment is applicable to setpoints that have a limit approached in one direction (single sided interest).

Per Sections 4.5.1.(1) and 4.4.13.(a), if the existing Tech. Spec. AV is conservative to the calculated AV, therefore preserved, then the existing AV should be used in any other Sections requiring AV, unless a change in AV is desired.

4.4.11.1 The RANDOM TERMS that should be considered for particular AV calculations include the following:

(1) Loop Accuracy under Trip conditions (A_L(trip))

(2) Process Measurement Accuracy (PMA)

(3) Primary Element Accuracy (PEA)

(4) The random portion of any other unique terms known to exist for a particular instrument application, excluding Drift.

4.4.11.2 BIAS TERMS that should be considered are:

(1) Any Biases associated with Process Measurement or the Primary Element (PMA/PEA).

(2) The bias component of Insulation Resistance Error (IRA).

(3) The bias portion of any other unique terms known to exist (including drift and software bias).

It should be noted that the sign applied to bias terms should be conservative relative to plant safety (i.e., credit should not be taken for a beneficial bias unless it can be assured that the beneficial bias will always be present).

4.4.12 Setpoints with Allowable Values

The NTSP should be calculated using either equation below, depending on the direction of process variable change when approaching the Analytical Limit. The first equation is for process variables, which increase to trip, and the second equation is for process variables that decrease to trip.

$$NTSP_{(INC)} = AV - AFT_L$$

$$NTSP_{(DEC)} = AV + AFT_L$$

4.4.12.1 Selecting Actual Setpoints

The actual setpoint used in calibrating instrumentation may not be the value of the NTSP calculated. The choice of the actual setpoint to be used in the plant is a matter of evaluating setpoint conservatism as compared to the AV and operational preferences. In other words, the existing plant setpoint may be conservative to the calculated setpoint and AV and pose limited impact on plant operations or spurious trips. This in-plant (existing) setpoint would satisfy both the calculation requirements and plant operation, as such, the channel would not require a setpoint revision. The existing setpoint, becomes the NTSP and used in any other Sections requiring NTSP.

4.4.12.2 Evaluation of Trip Reset Value

The reset setting is a variable % span adjustment of the trip setpoint. CPS calibration procedures typically has it set at 3% span (i.e. Trip is set at 100%, reset is shown as 97%). The same AFT and ALT is placed on the trip setpoint, as well as the reset, however, it is not possible for the trip to be found low in it's band, while the reset is found high. Areas to consider are as follows:

a. The loop has both a high and low setpoint, with the resets overlapping, thus potentially both alarms at the same time.
b. When calculated AFT is greater than the reset in calibration procedure.
c. Both trip and reset require a NTSP calculation to provide different functions.

The reset value may require adjustment different than the typical setting of 3% span.

4.4.13 Evaluating Results and Resolving Problems

The evaluation of results depends to some extent on the ultimate goal of the setpoint calculations. If there is no existing setpoint in use no evaluation may be necessary. However, in the more normal case, there is already an existing setpoint and, in some cases, Technical Specifications requirements. In this case, the evaluation of results should include:

a. Evaluate the calculated Nominal Trip Setpoint and Allowable Value against existing values. If existing values are not supported by the calculations, determine whether or not it is desirable to preserve the existing values.

b. If existing values are to be preserved, investigate iteration opportunities and revise the calculations.

4.4.13.1 Iteration to Resolve Setpoint Problems

There are usually opportunities for iteration as a means of resolving problems with a calculated setpoint, short of modifying instrument installations or hardware. As a minimum, the following alternatives should be considered:

(1) Modify the Analytical Limit. Frequently, analyses that are the source of the analytical limit have margin. Changes to the analytical limit, to take credit for existing analysis margins, is a powerful way to optimize setpoint calculations, since it has no impact on instrumentation or instrument error allowances. Further, there are many situations (even in plant transient or accident analyses) where relatively simple parameter studies can be used to adjust the analytical limit without re-doing the actual transient or accident analyses.

(2) Re-evaluate environmental assumptions. Many environmental assumptions are driven by worst case licensing assumptions, which may not be appropriate to instrument error analyses. For example, it makes no sense to use an environment that assumes plant conditions that the instrument setpoint of interest is designed to prevent. Environmental assumptions may also be optimized by careful consideration of trip timing, and by refining the analyses that predict environmental conditions.

(3) Re-evaluate calibration errors. Use of different calibration instruments, modified As-Found or As-Left Tolerances can be used to change calibration error allowances and improve setpoint calculations.

(4) Re-evaluate drift assumptions. Consider using statistical analyses of actual as-found and as-left data from surveillance testing to justify improved drift allowances.

(5) Evaluate other assumptions in setpoint calculations, such as function requirements for the instrumentation, trip timing, surveillance intervals, etc.

(6) Examine instrument applications. For example, for setpoints heavily impacted by a predicted radiation dose, a change from a standard model to a radiation resistant model of the same instrument can have major benefits (changing from a Rosemount 1153B "P" output to an 1153B "R" output, for example).

4.5 Calculation Nominal Trip Setpoints and Indication/Control Loops

The individual calculations associated with setpoint and channel error evaluations are outlined below. The engineer performing the calculations should determine which calculations apply to the particular situation, based on the guidance provided.

4.5.1 Setpoint with Analytical Limit

The following steps shall be performed for a Setpoint with Analytical Limit:

a. Calculate the individual device accuracy (A_i) per Section 4.3.1.

b. Calculate the individual device As-Left Tolerance (ALT_i) per Section 4.3.3.

c. Calculate the loop As-Left Tolerance (ALT_L) per Section 4.4.2.

d. Calculate the individual device Calibration Error (C_i) per Section 4.3.3.

e. Calculate the loop Calibration Error (C_L) per Section 4.4.3.

f. Calculate the individual device drift error (D_i) per Sections 4.3.2.

g. Calculate the loop Drift Error (D_L) per Section 4.4.4

h. Calculate the individual device As-Found Tolerance (AFT_i) per Section 4.3.3.

i. Calculate the loop As-Found Tolerance (AFT_L) per Section 4.4.5

j. Develop PMA, PEA, IRA, and other error terms per Sections 4.4.6 and 4.4.7 as applicable.

k. Calculate the Allowable Value (AV) from the Analytical Limit (AL) per Sections 4.4.10 and 4.4.11. .

l. Compare calculated Allowable Value to existing Technical Specification AV. Use the existing AV if conservative, unless it is desired to revise the existing Technical Specifications.

m. Calculate the Nominal Trip Setpoint (NTSP) from the Allowable Value per Section 4.4.12.

n. Consider whether adequate separation exists between the Nominal Trip Setpoint and Allowable Value to avoid LERs.

o. Use the existing setpoint if conservative, unless it is desired to revise it. Then select a setpoint to be used in the calibration procedure that is bounded by the Nominal Trip Setpoint.

p. Evaluate the Trip Reset Value

q. Optimize calculations, if necessary, to validate existing Technical Specifications, designs, etc.

4.5.2 Indication/Control Loop

The following steps shall be performed for a Indication/Control Loop:

a. Calculate values per Section 4.5.1.a through 4.5.1.j.
b. Calculate the channel uncertainty (CU) and channel error (CE) per Section 4.4.8.
c. Optimize calculations, if necessary, to validate existing Technical Specifications, designs, etc.

Note: If indication loop also provides indication for a specific reading as required by the Tech. Spec, then sections 4.5.1.k through 4.5.1.o should be addressed for that indicated reading (in lieu of setpoint).

4.5.3 Setpoint without Analytical Limit

The following steps shall be performed for Setpoint without Analytical Limit:

a. Calculate values per Section 4.5.1.a through 4.5.1.j.
b. Calculate the channel uncertainty (CU) and channel error (CE) per Section 4.4.8.
c. Identify the Nominal Process Limit (NPL) per Section 4.4.9. This also might be given as an Allowable value.
d. Calculate the Nominal Trip Setpoint (NTSP) from the Nominal Process Limit using the channel error per Section 4.4.9.
e. Use the existing setpoint if conservative, unless it is desired to revise it. Then select a setpoint to be used in the calibration procedure that is bounded by the Nominal Trip Setpoint.
f. Optimize calculations, if necessary, to validate existing designs, etc.

4.5.4 The following tables lists the equations developed in Sections 4.3 & 4.4 for the different calculation scenarios in Section 4.5.1 above.

Setpoint/Indication/Control Calculation	
Section	**Formulas**
4.3.1	Device Accuracy (A_I): $A_i = \pm N((VA_i/n)^2 + (ATE_i/n)^2 + (OPE_i/n)^2 + (SPE_i/n)^2$ $+(SE_i/n)^2 + (RE_i/n)^2 + (HE_i/n)^2 + (PSE_i/n)^2 + (REE_i/n)^2)^{1/2}$ ± Any bias term associated with the above random errors (2σ)
4.4.1	Loop Accuracy (A_L): $A_L = \pm(A_1^2 + A_2^2 + \ldots + A_i^2)^{1/2}$ ± any bias terms (2σ)
4.3.3	Device As-Left Tolerance (ALT_i): $ALT_I = \pm VA_i$ (2σ) See discussion on whether to use ALT from calibration procedures or establish as VA
4.4.2	Loop As-Left Tolerance (ALT_L): $ALT_L = \pm(N)[(ALT_1/n)^2 + (ALT_2/n)^2 + \ldots + (ALT_i/n)^2]^{1/2}$ (2σ) Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.
4.3.3	Determining Device Calibration Tolerances Guidance for M&TE is given in Appendix H
4.4.3	Loop Calibration Error (C_L): $C_L = \pm N (\Sigma(ALT_i/n)^2 + \Sigma (C_i/n)^2 + \Sigma (CSTD/n)^2)^{1/2}$ (2σ) Where N represents the number of standard deviations with which the value is evaluated to (normally 2

Setpoint/Indication/Control Calculation	
Section	**Formulas**
	standard deviations) and n represents the sigma value for each device.
4.3.2	Device Drift (D_i): Refer to Appendix I, Standard Assumptions for sigma value. $VD_M = (M/6)^{1/2} VD_{6\text{-month}}$
4.4.4	Loop Drift (D_L): $D_L = \pm N(D_1^2/n + D_2^2/n + ... + D_i^2/n)^{1/2} \pm$ bias terms (2σ) Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.
4.3.3	Device As-Found Tolerance (AFT_i): $AFT_i = \pm (N)((ALTi/n)^2 + (C_i/n)^2 + (D_i/n)^2)^{1/2}$ (2σ) Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.
4.4.5	Loop As-Found Tolerance (AFT_L): $AFT_L = \pm (N)(C_L/n)^2 + (D_L/n)^2)^{1/2}$ (2σ) Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.
4.4.6 & 4.4.7	Determine PMA, PEA, IRA, and other error terms
For Setpoint Calculations with Analytical Limit	
4.4.10 & 4.4.11	Allowable Value (AV): $AV_{(INC)}$ = AL -(1.645/N)(SRSS OF RANDOM TERMS)-BIAS TERMS $AV_{(DEC)}$ = AL +(1.645/N)(SRSS OF RANDOM TERMS)+BIAS TERMS

Setpoint/Indication/Control Calculation	
Section	**Formulas**
	Typically calculated and shown as below: $AV_{(INC)} = AL - ((1.645/N)((PMA^2 + PEA^2 + A_L^2)^{1/2} \pm B))$ $AV_{(DEC)} = AL + ((1.645/N)((PMA^2 + PEA^2 + A_L^2)^{1/2} \pm B))$ Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) **Note:** An (1.645/N) adjustment is applicable to setpoints that have a limit approached in one direction (single sided interest).
4.4.12	Nominal Trip Setpoint (NTSP): $NTSP_{(INC)} = AV - AFT_L$ $NTSP_{(DEC)} = AV + AFT_L$
For Indication/Control Calculations only	
4.4.8	Channel Error (CE): CE = ± (SRSS OF RANDOM TERMS) ± BIAS TERMS Typically calculated and shown as below: $CU = \pm N(PMA^2 + PEA^2 + A_L^2 + (C_L/n)^2 + (D_L/n)^2)^{1/2} \pm B \quad (2\sigma)$ Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device. And $CE = \pm (CU^2 + IRE^2)^{1/2} \pm \text{Bias Terms}$
For Setpoints without Analytical Limit and/or Indication/Control	
4.4.8	Channel Error (CE): CE = ± (1.645/N)(SRSS OF RANDOM TERMS) ± BIAS TERMS Typically calculated and shown as below:

Setpoint/Indication/Control Calculation	
Section	**Formulas**
	$CU = \pm N(PMA^2 + PEA^2 + A_L^2 + (C_L/n)^2 + (D_L/n)^2)^{1/2} \pm B\ (2\sigma)$ Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device. And $CE = \pm (1.645/N)(CU^2 + IRE^2)^{1/2}$ ± Bias Terms **Note:** An (1.645/N) adjustment to channel error is applicable to non-safety setpoints or required indicator readings that have a limit approached in one direction (i.e. increasing or decreasing only, but not both), single sided interest.
4.4.9	Nominal Trip Setpoint (NTSP): $NTSP_{(INC)} = NPL - CE$ Or $NTSP_{(DEC)} = NPL + CE$

5.0 REFERENCES

5.1 NEDC-31336, General Electric Improved Setpoint Methodology, October 1986, (GE Proprietary information)

5.2 Deleted

5.3 Industry Standard ANSI/ISA Standard S67.04, Setpoints for Nuclear safety Related Instrumentation Parts I and II

And,

ISA dTR 67.04.09, Graded Approaches to Setpoint Determination, Draft Technical Report, 1994 and the subsequent version Draft 4, May, 2000

5.4 GE Nuclear Energy internal procedures

5.5 General Electric Document EDE-40-1189 (Rev. 0)

5.6 ANS/ASME PTC 19.1-1985, Measurement Uncertainty

Establishes a basis for the principles of uncertainty analysis.

5.7 ASME MFC-3M-1989, Measurement of fluid Flow in Pipes Using Orifice, Nozzle, and Venturi

Provides information regarding expected uncertainties and errors associated with flow measurement.

5.8 ASME 1967 Steam Tables

Provides the basis for water density as a function of temperature and pressure. When used, the appropriate pages should be copied and made as an attachment to the calculation.

5.9 ANSI N42.18, American National Standard for Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents

This standard establishes minimum expected performance standards for certain types of radiation monitoring equipment.

5.10 The Institute for Nuclear Power Operations (INPO) Good Practice TS-405, Setpoint Change Control Program.

Provides guidance for setpoint change control and implementation practice.

5.11 Regulatory Guide 1.105, Rev. 01, Setpoints for Safety-Related Instrumentation

CPS has committed to Regulatory Guide 1.105 Rev 01 for guidance relative to instrument setpoint preparation and control. This Regulatory Guide 1.105 establishes the NRC's proposed endorsement of the ISA-67.04. The discussion also provides the NRC's perspective on various technical areas related to setpoint methodologies and statistical analysis.

5.12 NRC Information Notice 92-12, Effects of Cable Leakage Currents on Instrument Settings and indications

Information Notice 92-12 describes a potential problem related to instrument loop current leakage. During the high humidity and temperature conditions of a LOCA or HELB, insulation resistance can be degraded, thereby contributing to the measurement uncertainty of affected instrument loops.

5.13 Not Used

5.14 CPS 1512.01, Rev. 17b, Calibration and Control of Measuring and Test Equipment (M&TE) and CPS 1012.01, Rev.9, Control of Measuring and Test Equipment.

These procedures establish generic requirements and controls for calibration and verification of Test Equipment and Reference Standards. Additionally, the administrative requirements for controlling M&TE are provided. These procedures establish the minimum requirements for M&TE control. This Engineering Standard assumes that M&TE is controlled in accordance with this directive.

5.15 CPS 8801.01, Rev. 12b, Instrument Calibrations

This procedure provides instructions for performing operations verification and calibration of single and multiple input devices as an individual instrument. It also includes instructions for development of Instrument Data Sheets.

5.16 CPS 8801.02, Rev. 11a, Loop Calibrations

This procedure provides instructions for performing operations verification and calibration of instrument loops. It also includes instructions for development of Loop Calibration Data Sheets.

5.17 CPS 8801.05, Rev. 5, Corrections to Instrument Calibrations

This procedure provides instructions for scaling and applying corrections to setpoint data obtained from Engineering.

5.18 Not Used

5.19 Not Used

5.20 Not Used

5.21 NSED E.1, Rev. 10, Calculations

This procedure establishes generic requirements and controls for preparation, review, documentation and approval of design calculations.

5.22 Calculation 01ME127, Rev.0, DBA Influence On Insulation-Resistance Related Instrument Errors

This calculation determines the influence of design basis accident (DBA) conditions on containment instrumentation loop signal transmission systems (i.e., penetrations, cabling, splices, and conduit seals) and the consequent effect on the accuracy of measurement of safety-related process parameters. The calculation addresses those instrument loops which have the primary devices located inside containment and for which S&L has prepared instrument setpoint accuracy calculations per the requirements of Reg. Guide 1.105.

5.23 Calculation 01ME128, Rev. 0, DBA Influence On Insulation-Resistance Related Instrument Errors For GE RG 1.105 Instruments

This calculation determines the influence of design basis accident (DBA) conditions on containment instrumentation loop signal transmission systems (i.e., penetrations, cabling, splices, and conduit seals) and the consequent effect on the accuracy of measurement of safety-related process parameters. The calculation addresses those instrument loops which have the primary devices located inside containment and for which GE has prepared instrument setpoint accuracy calculations per the requirements of RG 1.105.

5.24 Calculation CI-CPS-187, Rev. 0, DBA Influence On Insulation-Resistance Related Instrument Errors

This calculation provides similar information as Calculations 01ME127 or 01ME128. Also, this calculation determines the bounding influence on instrumentation loops for each generic circuit type (current source, voltage source, and bridge current source), that can be applied to similar circuits under harsh conditions. This calculation addresses instrument loops that have the primary devices located outside containment and for which Sargent & Lundy prepared Reg. Guide 1.105 instrument setpoint calculations.

5.25 Not Used

5.26 Not Used

5.27 Not Used

5.28 Honeywell 4450 Extended Analog System Input 4400 AG-T, Termination Assembly, K2801-0116A, Tab 15, and Analog Input Subsystem, K2801-0116B, Book 1, Tab 2.

Vendor Manual and Specifications

5.29 Record of Teleconference from Carl M. Ingram to J. Miller.

File Nos. 126.5, S/U 33.1. 10/16/81

Computer Point Accuracy and digital gain error.

5.30 IP-C-0089 Rev. 0, "M&TE Uncertainty Calculation"

5.31 ASTM Standard D257-91, Standard Test Methods for D-C Resistance or Conductance of Insulating Materials, Appendix XI

5.32 EPRI TR-103335, Rev. 1, Statistical Analysis of Instrument Calibration Data.

5.33 EPRI TR-102644, Calibration of Radiation Monitors at Nuclear Power Plants

5.34 Regulatory Guide 1.97, Rev. 3, Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident.

5.35 Regulatory Guide 1.89, Rev. 0, Qualification of Class 1E Equipment For Nuclear Power Plants

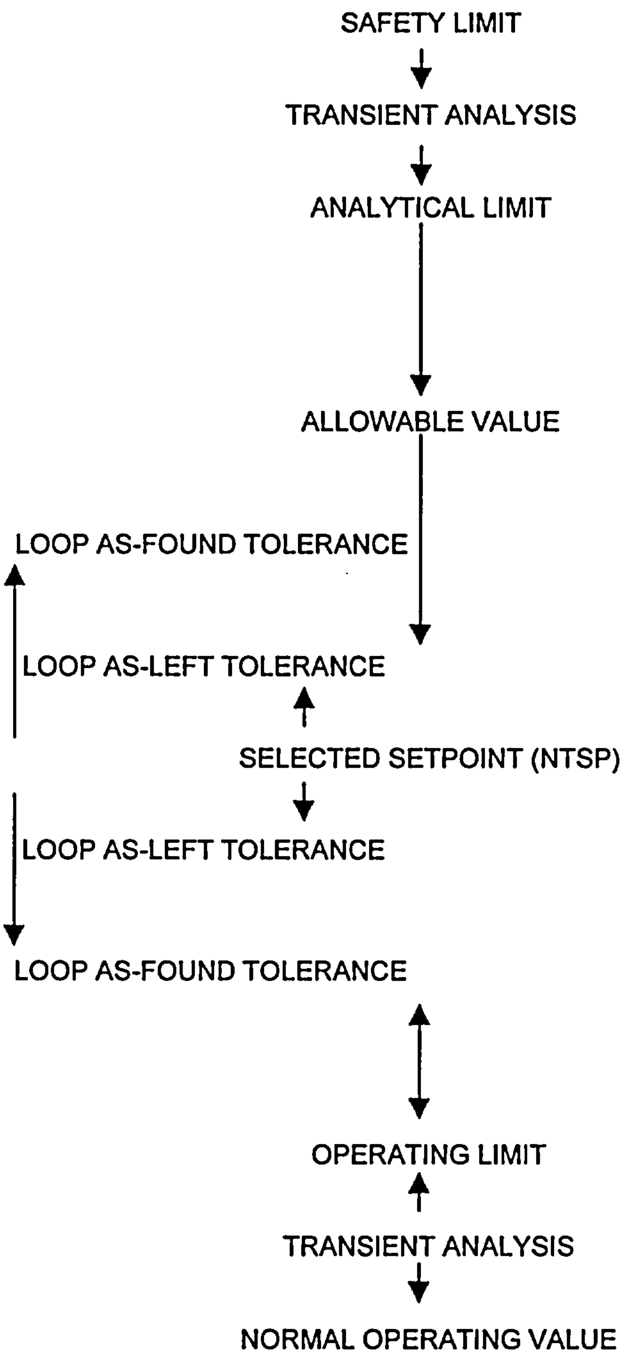
5.36 DC-ME-09-CP, Rev. 11, "Equipment Environmental Design Conditions, Design Criteria."

5.37 CPS 1003.09, Rev. 0a, "CPS Instrument Setpoint Program Interfaces"

6.0 APPENDICES

This Engineering Standard includes Appendices organized to provide all required technical information necessary to prepare a CPS Instrument Setpoint Calculation. The Appendices are listed as follows:

Figure 2. Setpoint Relationships



APPENDIX A

GUIDANCE ON DEVICE SPECIFIC ACCURACY AND DRIFT ALLOWANCES

A.1 Overview

In general, there are three parameters relating to Accuracy and Drift, which must be determined for any given device. These are Accuracy under normal conditions (A_i(normal)), Accuracy under trip conditions (A_i(trip)) and Drift (D_i). There are two steps that must be taken to determine these values.

a. Identify the individual effects that may contribute to these errors.

b. Obtain numerical data on the identified individual effects.

In determining the effects that may contribute, and identify the numerical values, consideration should be given to the following sources of information (in order of importance):

c. Clinton specific data from testing of actual instruments, surveillance records, qualification programs, etc.

d. Generic data from testing of actual instruments, surveillance data, qualification programs, etc.

e. Vendor supplied data sheets and data.

f. Purchase specifications for equipment

g. Generally accepted assumptions.

The purpose of this appendix is to provide guidance for the process described above.

A.2 Effects Expected to be Present in Accuracy and Drift Values

A.2.1 Accuracy

As discussed in paragraph 4.3.1 and defined in Section 2.2, the following effects may typically be part of instrument accuracy (potentially, for both normal and trip conditions):

a. Vendor Accuracy (VA)

b. Accuracy Temperature Effect (ATE)

c. Overpressure Effect (OPE)

d. Static Pressure Effect (SPE)

e. Seismic Effect (SE)

f. Radiation Effect (RE)

g. Humidity Effect (HE)

h. Power Supply Effect (PSE)

i. RFI/EMI Effect (REE)

It may not be possible, in many cases, to determine all of the above effects. Qualification testing, or vendor performance specifications may simply state a value for accuracy, and then stipulate a range of temperatures, radiation levels, seismic loads, humidity and other boundaries within which the value of accuracy is applicable. In such cases, there is no need to determine the separate effects.

A.2.1.a Rosemount Transmitter Devices

In the absence of suitable vendor data, Clinton specific qualification data or surveillance test data GE recommends that the information in the following paragraphs be used. For a selected group of Rosemount devices GE has determined recommended accuracy assumptions based on generic qualification testing. This information has been provided to the USNRC (Reference 2.1) and used for many setpoint calculations accepted by the NRC.

A.2.1.a(1) Rosemount Transmitters

GE recommends that the following be used as a basis for determining normal and trip environment accuracies for Rosemount transmitters (models 1151, 1152-T0280, 1153 Series B, and 1154).

A.2.1.a.(1).(a) Vendor Accuracy (VA), Accuracy Temperature Effect (ATE), Power Supply Effect (PSE), Humidity Effect (HE) and RFI/EMI Effect (REE)

VA = 0.25% SP (3 Sigma)

ATE = (0.75% UR + 0.5% SP) (delta T_a)/100 (3 Sigma)

(double this value for Range Code 3)

PSE = 0.005% SP per volt (3 Sigma)

HE = 0 (included in VA)

REE = 0 (Normally negligible)

Determination of 'delta T_a' is discussed in paragraph A.2.3.

A.2.1.a.(1).(b) Overpressure Effect (OPE)

This effect varies depending on the instrument range, and is identified in Rosemount product data sheets. GE treats the resulting values as 3 Sigma values based on experience with the Rosemount data.

A.2.1.a.(1).(c) Static Pressure Effect (SPE)

As discussed in paragraph 4.3.1, SPE sometimes consists of several effects, some of which are random and some of which are bias. This is particularly the case with Rosemount differential pressure transmitters (note, SPE does not apply to absolute pressure or gage pressure transmitters). In the case of Rosemount transmitters, there are three SPE components: (1) a random zero point error, (2) a random span error, and (3) a bias span error. The bias span error is easily adjusted for as part of the calibration process (this is often done). If accommodated in the calibration process, it need not be included in the accuracy error calculations.

GE has found that the Rosemount manuals may be difficult to interpret concerning SPE. For this reason, the following summary is provided to describe definition of the Rosemount SPE.

The components of SPE are calculated as follows:

Random Zero Effect; SPE_Z = (Zero)% UR (delta P)/1000 (3 Sigma)

Random Span Effect; SPE_S = (Span)% SP (delta P)/1000 (3 Sigma)

Bias Span Effect; SPE_{BS} = (BS)% SP (delta P/1000 (3 Sigma)

Where 'delta P' is the pressure difference between the system pressure at calibration and the system pressure under trip conditions, and the terms SPE_Z, SPE_S, and SPE_{BS} are shown in Table A.1.

TABLE A.1 ROSEMOUNT STATIC PRESSURE EFFECT

EFFECT	RANGE	1151DP	1152-T0280	1153B	1154
		(Zero)%	(Zero)%	(Zero)%	(Zero)%
Random Zero Error (SPE_Z)	3	0.25	0.25	0.50	N/A
	4,5	0.125	0.125	0.2	0.2
	6, 7, 8	0.125	0.25	0.5	0.5
		(Span)%	(Span)%	(Span)%	(Span)%
Random Span Error (SPE_S)	3	0.5	0.25	0.5	N/A
	4,5,6,7,8	0.25	0.25	0.5	0.5
		(BS)%	(BS)%	(BS)%	(BS)%
Bias Span Error (SPE_{BS})	3	1.75	1.5	1.5	N/A
	4	0.87	1.0	0.75	0.75
	5	0.81	1.0	0.75	0.75
	6	1.45	1.0	1.25	1.25
	7	1.05	1.0	1.25	1.25
	8	0.55	1.0	0.75	0.75
CPS Vendor Manual		4256/57 (3/87)	K2801-091, Tab 1	K2801-091, Tab 2	M008-0002

NOTE: Rosemount manuals supplied with purchased instrumentation should be checked to determine if any changes apply to this information.

A.2.1.a.(1).(d) Seismic Effect (SE)

Based on an evaluation of Rosemount test data, GE recommends the following:

SE = 0.23% UR (2 Sigma)

Where equation applies to situations in which the Zero Period Acceleration (ZPA) at the mounting location of the transmitter does not exceed 1 "g" for the event of interest, and where the transmitter is expected to be performing its trip function simultaneous with the seismic event.

SE = (0.03 ZPA + 0.20)% UR (2 Sigma)

Where ZPA exceeds 1 "g", but not 10 "g", and the transmitter is expected to be performing its trip function simultaneous with the seismic event.

SE = 0.25% UR (2 Sigma)

Where ZPA exceeds 2 "g", but the seismic event is expected to occur between the time of the last calibration and the time of trip, but not simultaneously.

If the seismic event ZPA does not exceed 2 "g", and the event is not simultaneous with the trip event, the effect on transmitter accuracy is negligible.

A.2.1.a.(1).(e) Radiation Effect (RE)

GE does not recommend use of Rosemount model 1151 transmitters for trip applications for which the gamma Total Integrated Dose (TID) to time of trip exceeds approximately 10^4 RAD. Up to this value, the radiation effect on 1151 transmitters is negligible (plant specific EQ program data should be used to support use of 1151 transmitters in a radiation environment, if such data is available).

For the **1152-T0280** transmitter:

RE = (1.25X + 1.25)% UR (2 Sigma)

Where TID exceeds 0.1 MRAD, but does not exceed 0.4 MRAD. This effect should be multiplied by 1.68 for Range Code 3. There is no effect at or below 0.1 MRAD.

RE = (4.5X + 4.5)% UR (2 Sigma)

Where TID exceeds 0.4 MRAD, but not 20 MRAD. This effect should also be multiplied by 1.68 for Range Code 3.

The term "X" is defined as:

X = (setpoint of interest-instrument zero)/calibrated span

For the **1153 Series B** transmitter with a **"P" output:**

RE = (3.0X + 3.0)% UR (2 Sigma)

Where TID exceeds 0.1 MRAD, but not 22 MRAD. There is no effect at or below 0.1 MRAD. This effect should also be multiplied by 1.68 for Range Code 3.

For the **1153 Series B** transmitter with an **"R" output:**

RE = (1.5X + 1.5)% UR (2 Sigma)

Where TID exceeds 0.1 MRAD, but not 22 MRAD. There is no effect at or below 0.1 MRAD. This effect should also be multiplied by 1.68 for Range Code 3.

For the **1154** transmitter:

RE = (1.0X + 1.0)% UR (2 sigma)

Where TID exceeds 0.5 MRAD, but not 50 MRAD. There is no effect at or below 0.5 MRAD. This effect should also be multiplied by 1.68 for Range Code 3.

A.2.1.a.(2) Rosemount Trip Units

For unmodified Rosemount model **510DU and 710DU** trip units use vendor specified data for instrument uncertainties. For trip units modified by GE (model number 147D8505G005), use GE Performance Specification 22A7866 for instrument uncertainties.

A.2.2 Drift

As discussed paragraph 4.3.2, there are two terms of interest in determining device drift. These are Vendor Drift (VD) and some time interval associated with VD(usually 6 months). These effects should be determined from vendor data, field data, or qualification data, if available.

A.2.2.a Rosemount Devices

For a selected group of Rosemount devices GE has determined recommended drift assumptions based on generic qualification testing. This information has been provided to the USNRC (Reference 5.1) and used for many setpoint calculations accepted by the NRC. In the absence of suitable Clinton specific qualification data or surveillance test data GE recommends that the information in the following paragraphs be used.

A.2.2.a.(1) Rosemount Transmitters

For Rosemount model **1151, 1152-T0280, 1153 Series B and 1154** transmitters refer to vendor supplied information for the appropriate drift term. Due to Rosemount correspondences in the year 2000, the Rosemount drift terms will conservatively be considered to be 2 sigma.

A.2.2.a.(2) Rosemount Trip Units

For Rosemount model **510DU and 710DU** trip units use the vendor specified data. For trip units modified by GE (model number 147D8505G005), use the GE Performance Specification 22A7866

A.2.3 (Deleted)

A.2.4 Interpreting Vendor Data

For many devices, it may be necessary to use vendor data sheets or specifications as the source of accuracy and drift information for setpoint calculations. However, vendors commonly use many different terms to describe the performance of their equipment. In addition, most vendors do not specify their data in terms of a probability of error (i.e., they don't say how many standard deviations their values represent). Therefore, interpretation is necessary.

When interpreting terminology, the definitions in Section 2.2 of this document should be used to ensure consistent interpretation. For example, the definition of Channel Instrument Accuracy, paragraph 2.2.11, states that accuracy, as referred to in the CPS Setpoint Methodology, includes "the combined conformity, hysteresis and repeatability errors". Paragraph 2.2.11 also indicates certain terms, which are not considered to be part of accuracy.

Care should be exercised to relate the vendor-defined errors to the functions of the instrument channel. For example, a Rosemount trip unit with an analog indicator has two distinct sets of errors. There are errors associated with the trip circuitry, and which apply to a trip setpoint calculation. There are also errors associated with the analog indicator, which do not apply to the trip function, but which would apply if the purpose of the calculation is to define the error associated with readings taking using the analog indicator.

In some cases, vendors may not identify all errors of interest. For some types of devices, vendors identify accuracy errors but no drift effects. In such cases, it is necessary to first determine whether or not there is satisfactory evidence that the omitted item (drift, for example) does not apply to this type of device. If available information is not convincing, it may be necessary to assume a value. Paragraphs A.2.5 and A.2.6 contain recommendations for establishing error terms on the basis of field data and/or conservative assumptions.

The final aspect of importance when interpreting vendor data is determining how many standard deviations (sigma values) the data represents. In general, this is an issue of how much confidence we have in the vendor data. Data may be qualitatively classified into three categories: (1) best estimate data, (2) worst case data which is backed by limited testing, and (3) worst case data backed by extensive qualification testing or testing of every delivered device. In the absence of information from a vendor, which specifies the sigma value associated with the data, GE recommends treating data as follows:

a. Best Estimates: Assume they are (1) sigma values.

b. Worst case data backed by limited testing: Assume two (2) sigma.

c. Worst case data extensively backed: Assume three (3) sigma.

Under normal circumstances, all vendor data will be one of the latter two cases (i.e., 2 or 3 sigma). This is because most vendors specify instrument performance in terms of guaranteed performance. In order to guarantee performance, the vendor must have considerable confidence in the data. A two (2) sigma value corresponds to a 95% probability value, while three (3) sigma corresponds to slightly greater than 99%. Thus, assignment of the sigma value to be assumed in the calculations is a question of the confidence placed in the vendor data.

A.2.5 Interpreting Surveillance Test Data

Surveillance test data can be a valuable source of information with which to improve the database and refine setpoint calculations. The primary use of surveillance test data is in validating and/or refining drift assumptions, and in extending instrument surveillance intervals. The primary limitation associated with use of field data is that there must be a valid basis for assumptions as to what the data contains. For example, surveillance data is normally valid as a source of improved drift information, and may be used to estimate other surveillance test related errors, but is not a good source for validating accuracy assumptions. Instrument accuracies may be quite different under trip conditions than during surveillance testing.

The basic approach to use of surveillance test data is a three part approach:

a. Define, in terms of the values of interest (drift, etc.), what the surveillance data represents, as a means of defining how you will interpret the data.

b. Collect the surveillance data needed to provide a strong statistical basis.

c. Perform a statistical analysis of the data, and establish the desired values along with the associated sigma level for use in channel error calculations or setpoint calculations.

The area of greatest potential benefit associated with surveillance test data analyses are the use of test data to validate reduced drift assumptions for existing surveillance test intervals, and the use of the data to predict revised drift values for longer surveillance test intervals. This latter is particularly useful in preparing justifications for temporary surveillance interval extensions in order to avoid undesired plant shutdowns for surveillance testing.

Detailed calculation models and methods for evaluating surveillance test data are beyond the scope of this document. Standard statistical methods may be used. In addition, References 5.1, 5.3, & 5.32 contain a detailed discussion of validating drift assumptions from surveillance test data.

A.2.6 Recommended Assumptions in the Absence of Data

In the absence of better information, GE recommends the following assumptions be used in channel error and setpoint calculations:

a. Calibrating equipment accuracies are taken as 3 sigma values provided that the calibration of these devices is to NIST traceable standards and minimizes the effects of hysteresis, linearity and repeatability. The accuracies of the standards themselves are also taken to be 3 sigma values.

b. If Vendor Drift (VD) is not specified by the vendor or available from other sources, and if there is no basis for assuming drift is zero or negligible, assume VD equals Vendor Accuracy (VA) over the entire calibration period.

A.2.7 Cautions Concerning Use of Qualification Program Data

Plant specific data from Equipment Qualifications programs is a valuable source of data on instrument performance, particularly regarding the various accident related accuracy error terms (Radiation Effect, Seismic Effect, etc.). However, care should be exercised in use of this data.

In many cases, Equipment Qualification programs have been conducted to prove that class IE equipment will function throughout its intended lifetime. Because the post-accident functions include indications for operator use, the environmental conditions used in EQ programs may include long term post-accident conditions, which do not apply to most setpoint calculations. Use of EQ results, without taking into account less severe trip conditions can result in extreme conservatism. Overly conservative setpoints can impact plant operations and lead to unnecessary challenges to safety systems.

APPENDIX B

SAMPLE CALCULATION FORMAT

This sample presents, the format used for a setpoint and indication/control calculation. An Example of these types of calculations can be obtained from the Setpoint Program Coordinator. The calculation cover sheets are produced using E-1, Reference 5.21, Forms NF-161.01 through NF-161.04). The calculation shall reflect the name and order of major sections as shown in the TOC below, however, it is only recommended that sections within each major section be presented as shown in this Attachment. For other types of calculations, such as NIs, APRMs, and Radiation Monitors, the major sections of this sample should be used and Appendix P for guidance. The Setpoint Program Coordinator can provide examples of what is shown within each major section.

TABLE OF CONTENTS

1.0 OBJECTIVE

Should state purpose, functions and objectives of calculation, including the category to which the amount of rigor is required.

2.0 ASSUMPTIONS

Other than CPS Standard Assumptions, there are two types that can be made: an assumption as to a value; or an assumption as to the quality of input information. For each assumption, a judgement must be made as to whether confirmation is required or justification is provided to show it is reasonable. Refer to NSED E.1, for further guidance.

All standard assumptions (See Appendix I, Section I.11) required by this calculation will be listed first. Any additional assumptions as discussed above, will follow standard assumptions.

3.0 METHODOLOGY

Typical:

This calculation will determine the instrument uncertainty associated with the (Function – Description). The evaluation will determine the loop setpoint and Allowable Value for the (Function). Instrument uncertainty will be determined in accordance with CI-01.00, "Instrument Setpoint Calculation Methodology". The evaluation will then compare the current setpoint and Allowable Value with the results determined by this calculation.

M&TE error will be determined from the results of Calculation IP-C-0089, which uses building temperature minimum and maximums to develop the uncertainty, and review of the corresponding loop and device calibration procedures. Any changes to the calibration procedures will be shown in Attachment 2.

Per CI-01.00, Head Correction is determined by evaluating design drawings, survey data, and/or walk down data as applicable and calculated in Attachment 1.

4.0 INPUTS

Inputs that cannot be easily retrieved from the CPS Document System, should be also added as attachments. Typical: (Number, Revision Level, Title)

5.0 OUTPUTS

Typical: (Number, Revision Level, Title)

Calibration procedures and other calculations as required.

6.0 REFERENCES

Typical: (Number, Revision Level, Title).

7.0 ANALYSIS AND COMPUTATION SECTION(S)

This section should list all of the equations identified in Section 4.5.11 of CI-01.00 for the type of calculation to be performed. All inputs, outputs, and references should be identified as required within the document (eg Input 4.1, Output 5.1, Ref. 6.1). Titles can be shown in document (typically not shown), however revision levels shall only be identified in Sections4.0, 5.0, and 6.0.
From CI-01.00, Section 4.5.11,

Note: The individual terms and acronyms are defined in CI-01.00, Section 2.2.

7.1 Loop Function
7.2 Loop Diagram
7.3 Equations

7.3.1 Loop Accuracy (A_L):

For component,

$$A_i = \pm N\sqrt{\left(\frac{VA_i}{n}\right)^2 + \left(\frac{ATE_i}{n}\right)^2 + \left(\frac{OPE_i}{n}\right)^2 + \left(\frac{SPE_i}{n}\right)^2 + \left(\frac{SE_i}{n}\right)^2 + \left(\frac{RE_i}{n}\right)^2 + \left(\frac{HE_i}{n}\right)^2 + \left(\frac{PSE_i}{n}\right)^2 + \left(\frac{REE_i}{n}\right)^2} \pm B \qquad (2\sigma)$$

For loop,

$$A_L = \pm\sqrt{A_1^2 + A_2^2 + \ldots + A_i^2} \pm B \qquad (2\sigma)$$

7.3.2 Calculation of As-Left Values

For component,
ALT = (existing ALT or VA) (2σ)

The loop As-Left Tolerance (ALT) will be calculated as follows:

$$ALT_L = \pm(N)\sqrt{\left(\frac{ALT_1}{n}\right)^2 + \left(\frac{ALT_2}{n}\right)^2 + \ldots + \left(\frac{ALT_i}{n}\right)^2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

7.3.3 Loop Calibration Error (C_L):

$$C_L = \pm N\sqrt{\sum\left(\frac{ALT_i}{n}\right)^2 + \sum\left(\frac{C_i}{n}\right)^2 + \sum\left(\frac{CSTD}{n}\right)^2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

7.3.4 Loop Drift (D_L):

$$D_L = \pm N\sqrt{\left(\frac{D_1}{n}\right)^2 + \left(\frac{D_2}{n}\right)^2 + \ldots + \left(\frac{D_i}{n}\right)^2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

7.3.5 Calculation of As-Found Values

For component,

$$AFT_l = \pm(N)\sqrt{\left(\frac{ALT_l}{n}\right)^2 + \left(\frac{D_l}{n}\right) + \left(\frac{C_l}{n}\right)^2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.
The loop As-Found Tolerance (AFT) will be calculated as follows:

$$AFT_L = \pm(N)\sqrt{\left(\frac{C_L}{n}\right)^2 + \left(\frac{D_L}{n}\right)^2} \qquad (2\sigma)$$

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

7.3.6 Channel Uncertainty (CU) and Channel Error (CE):

This Section is for non-safety setpoints, indication, and control loops, and need not be derived for Safety Related setpoints.

$$CU = \pm N\sqrt{PMA^2 + PEA^2 + A_L^2 + \left(\frac{C_L}{n}\right)^2 + \left(\frac{D_L}{n}\right)^2} \pm B$$

(2σ)

Where N represents the number of standard deviations with which the value is evaluated to (normally 2 standard deviations) and n represents the sigma value for each device.

And

$$CE = \pm\left(\frac{1.645}{N}\right)\sqrt{CU^2 + IRE^2} \pm B$$

Note: An (1.645/N) adjustment to channel error is applicable to non-safety setpoints or required indicator readings that have a limit approached in one direction (single sided interest).

7.3.7 Setpoints with no Analytical Limits or Allowable Values

$$NTSP_{(INC)} = NPL - CE$$

$$NTSP_{(DEC)} = NPL + CE$$

7.3.8 Allowable Value Calculation

Allowable Value calculated for an increasing trip,

$$AV = AL - \left(\frac{1.645}{N}\right)\sqrt{PMA^2 + PEA^2 + A_L^2} - B$$

Allowable Value calculated for a decreasing trip,

$$AV = AL + \left(\frac{1.645}{N}\right)\sqrt{PMA^2 + PEA^2 + A_L^2} + B$$

Note: An (1.645/N) adjustment is applicable to setpoints that have a limit approached in one direction (single sided interest)

Note: The calculation of the AV does not include the C_L and D_L terms.

7.3.9 Nominal Trip Setpoint Calculation

The Nominal Trip Setpoint (NTSP) should be calculated using the equations below depending on the direction of process variable change when approaching the Analytical Limit.

For process variables that increase to trip,

$$NTSP = AV - AFT_L$$

For process variables that decrease to trip,

$$NTSP = AV + AFT_L$$

7.4 Determination of Uncertainties

A section is required for each device in the loop as shown by the loop diagram in section 7.2. In cases where there are multiple loops, and one device depicted in the loop diagram has different manufacture/model numbers (i.e. two channels, where the sensor has two different model numbers). A section evaluating each manufacture/model number is required and the worst case will be used in the Results, Section 8.0. Below is example for Rosemount Transmitter:

7.4.1 Sensor/Transmitters;

Calculations are typically performed in % Span and converted to engineering units as required in different sections of calculation. This is not a requirement, however all values calculated for output to calibration procedures shall be in the units and precision necessary to support the calibration procedure.

7.4.1.1 Vendor Accuracy of pressure transmitters (VA_{PT})

Calculation or conversion if required. Refer to the Appendices for aid in developing value.

$VA_{PT} = \pm$ [ ]% Span **(?σ)**

7.4.1.2 Accuracy Temperature Effect

7.4.1.2.1 Normal Accuracy Temperature Effect ($ATE_{PT(Normal)}$)

Calculation or conversion if required. Refer to the Appendices for aid in developing value. Use standard assumption when no vendor information is available.

$ATE_{PT(Normal)} = \pm$ [ ]% Span **(?σ)**

7.4.1.2.2 Accident Accuracy Temperature Effect ($ATE_{PT(Accid)}$)

This Section based on time when function is required; may need to be calculated. Refer to the Appendices for aid in developing value. Also, refer to the EQ manuals for more information.

$ATE_{PT(Accid)} = \pm$ [ ]% Span **(?σ)**

7.4.1.3 Humidity Effect (HE_{PT})

Calculation or conversion if required. Refer to the Appendices for aid in developing value. Use standard assumption when no vendor information is available.

$HE_{PT} = \pm$ [ ]% Span **(?σ)**

7.4.1.4 Radiation Effect

7.4.1.4.1 Normal Radiation Effect ($RE_{PT(Normal)}$)

Calculation or conversion if required. Refer to the Appendices for aid in developing value. Use standard assumption when no vendor information is available.

$RE_{PT(Normal)}$ = ± [ ]% Span **(?σ)**

7.4.1.4.2 Accident Radiation Effect ($RE_{PT(Accidnetl)}$)

This Section based on time when function is required; may need to be calculated. Refer to the Appendices for aid in developing value. Also, refer to the EQ manuals for more information

$RE_{PT(Accid)}$ = ± [ ]% Span **(?σ)**

7.4.1.5 Power Supply Effects of pressure transmitters (PSE_{PT})

Calculation or conversion if required. Refer to the Appendices for aid in developing value. Use standard assumption when no vendor information is available.

PSE_{PT} = ± [ ]% Span **(?σ)**

7.4.1.6 Static Pressure Effect (SPE_{PT})

Calculation or conversion if required. Refer to the Appendices for aid in developing value.

SPE_{PT} = ± [ ]% Span **(?σ)**

7.4.1.7 Overpressure Effect (OPE_{PT})

Calculation or conversion if required. Refer to the Appendices for aid in developing value.

OPE_{PT} = ± [ ]% Span **(?σ)**

7.4.1.8 Seismic Effect

7.4.1.8.1 Normal Seismic Effect ($SE_{PT(Normal)}$)

Use standard assumption.

$\mathbf{SE_{PT(Normal)} = 0}$

7.4.1.8.2 Accident Seismic Effect ($SE_{PT(Accid)}$)

Per Section C.3.14, A seismic event coincident with a LOCA is a design basis event per USAR 15.6.5. However, per USAR 15.6.5.1.1, there are no realistic, identifiable events which would result in a pipe break inside the containment of the magnitude required to cause a loss-of-coolant accident coincident with a safe shutdown earthquake. Therefore, each setpoint calculation should consider the larger effect of a seismic event or loss-of-coolant.

$\mathbf{SE_{PT(Accid)} = 0}$

7.4.1.8.3 OBE/SSE Seismic Effect ($SE_{PT(Seismic)}$)

Refer to the Appendices for aid in developing value. Also, refer to the SQ manuals for more information

$\mathbf{SE_{PT(Seismic)} = \pm [\ \ ]\%\ Span}$ **(?σ)**

7.4.1.9 RFI/EMI Effect (REE_{PT})

Use standard assumption, if applicable or review historical work packages and vendor data to build a justifiable assumption.

$\mathbf{REE_{PT} = 0}$

7.4.1.10 Bias (B_{PT}) –

Refer to Appendix C for guidance.

$\mathbf{B_{PT} = \pm [\ \ ]\%\ Span}$ **(?σ)**

7.4.1.11 Pressure Transmitter Accuracy

Refer to Section 7.3.1 for formula.

7.4.1.11.1 Normal Pressure Transmitter Accuracy ($A_{PT(Normal)}$)

$\mathbf{A_{PT(Normal)} = \pm[\ \ ]\%\ Span}$ **(?σ)**

7.4.1.11.2 Accident Pressure Transmitter Accuracy ($A_{PT(Accid)}$)

Calculated the same as normal, however the accident uncertainties replace the similar normal uncertainities.

$\mathbf{A_{PT(Accid)} = \pm[\ \ ]\%\ Span}$ **(?σ)**

7.4.1.11.3 Seismic Pressure Transmitter Accuracy ($A_{PT(Seismic)}$)

Calculated the same as normal, however the seismic uncertainty replaces the normal seismic uncertainity.

$\mathbf{A_{PT(Seismic)} = \pm[\ \ ]\%\ Span}$ **(?σ)**

7.4.1.11.4 Pressure Transmitter Accuracy (A_{PT})

Based on the above, use the largest uncertainty is calculated under [normal/accident/seismic] conditions to determine AV, NTSP, and CE. Therefore:

$A_{PT} = \pm A_{PT(normal/accident/seismic)}$

$\mathbf{A_{PT} = \pm[\ \ ]\%\ Span}$ **(?σ)**

7.4.2 Loop Accuracy (A_L)

Refer to Section 7.3.1 for formula

$\mathbf{A_L = \pm[\ \ ]\%\ Span}$ **(2σ)**

7.5 As-Left Values (ALT)

Each device in loop requires an ALT_i.
For component,

ALT = (existing ALT or VA) **units** **(3σ)**

The loop As-Left Tolerance (ALT) will be calculated as follows:

Refer to Section 7.3.2 for formula.

ALT_L = ±[ ] units (2σ)

7.6 Loop Calibration Error (C_L)

Refer to Section 7.3.3 for formula

7.6.1 As-Left Tolerance (ALT_L)

Refer to Section 7.5 for values.

ALT_L = ±[ ]% Span (2σ)

7.6.2 Calibration Tool Error (C_i)

Each device requires a calibration tool error.

7.6.2.1 Transmitter Calibration Tool Error (C_{PT})

Refer to M&TE calculation IP-C-0089, for maximum values however, if extra margin is required, refer to Appendix H for additional guidance.

C_{PT} = ± [ ]% Span (3σ)

7.6.3 Calibration Standard Error (C_{STD}):

Per Assumption [ ], Calibration Standard Error is considered negligible for the purposes of this analysis.

C_{STD} = 0

7.6.4 Loop Calibration Error (C_L):

Calculate using formula from Section 7.6 above. Only the M&TE required for the loop is used for calculating the Loop Calibration Error (C_L).

C_L = ± [ ]% Span (2σ)

7.7 Loop Drift

Each device requires a dift evaluation.

7.7.1 Pressure Transmitter Drift (D_{PT}):

Calculation or conversion if required. Refer to the Appendices for aid in developing value. Use standard assumption when no vendor information is available.

D_{PT}= ± [ ]% Span **(?σ)**

7.7.2 Loop Drift (D_L):

Refer to Section 7.3.4 for formula.

D_L = ±[ ]% Span **(2σ)**

7.8 Calculation of As-Found Values (AFT)

Each device in loop requires an AFT_i. Refer to Section 7.3.5 for formulas.

For component,

AFT_i = ±[ ] units **(2σ)**

The loop As-Found Tolerance (AFT_L) will be calculated as follows:

AFT_L = ±[ ] units **(2σ)**

7.9 Process Measurement Accuracy (PMA):

Discussion and calculation as required. Refer to the Appendices for aid in developing value.

PMA = ±[ ]% Span **(?σ)**

7.10 Primary Element Accuracy (PEA):

Discussion and calculation as required. Refer to the Appendices for aid in developing value.

PEA = ±[ ]% Span **(?σ)**

7.11 Insulation Resistance Accuracy Error (IRA):

References 5.22, 5.23, 5.24 from CI-01.00, may provide a bounding IRA value to use, if the device is identified by these calculations. However, if a more precise IRA value for the identified devices is needed or a non identified device requires IRA to be established, then the guidance, provided in Appendix D shall be used.

8.0 RESULTS

8.1 Determine Channel Uncertainty (CU):

This section is only applicable to indication/control loop calculations. Refer to Section 7.3.6 for formula. N/A for safety related setpoint calculations.

CU = ± [ ] units **(2σ)**

CE = ± [ ] units **(2σ)**

8.2 Calculation of Setpoints with not Analytical Limits or Allowable Values

This section is only applicable to setpoint calculations. Refer to Section 7.3.7 for formula. N/A for safety related setpoint calculations.

NTSP = [ ] units

8.3 Calculation of the Allowable Value (AV)

This section is only applicable to setpoint calculations. Refer to Section 7.3.8 for formula. N/A for non-safety related setpoint, indication, and control loop calculations.

AV = [ ] units **(2σ)**

8.4 Calculation of the Nominal Trip Setpoint (NTSP)

This section is only applicable to setpoint calculations. Refer to Section 7.3.9 for formula. N/A for non-safety related setpoint, indication, and control loop calculations.

NTSP = [ ] units

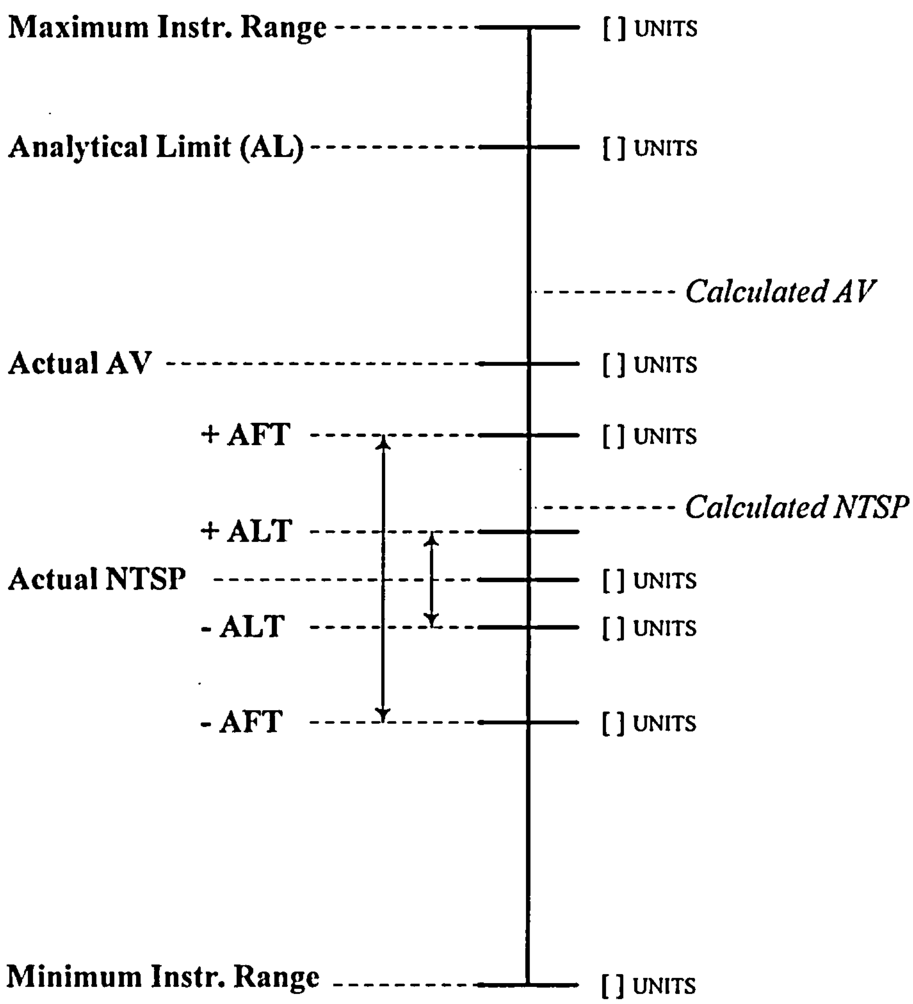
8.5 Evaluation of Reset Value

Evaluate per guidance given by Section 4.4.12.2

9.0 CONCLUSIONS

Add discussion of results to verbalize that the objectives are met and that they graphically presented, the figure should reflect the direction of the setpoint.

FIGURE 1 – [NAME] FUNCTION



ATTACHMENT 1
SCALING OF THE {NAME} FUNCTION

There should be a discussion whether head correction is applicable or not. If applicable then it should be developed. CPS 8801.05 shall be used as guidance, however only verified information (typically, walkdowns) may be used from existing CPS 8801.05 head corrections.

Scaling shall be performed for each device in loop, as presently presented in the existing calibration procedures (Cardinal Points, units, and precision). Discussion with C&I maintenance shall be required when unable to support existing calibration procedures.

1 Transmitter

EINs

Manufacturer: Rosemount Inc.
Model No.:
Input:
Output:

Process Range

Min (p)	Max (P)	Units

Transmitter Output Range

Min(o)	Max(O)	Units

EINs
Transmitter Calibration

Cal. Pt.	**Input**	**Output (volts DC)**	
	Units	AFT ± [ ] units	ALT ± [ ] units
0%		[ ] (to)	[ ] (to)
25%		[ ] (to)	[ ] (to)
50%		[ ] (to)	[ ] (to)
75%		[ ] (to)	[ ] (to)
100%		[ ] (to)	[ ] (to)

ATTACHMENT 2
RESULTS SUMMARY

The following tables list the applicable results of this calculation:

Primary Sensor Scaling/Calibration					
Primary Sensor	Calibration Span				
	0%	25%	50%	75%	100%
	[ ] units	[ ] units	[ ] units	[ ] units	[ ] units

Individual Component Setting Tolerances		
Component EIN	As-Found (units)	As-Left (units)

Trip Setpoint and Loop Setting Tolerances			
Component EIN	Setpoint (units)	As-Found (units)	As-Left (units)

M&TE Used In Calculation		
Manufacturer	Model Number	Range

USAR/Technical Specification Setpoints		
Component EIN	Allowable Value / Design Setpoint	USAR/Technical Specification Section
		Tech. Spec. Tables: ORM Tables:

APPENDIX C
UNCERTAINTY ANALYSIS FUNDAMENTALS

The ideal instrument would provide an output that accurately represents the input signal, without any error, time delay, or drift with time. Unfortunately, this ideal instrument does not exist. Even the best instruments tend to degrade with time when exposed to adverse environments. Typical stresses placed on field instruments include ambient temperature, humidity, vibration, temperature cycling, mechanical shock, and occasionally radiation. These stressors may affect an instrument's reliability and accuracy. This Appendix discusses the various elements of uncertainty that should be considered as part of an uncertainty analysis. The methodology to be applied to uncertainty analysis and the determination of trip setpoints is also described in this Appendix.

Instrument loop uncertainty is a combination of individual instrument uncertainties and variations in the process that the loop is monitoring. Individual instrument uncertainty may vary with the environmental conditions around the instrument and with process variations.

The are five general categories of environmental and process conditions which need to be considered: (1) normal operations, (2) seismic event, (3) post seismic, (4) accident, which could be LOCA, MSLB, HELB, etc., (5) post accident. This standard provides information for determining instrument uncertainties under each condition. The total instrument uncertainty may be used alone, as for indicators and recorders to provide an estimate of possible error between actual and indicated process conditions, or as a step toward determining instrument setpoints and operator decision points.

Not all categories of uncertainty described in this Appendix will apply to every configuration. But, the analyst should provide, in the body of the calculation, a discussion sufficient to explain the rationale for any uncertainty category that is not included.

C.1 Categories of Uncertainty

The basic model used in this design standard requires that the user categorize instrument uncertainties as random, bias, or arbitrarily distributed. This section describes the various categories of instrument uncertainty and provides insight into the process of categorizing instrumentation based on performance specifications, test reports, and plant calibration data.

The estimation of uncertainty is an interactive process requiring the development of assumptions and, where possible, verification of assumptions based on actual data. Ultimately, the user is responsible for defending assumptions that affect the basis of uncertainty estimates.

It should not be assumed that, since this design standard addresses three categories of uncertainty, all three types must be used in each uncertainty calculation. Additionally, it should not be assumed that instrument characteristics would fit neatly into a single category. For example, the nature of some data may require that an instrument's static pressure effect be described as bimodal, which might best be represented as a random uncertainty with an associated bias.

C.1.1 Random Uncertainties

When repeated measurements are taken of some fixed parameter, the measurements will generally not agree exactly. Just as these measurements do not precisely agree with each other, they also deviate by some amount from the true value. Uncertainties that fluctuate about the true value without any particular preference for a particular direction are said to be *random.*

Random uncertainties are sometimes referred to as a quantitative statement of the reliability of a single measurement or of a parameter, such as the arithmetic mean value, determined from a number of random trial measurements. This is often called the statistical uncertainty and is one of the so-called precision indices. The most commonly used indices, usually in reference to the reliability of the mean, are the standard deviation, the standard error (also called the standard deviation in the mean), and the probable error.

In the context of instrument uncertainty, it is generally accepted that random uncertainties are those instrument uncertainties that a manufacturer specifies as having a ± magnitude and are defined in statistical terms. It is important to understand the manufacturer's data thoroughly and be prepared to justify the interpretation of the data. After uncertainties have been categorized as random, it is required that a determination be made whether there exists any dependency between the random uncertainties. Figure C-1 shows the expected nature of randomly distributed data. There is a greater likelihood that data will be located near the mean; the standard deviation defines the variation of data about the mean.

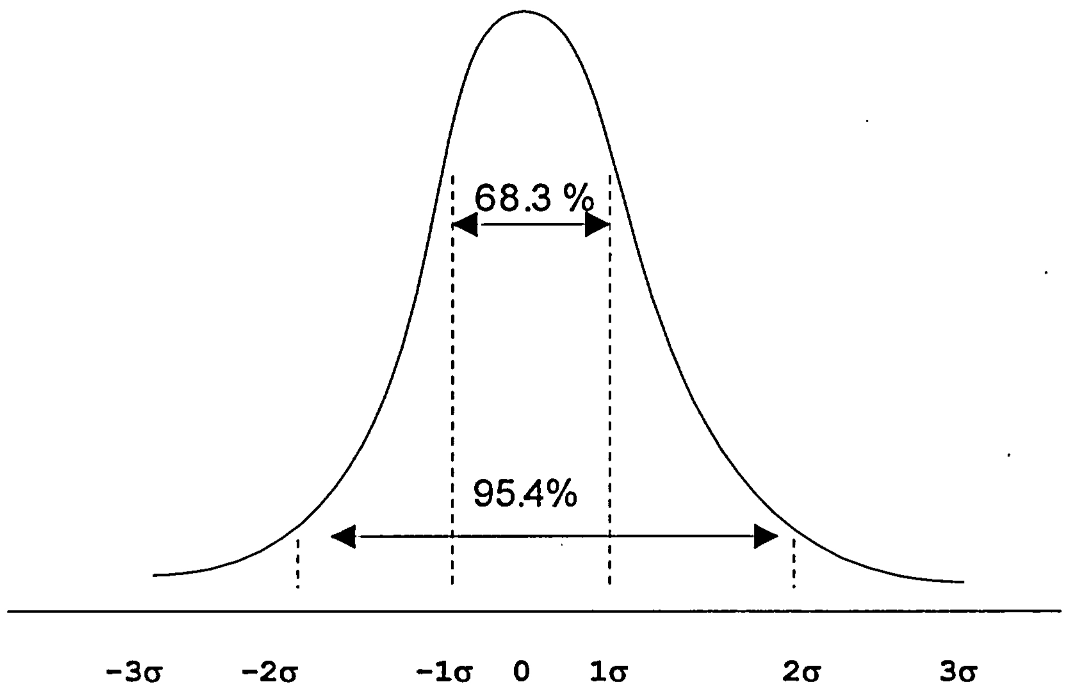


Figure C-1
Random Behavior

C.1.2 Bias Uncertainties

Suppose that a tank is actually 50% full, but a poorly designed level monitoring circuit shows the tank level as fluctuating randomly about 60%. As discussed in the previous section, the fluctuations about some central value represent random uncertainties. However, the fixed error of 10% in this case is called a *systematic* or *bias* uncertainty. In some cases, the bias error is a known and fixed value that can be calibrated out of the measurement circuit. In other cases, the bias error is known to affect the measurement accuracy in a single direction, but the magnitude of the error is not constant.

Bias is defined as a systematic or fixed instrument uncertainty, which is predictable for a given set of conditions because of the existence of a known direction (positive or negative). A very accurate measurement can be made to be inaccurate by a bias effect. The measurement might othèrwise have a small standard deviation (uncertainty), but read entirely different than the true value because the bias effectively shifts the measurement over from the true value by some fixed amount. Figure C-2 shows an example of bias; note that bias as shown in Figure C-2 shifts the measurement from the true process value by a fixed amount.

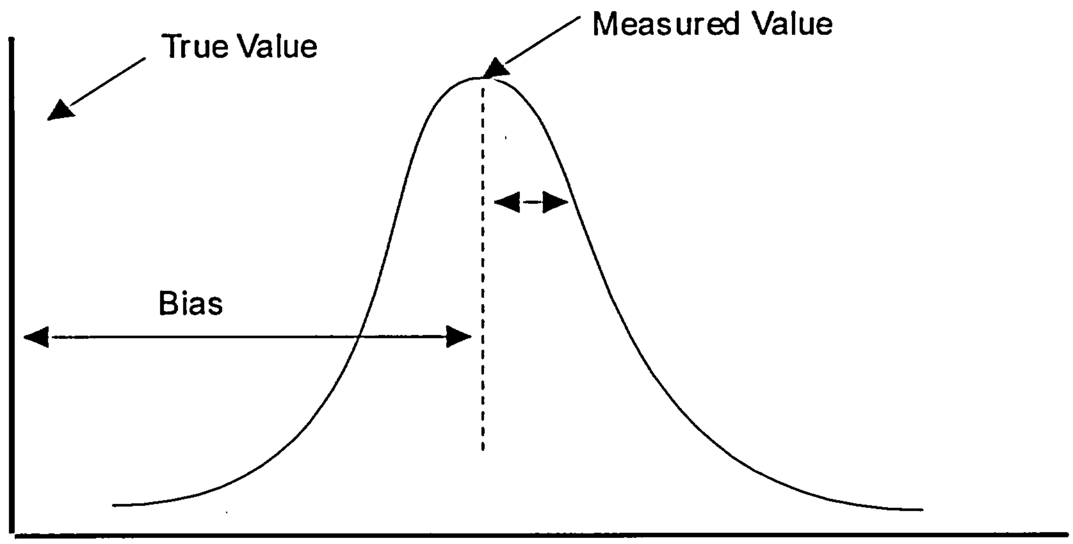


Figure C-2
Effect of Bias

Examples of bias include head correction, range offsets, reference leg heat-up or flashing and changes in flow element differential pressure because of process temperature changes. A bias error may have a random uncertainty associated with the magnitude.

Some bias effects, such as static head of the liquid in the sensing lines, can be corrected by the calibration process. These bias effects can be left out of the uncertainty analysis if verified to be accounted for by the calibration process. Note that other effects, such as density variations of the static head, might still contribute to the measurement uncertainty.

C.1.3 Arbitrarily Distributed Uncertainty

Some uncertainties do not have distributions that approximate the normal distribution. Such uncertainties may not be eligible for the rules of statistics or square root of the sum of the squares combinations and are categorized as arbitrarily distributed uncertainties. Because they are equally likely to have a positive or a negative deviation, worst-case treatment should be used.

It is important that the engineer recognize that the direction (sign) associated with a bias is known, whereas the sign associated with an arbitrarily distributed uncertainty is not known but is assumed based on a worst-case scenario.

C.1.4 Independent Uncertainties

Independent uncertainties are all those uncertainties for which no common root cause exists. It is generally accepted that most instrument channel uncertainties are independent of each other.

C.1.5 Dependent Uncertainties

Because of the complicated relationships that may exist between the instrument channels and various instrument uncertainties, it should be recognized that a dependency might exist between some uncertainties. The methodology presented here provides a conservative means for addressing these dependencies. If, in the engineer's judgment, two or more uncertainties are believed to be dependent, then these uncertainties should be added algebraically to create a new, larger independent uncertainty. For the purpose of this design standard, dependent uncertainties are those for which the user knows or suspects that a common root cause exists, which influences two or more of the uncertainties with a known relationship.

C.2 Interpretation of Uncertainty Data

The proper interpretation of uncertainty information is necessary to ensure that high confidence levels are selected and that protective actions are initiated before safety limits are violated. Also, proper interpretation is necessary for the valid comparison of instrument field performance with setpoint calculation allowances. This comparison confirms the bounding assumptions of the appropriate safety analysis.

Accuracy (uncertainty) values should be based on a common confidence level (interval) of at least two standard deviations (95% corresponds to approximately 2 standard deviations). The use of three or more standard deviations may be unnecessarily conservative, resulting in reduced operating margin. Some uncertainty values may need to be adjusted to 2-standard deviation values.

For example, if a vendor accuracy for a 99% level (3 standard deviations) is given as ±6 psig, the 95% confidence level corresponds to ±4 psig (= (2/3) x 6). This approach assumes that vendor data supports this 3 standard deviation claim.

Performance specifications should be provided by instrument or reactor vendors. Data should include vendor accuracy, drift, environmental effects and reference conditions. Since manufacturer performance specifications often describe a product line, any single instrument may perform significantly better than the group specification. If performance summary data is not available or if it does not satisfy the needs of the users, raw test data may need to be reevaluated or created by additional testing.

If an uncertainty is known to consist of both random and bias components, the components should be separated to allow subsequent combination of like components. Bias components should not be mixed with random components during the square root of the sum of the squares combination.

Historically, there have been many different methods of representing numerical uncertainty. Almost all suffer from the ambiguity associated with shorthand notation. For example, without further explanation, the symbol ± is often interpreted as the symmetric confidence interval associated with a random, normally distributed uncertainty. Further, the level of confidence may be assumed to be 68% (standard error, 1 standard deviation), 95% (2 standard deviations) or 99% (3 standard deviations). Still others may assume that the ± symbol defines the limits of error (reasonable bounds) of bias or non-normally distributed uncertainties. Vendors should be consulted to avoid any misinterpretation of their performance specifications or test results.

Reactor vendors typically utilize nominal values for uncertainties used in a setpoint analysis associated with initial plant operation. These generic values are considered conservative estimates, which may be refined if plant-specific data is available. Since plant-specific data may be less conservative than the bounding generic data, care should be taken to ensure that it is based on a statistically significant sample size.

One source of performance data that requires careful interpretation is that obtained during harsh environment testing. Often, such tests are conducted only to demonstrate the functional capability of a particular instrument in a harsh environment. This usually requires only a small sample size and invokes inappropriate rejection criteria for a probabilistic determination of instrument uncertainties. The meager data base typically results in limits of error (reasonable bounds) associated with bias or non-normally distributed uncertainties.

The limited database from an environmental qualification test also precludes adjusting the measured net effects for normal environmental uncertainties, vendor accuracies, etc. Thus, the results of such tests describe several mutually exclusive categories of uncertainty. For example, the results of a severe environment test may contain uncertainty contributions from the instrument vendor accuracy, measuring and test equipment uncertainty, calibration uncertainty and others, in addition to the severe environment effects. A conservative practice is to treat the measured net effects as only uncertainty contributions due to the harsh environment.

In summary, avoid improper use of vendor performance data. Just as important, do not apply overly conservative values to uncertainty effects to the point that a setpoint potentially limits normal operation or expected operational transients. Because of the diversity of data summary techniques, notational ambiguities, inconsistent terminology and ill-defined concepts that have been apparent in the past, it is recommended that vendors be consulted whenever questions arise. If a vendor-published value of an uncertainty term (source) is confirmed to contain a significant bias uncertainty, then the ± value should be treated as an estimated limit of error. If the term is verified to represent only random uncertainties (no significant bias uncertainties), then the ± value should be treated as the 2-standard deviation interval for an approximately normally distributed random uncertainty.

C.3 Elements of Uncertainty

NOTE: The following sections may expand or add clarification for elements of uncertainty, but does not replace the definitions specified in Section 2.2.

C.3.1 Process Measurement Accuracy (PMA)

PMA are those effects that have a direct effect on the accuracy of a measurement. PMA variables are independent of the process instrumentation used to measure the process parameter. PMA can often be thought of as physical changes in the monitored parameter that cannot be detected by conventional instrumentation.

The following are examples of PMA variables:

- Temperature stratification and inadequate mixing of bulk temperature measurements
- Reference leg heatup and process fluid density changes from calibrated conditions
- Piping configuration effects on level and flow measurements
- Fluid density effects on flow and level measurements
- Line pressure loss and pressure head effects
- Temperature variation effect on hydrogen partial pressure
- Gas density changes on radiation monitoring

Some PMA terms are easily calculated, some PMA terms are quite complex and are obtained from General Electric documents, and other PMA terms are allowances developed and justified by Design Basis Documents.

C.3.2 Primary Element Accuracy (PEA)

PEA is generally described as the accuracy associated with the primary element, typically a flow measurement device such as an orifice, venturi, or other devices from which a process measurement signal is developed. The following devices are typically considered to have a primary element accuracy that requires evaluation in an uncertainty analysis:

- Flow venturi
- Flow nozzle
- Orifice plate
- RTD or thermocouple thermowell
- Sealed sensors such as a bellows unit to transmit a pressure signal

PEA can change over time because of erosion, corrosion, or degradation of the sensing device. Installation uncertainty effects can also contribute to PEA errors.

C.3.3 Vendor Accuracy (VA)

VA defines a limit that error will not exceed when a device is used under reference or specified operating conditions. An instrument's accuracy consists primarily of three instrument characteristics: repeatability, hysteresis, and linearity. These characteristics occur simultaneously and their cumulative effects are denoted by a band, that surrounds the true output (see Figure C-3). This band is normally specified by the manufacturer to ensure that their combined effects adequately bounds the instrument's performance over its design life. Deadband is another attribute that is sometimes included within the vendor accuracy (see Section C.3.9).

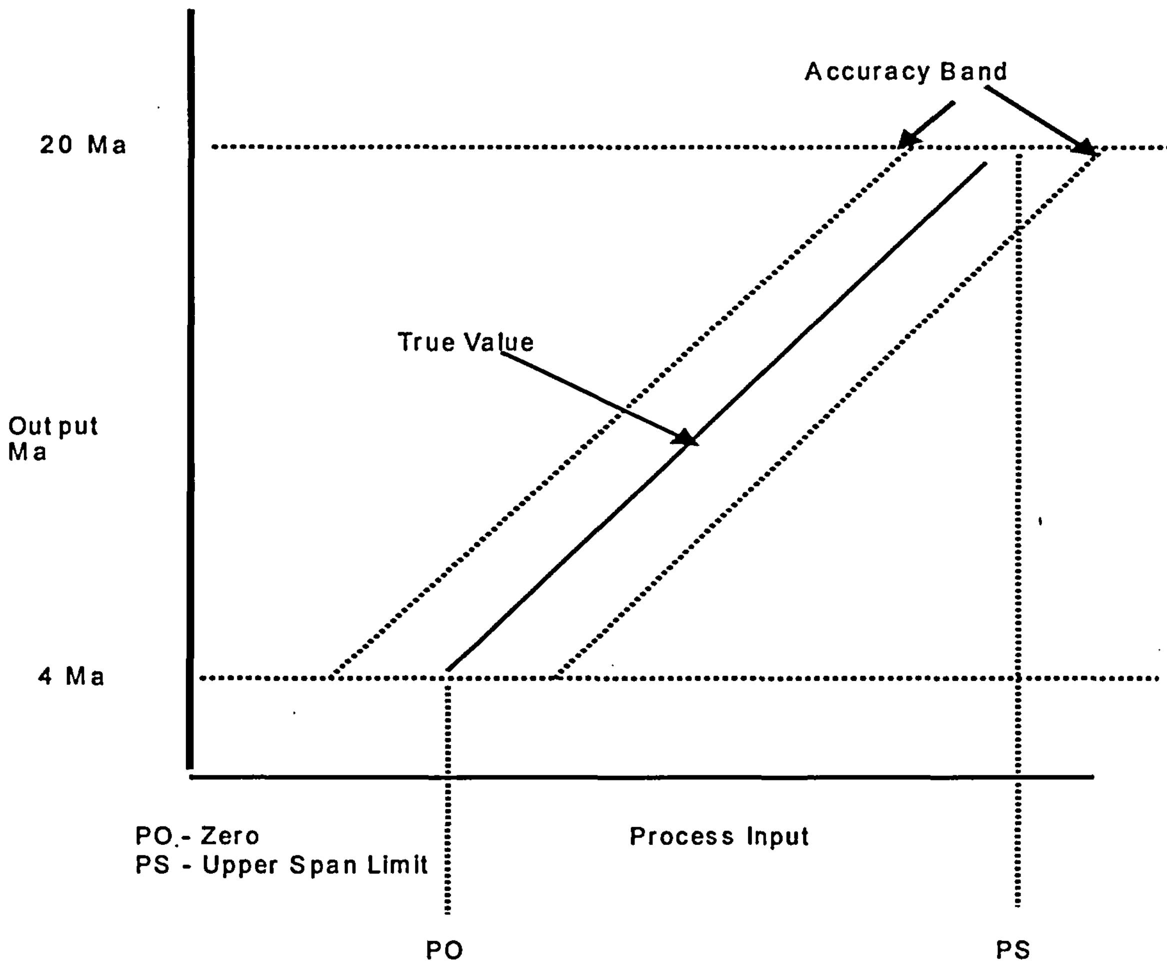


Figure C-3
Instrument Accuracy

Repeatability is an indication of an instrument's stability and describes its ability to duplicate a signal output for multiple repetitions of the same input. Repeatability is shown on Figure C-4 as the degree that signal output varies for the same process input. Instrument repeatability can degrade with age as an instrument is subjected to more cumulative stress, thereby yielding a scatter of output values outside of the repeatability band.

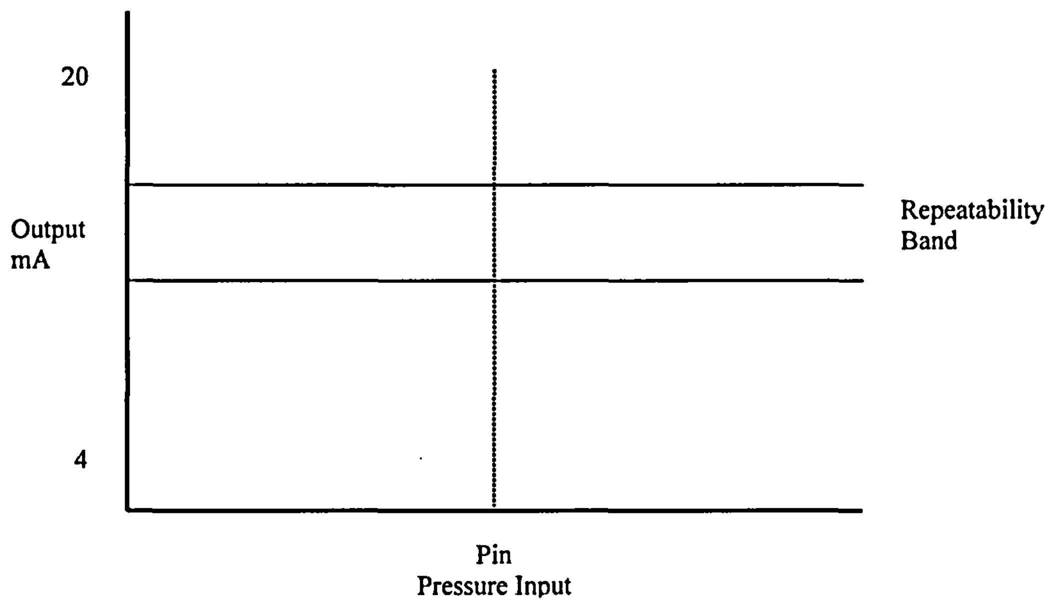


Figure C-4
Repeatability

Hysteresis describes an instrument's change in response as the process input signal increases or decreases (see Figure C-5). The larger the hysteresis, the lower is the corresponding accuracy of the output signal. Stressors can affect the hysteresis of an instrument.

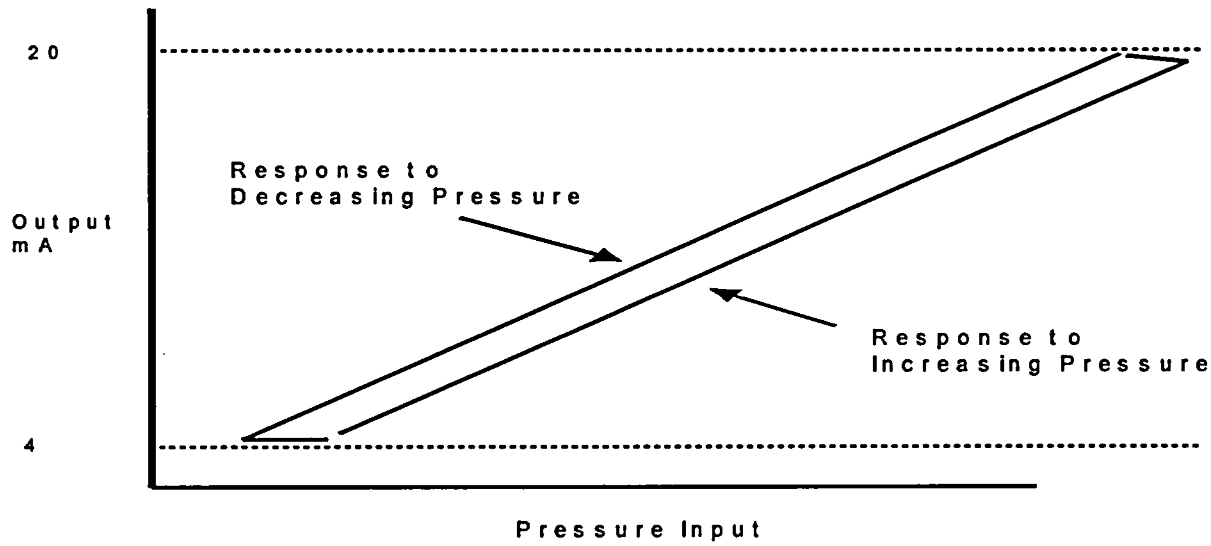


Figure C-5
Hysteresis

All instrument transmitters preferably exhibit linear characteristics, i.e., the output signal should be linearly and proportionately related to the input signal. Linearity describes the ability of the instrument to provide a linear output in response to a linear input (see Figure C-6). The linear response of an instrument can change with time and stress.

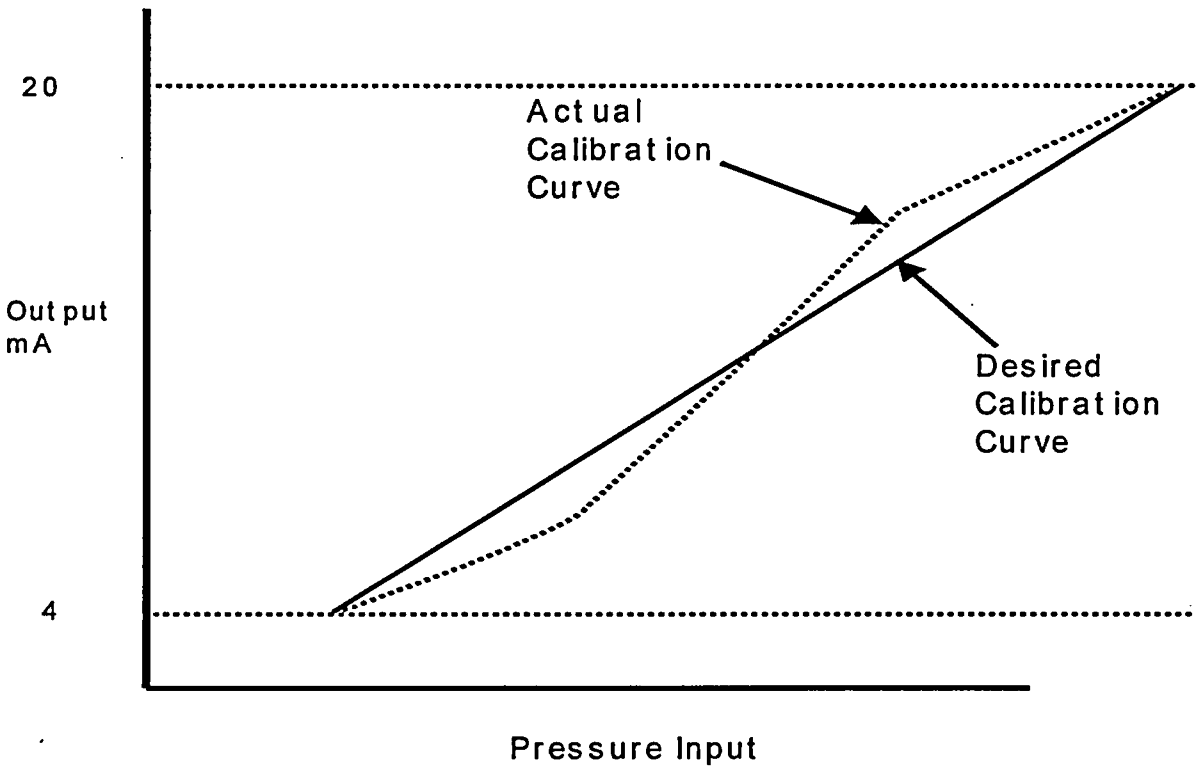


Figure C-6
Linearity

In cases in which the measurement process is not linear, the more appropriate term to use is conformity, meaning that the output follows some desired curve. Linearity and conformity are often used interchangeably.

As discussed, vendor accuracy is generally described as the combined effect of hysteresis, linearity, and repeatability. These three separate effects are sometimes combined to form the bounding estimate of vendor accuracy as follows:

$VA = \pm(h^2 + l^2 + r^2)^{1/2}$

where,

VA	=	Vendor Accuracy
h	=	Hysteresis
l	=	Linearity
r	=	Repeatability

Accuracy cannot be adjusted, improved, or otherwise affected by the calibration process. Rather, accuracy is a performance specification against which the device is tested during calibration to determine its condition. A 5-point calibration check, (0%, 25%, 50%, 75%, and 100%), of an instrument's entire span verifies linearity. If a 9-point check is performed, by checking up to 100% and back down to 0%, hysteresis is also verified. Finally, if the calibration check is performed a second time (or more), repeatability is verified. The calibration check process is rarely performed to a level of detail that also confirms repeatability but if it is, per ISA S 67.04, both vendor accuracy and the calibrations tolerance do not both need to be included in the uncertainty analysis. For this reason, the vendor accuracy term should be checked to verify that it includes the combined effects of linearity, hysteresis, and repeatability. If the vendor accuracy specification does not include all of these terms, the missing terms are included into the vendor accuracy specification as follows:

$$VA = \pm(va^2 + h^2 + l^2 + r^2)^{1/2}$$

where,

VA	=	Revised estimate of vendor accuracy
va	=	Vendor's stated accuracy with some terms not included
h	=	Hysteresis (if not already included)
l	=	Linearity (if not already included)
r	=	Repeatability (if not already included)

Vendor accuracy is considered an independent and random uncertainty component unless the manufacturer specifically states that a bias or dependent effect also exists. Vendor accuracy is normally expressed as a percent of instrument span, but this should be confirmed from the manufacturer's specifications.

Bistables, trip units, and pressure switches may not require a consideration of hysteresis and linearity because the calibration might be checked only at the setpoint. If the accuracy is checked at the setpoint for these devices, the accuracy elsewhere in the instrument's span is not directly verified.

The calibration process might not adequately confirm the vendor accuracy if the measuring and test equipment (M&TE) uncertainty significantly exceeds the accuracy of the device being calibrated. For example, the calibration process cannot verify a 0.1% accuracy specification with M&TE having an uncertainty of 0.5%. If the M&TE uncertainty exceeds the specified vendor accuracy, then the vendor accuracy should be considered no better than the M&TE allowance.

C.3.4 Drift

Drift is commonly described as an undesired change in output over a period of time; the change is unrelated to the input, environment, or load. A shift in the zero setpoint of an instrument is the most common type of drift. This shift can be described as a linear displacement of the instrument output over its operating range as shown in Figure C-7. Zero shifts, can be caused by transmitter aging, an overpressure condition such as water hammer, or sudden changes in the sensed input that might stress or damage sensor components.

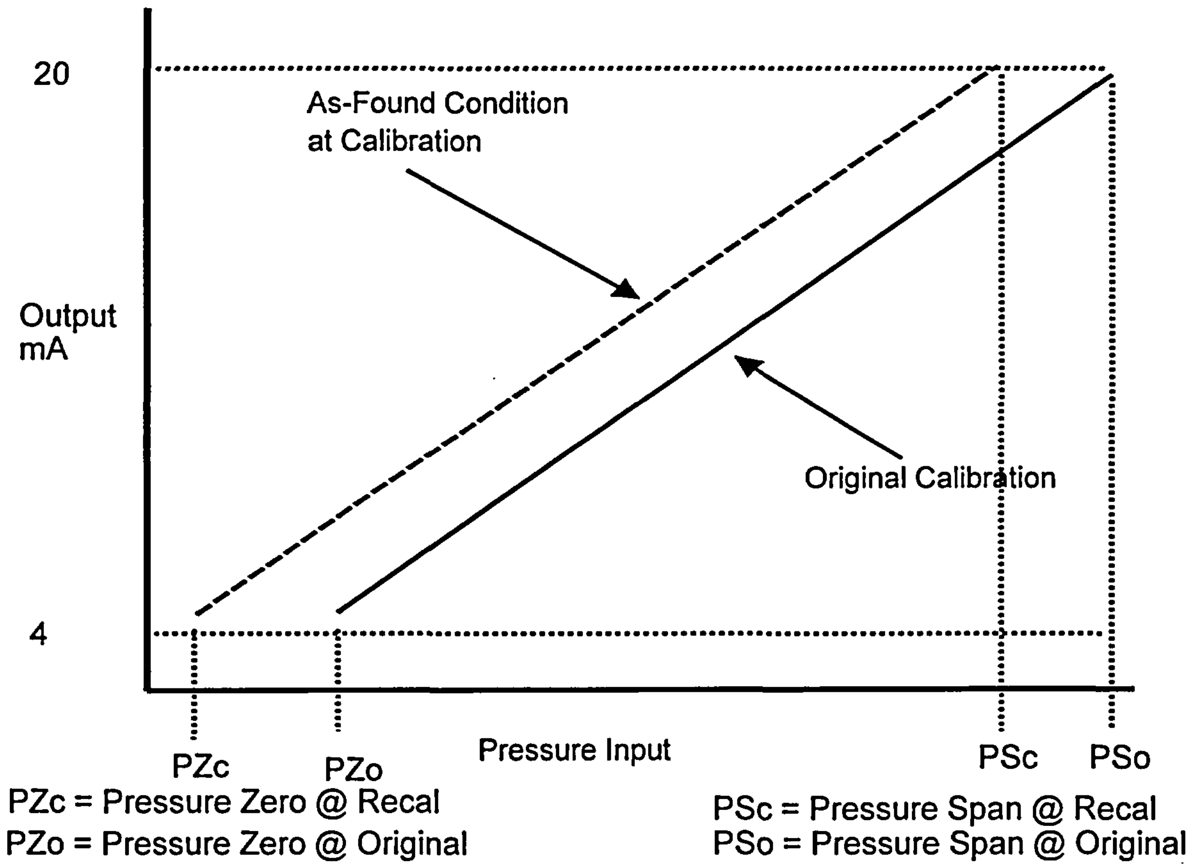


Figure C-7
Zero Shift Drift

Span shifts are less common than zero shifts and are detected by comparing the minimum and maximum current outputs to the corresponding maximum and minimum process inputs. Figure C-8 shows an example of forward span shift in which the instrument remains in calibration at the zero point, but has a deviation that increases with span. Reverse span shift is also possible in which the deviation increases with decreasing span.

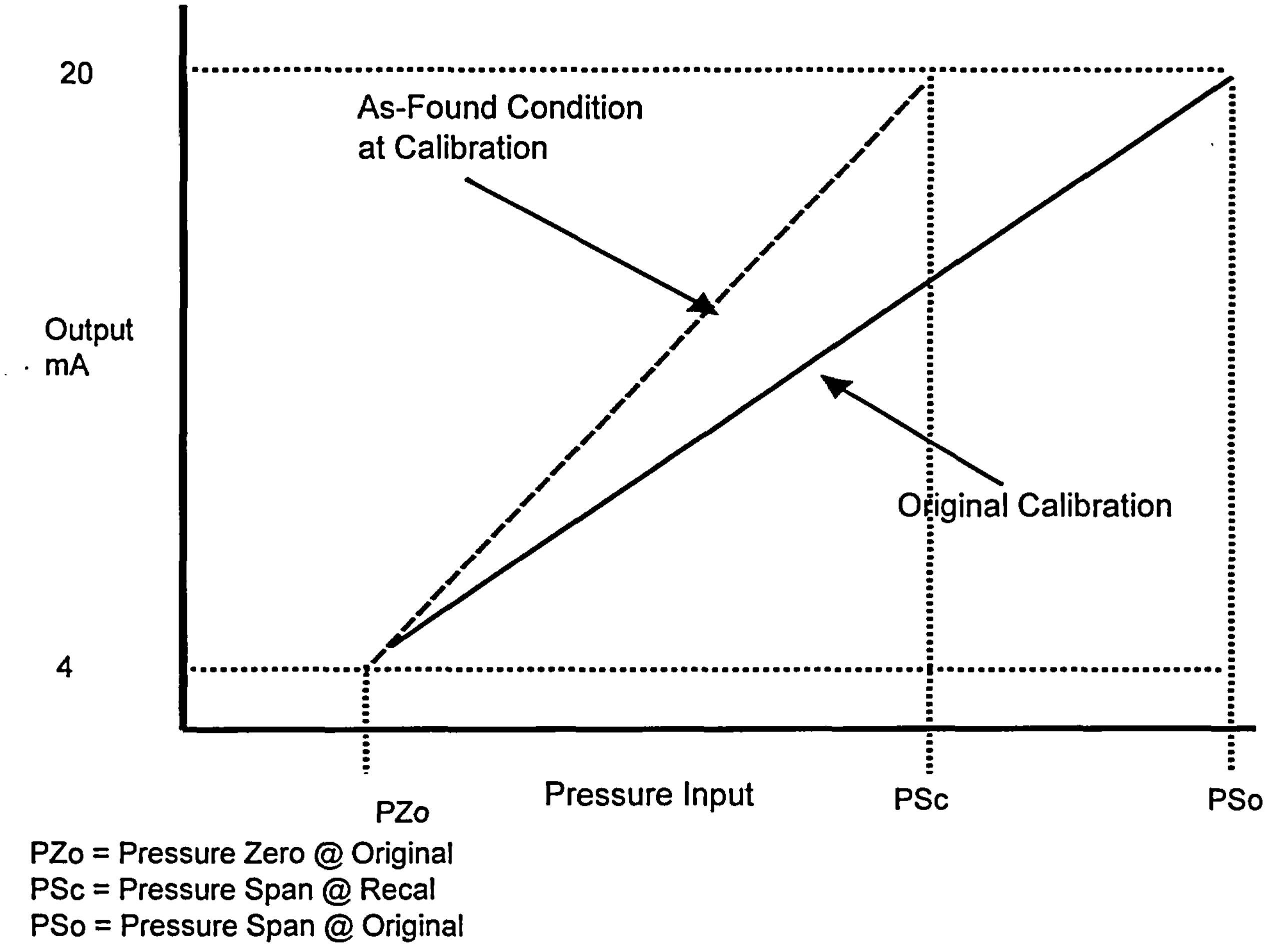


Figure C-8
Span Shift Drift

The amount of drift allowed for an instrument depends on the manufacturer's drift specifications and the period of time assumed between calibrations. For safety-related devices, the drift allowance should be based on the Technical Specifications allowance for plant operation (i.e. 18 months) plus an additional allowance of 25%. Note that not all equipment is checked at this frequency; the Technical Specifications still states a shorter frequency for certain equipment, such as quarterly checks of trip units.

The manufacturer's specified drift is often based on a maximum interval of time between calibration checks. Several methods are available to adjust the drift allowance to match the calibration period of the instrument. If the instrument drift is assumed to be linear as a function of time, the drift allowance would be calculated as shown in Section 4.3.2.

The approach in section 4.3.2 assumes that the drift is a linear function of time that continues in one direction once it starts. In the absence of other data, this is a conservative assumption.

However, if the vendor states that the drift during the calibration period is random and independent, then it is just as likely for drift to randomly change directions during the calibration period. In this case, the square root of the sum of the squares of the individual drift periods between calibrations could be used. In this case, the total drift allowance for 30 months would be:

$$DR_{30} = \pm(0.5\%^2 + 0.5\%^2 + 0.5\%^2 + 0.5\%^2 + 0.5\%^2)^{1/2} = \pm1.12\% \text{ of span}$$

Some vendors have stated that the majority of drift tends to occur in the first several months following a calibration and that the instrument output will not drift significantly after the "settle-in period." In this case, a lower drift value might be acceptable provided that the vendor can supply supporting data of this type of drift characteristic. However, when the vendor stated drift is for a longer period (i.e. Rosemount drift = 0.2% for 30 months) then the calibration period it is not acceptable to arbitrarily reduce the drift value. In this case the data supporting a "settle-in period" drift characteristic must be evaluated.

$$VD_{30} = \pm[VD_{yr}^2 + VD_{yr}^2 + (VD_{yr}^2 \div 2)]^{1/2}$$

In the above expression of drift, VD_{yr} represents the annual drift estimate and the resultant drift, VD_{30}, represents the 30-month drift estimate. If VD_{yr} = 1%, the 30-month drift estimate is obtained by:

$$VD_{30} = \pm[1.0\%^2 + 1.0\%^2 + (1.0\%^2 \div 2)]^{1/2} = \pm1.58\% \text{ of span}$$

Drift can also be inferred from instrument calibration data by an analysis of as-found and as-left data. Typically, the variation between the as-found reading obtained during the latest calibration and the as-left reading from the previous calibration is taken to be indicative of the drift during the calibration interval. By evaluating the drift over a number of calibrations for functionally equivalent instruments, an estimate of the drift can be developed. Typically, the calibration data is used to calculate the mean of drift, the standard deviation of drift, and the tolerance interval that contains a defined portion of the drift data to a certain probability and confidence level (typically 95%/95%). This statistically determined value of drift can be used to validate the vendor's performance specification and can also be used as the best estimate of drift in the uncertainty calculation. Assigning all of the statistically determined drift from plant specific data is especially conservative because this drift allowance contains many other contributors to uncertainty, including:

- Instrument hysteresis and linearity error present during the first calibration

- Instrument hysteresis and linearity error present during the second calibration
- Instrument repeatability error present during the first calibration
- Instrument repeatability error present during the second calibration
- Measurement and test equipment error present during the first calibration
- Measurement and test equipment error present during the second calibration
- Personnel-induced or human-related variation or error during the first calibration
- Personnel-induced or human-related variation or error during the second calibration
- Instrument temperature effects due to a difference in ambient temperature between the two calibrations (this is particularly true for 18 month cycle plants in which the first calibration is performed in the winter and the second calibration is performed in the summer)
- Environmental effects on instrument performance, e.g., radiation, temperature, vibration, etc., between the two calibrations that cause a shift in instrument output
- Misapplication, improper installation, or other operating effects that affect instrument calibration during the period between calibrations
- True instrument "drift" representing a change, time-dependent or otherwise, in instrument output over the time period between calibrations

Regardless of the approach taken for determining the drift allowance, the uncertainty calculation should provide the basis for the value used.

C.3.5 Accuracy Temperature Effects (ATE)

The ambient temperature is expected to vary somewhat during normal operation. This expected temperature variation can influence an instrument's output signal and the magnitude of the effect is referred to as the temperature effect. Using a maximum temperature that bounds the maximum observed temperature can reduce the conservatism of using the maximum temperature difference. Larger temperature changes associated with accident conditions are considered part of the environmental allowance and the effect of larger temperature changes was determined as part of an environmental qualification test. The temperature effects described here only relate to the effect on instrument performance during normal operation.

The vendor normally provides an allowance for the predicted effect on instrument performance as a function of temperature. For example, a typical temperature effect might be ±0.75% per 100°F change from the calibrated temperature. This vendor statement of the temperature effect would be correlated to plant-specific performance as follows:

$$ATE = \pm(|nt - ct|)\ (vte)$$

where,

ATE	=	Temperature effect to assume for the uncertainty calculation
nt	=	Normal expected maximum or minimum temperature (both sides should be checked)
ct	=	Calibration temperature (typically, minimum zone temp.)
vte	=	Vendor's temperature effects expression

For example, if the vendor's temperature effects expression is ±0.75% of span per 100°F, the calibration temperature is 65°F if known, otherwise use the minimal temperature for that zone, and the maximum expected temperature is 110°F. This vendor statement of the temperature effect would be correlated to plant-specific performance as follows:

$$ATE = \pm[|\ 110°F - 65°F| \times (0.75\% \div 100°F)] = \pm\ 0.3375\%\ \text{of span}$$

Notice that the above approach starts with the minimal zone temperature, and then determines the maximum expected variation from the minimal zone temperature under normal operating conditions. Design Criteria DC-ME-09-CP "Equipment Environmental Design Conditions" provides all normal and harsh environments for the plant.

The above discussion applies to temperature effects on instrumentation, in response to expected ambient temperature variations during normal plant operation. Some manufacturers have also identified accident temperature effects that describe the expected temperature effect on instrumentation for even larger ambient temperature variations. An accident temperature effect describes an uncertainty limit for instrumentation operating outside the normal environmental limits and in some cases may include normal temperature effects.

Temperature effect is considered a random error term unless otherwise specified by the manufacturer.

C.3.6 Radiation Effects (RE)

During normal operation, most plant equipment is exposed to relatively low radiation levels. Although the lower dose rate, radiation effects, might have a nonreversible effect on an instrument, the calibration process can eliminate them. If the dose rate is low enough, the ambient environment might be considered mild during normal operation and radiation effects can be considered negligible. Any effects of relatively low radiation effects are considered indistinguishable from drift and are calibrated out during routine calibration checks.

If the normal operation dose rate is high enough that radiation effects should be considered, the environmental qualification test report will provide the best source of radiation effect information. During the worst-case accident environment, radiation effects can be part of the simultaneous effect of temperature, pressure, steam, and radiation that was determined during the environmental qualification process. Other plant locations might experience a more benign temperature and pressure environment, but still be exposed to significant accident radiation. For each case, the determination of the radiation effects should rely on the data in the environmental qualification report. Environmental qualification test report data should usually be treated as an arbitrarily distributed bias unless the manufacturer has provided data supporting its treatment as a random contributor to uncertainty.

C.3.7 Static Pressure Effects (SPE)

Some devices exhibit a change in output because of changes in process or ambient pressure. A differential pressure transmitter might measure flow across an orifice with a differential pressure of a few hundred inches of water while the system pressure is over 1,000 psig. The system pressure is essentially a static pressure placed on the differential pressure measurement. The vendor usually specifies the static pressure effect; a typical example is shown below:

Static pressure effect = ±0.5% of span per 1,000 psig

The static pressure effect is a consequence of calibrating a differential pressure instrument at low static pressure conditions, but operating at high static pressure conditions.

If the static pressure effect is considered a bias by the manufacturer, the operating manual usually provides instructions for calibrating the instrument to read correctly at the normal expected operating pressure, assuming that the calibration is performed at low static pressure conditions. This normally involves changing the zero and span adjustments by a manufacturer-supplied correction factor at the low-pressure (calibration) conditions so that the instrument will provide the desired output signal at the high-pressure (operating) conditions. The device could also be calibrated at the expected operating pressure to reduce or eliminate this effect, but is not normally done because of the higher calibration cost and complexity.

Some static pressure effects act as a bias rather than randomly. For example, some instruments are known to read low at high static pressure conditions. If the calibration process does not correct the bias static pressure effect, the uncertainty calculation needs to include a bias term to account for this effect.

Ambient pressure variation can cause some gauge and absolute pressure instruments to shift up or down scale depending on whether the ambient pressure increases above or decreases below atmospheric pressure. Normally, this effect is only significant on 1) applications measuring very small pressures or 2) applications in which the ambient pressure variations are significant with respect to the pressure being measured. Gauge pressure instruments can be sensitive to this effect when the reference side of a sensing element is open to the atmosphere. If the direction of the ambient pressure change is known, the effect is a bias. If the ambient pressure can randomly change in either direction, the effect is considered random.

C.3.8 Overpressure Effect (OPE)

In cases where an instrument can be over-ranged by the process pressure without the process pressure exceeding system design pressure, an overpressure effect must be considered. Overpressure effects are often considered in low-range monitoring instruments in which the reading is expected to go off-scale high as the system shifts from shutdown to operating conditions. Some pressure switches may also be routinely over-ranged during normal operation. The overpressure effect is normally considered random and is usually expressed as a percent uncertainty as a function of the amount of overpressure. The contribution of the overpressure effect on instrument uncertainty would only apply after the instrument has been over-ranged.

C.3.9 Deadband

Deadband represents the range within which the input signal can vary without experiencing a change in the output. The ideal instrument would have no deadband and would respond to input changes regardless of their magnitude. Instrument stressors can change the deadband width over time, effectively requiring a greater change in the input before an output response is achieved.

The vendor's instrument accuracy specification might include an allowance for deadband or it might be considered part of hysteresis (included in vendor accuracy). Recorders generally have a separate allowance for deadband to account for the amount the input signal can change before the pen physically responds to change.

Pressure switches are also susceptible to deadband. For this reason, a pressure switch setpoint near the upper or lower end of span should confirm that the setpoint allows for deadband. In extreme cases, the pressure switch might reach a mechanical stop with the deadband not allowing switch actuation.

C.3.10 Measuring and Test Equipment Uncertainty

Measuring and test equipment (M&TE) uncertainty is defined in Section 2.2 and further described in Appendix H.

C.3.11 Turndown Ratio Effect

If a transmitter has an adjustable span over some total range, the uncertainty expression may require adjustment by the turndown factor. For example, a transmitter may have a range of 3,000 psig with an uncertainty of 2% of the total range, sometimes referred to as the upper range limit (URL). If the span is adjusted such that only 1,000 psig of the entire 3,000 psig range is used, the transmitter has not somehow become more accurate. The 2% uncertainty of the 3,000 psig span is 60 psig, which equates to a 6% uncertainty for the 1,000 psig span. Transmitters with variable spans typically define performance specifications in terms of the total range and the calibrated span.

If the performance specifications are quoted as a percent of full span (FS), the uncertainty expression will not require an adjustment for the turndown factor.

C.3.12 Power Supply Effects (PSE)

Power supply effects are the changes in an instrument's input-output relationship due to the power supply stability. For 2-wire current loop systems, AC supply variations must be considered for their effects on the loop's DC power supply. The consequential DC supply variations must then be considered for their effects on other components in the series loop, such as the transmitter.

Using the manufacturer's specifications, the power supply is typically calculated as follows:

PSE = (pss)(vpse)

where,

PSE = Power supply effect to assume for the uncertainty calculation
pss = Power supply stability
vpse = Vendor's power supply effect expression

Power supply stability refers to the variation in the power supply voltage under design conditions of supply voltage, ambient environment conditions, power supply accuracy, regulation, and drift. This effect can be neglected when it can be shown that the error introduced by power supply variation is ≤10% of the instrument's reference accuracy.

Harmonic distortion on the electrical system can also contribute to power supply uncertainty.

C.3.13 Indicator Reading Error (IRE)

An analog indicator can only be read to a certain accuracy. The uncertainty of an indicator reading depends on the type of scale and the number of marked graduations (See Section 4.4.7.1). An analog indicator can generally be read to a resolution of ½ of the smallest division on the scale. Figure C-9 shows an example of a linear analog scale. As shown, the indicator would be read to ½ of the smallest scale. Anyone reading this scale is able to confirm that the indicator pointer is between 40 and 45. In this case, the estimated value would be 42.5. If an imaginary line is mentally drawn at the ½ of smallest scale division point, an operator can also tell whether the pointer is on the high side or the low side of this line. Therefore, the uncertainty associated with this reading would be ± ¼ of the smallest scale division, or ±1.25 for the example shown in Figure C-9. Notice that this approach defines first the resolution to which the indicator could be read (½ of smallest scale division) with an uncertainty of ± ¼ of smallest scale division about this reading resolution. In terms of an uncertainty analysis, it is not the reading resolution, but the uncertainty of the resolution that is of interest.

Per Section 4.3.3, the AFT and ALT values are rounded to the next ½ minor marking, thus typically eliminates the need to include the ± ¼ minor division uncertainty. Also, for cases where calibration procedures require reverse calibration of devices, where readability of the end device does not need to be taken into account. However, readability of M&TE may need to be considered.

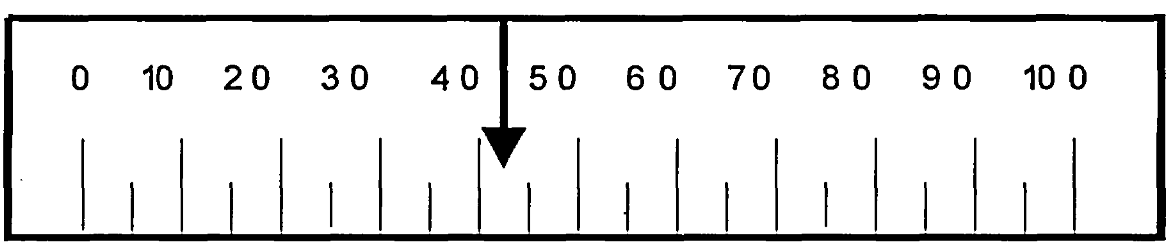


Figure C-9
Analog Scale

Type of Scale	Discussion
Analog Linear	An uncertainty of ± ¼ of the smallest division should be assigned as the indication reading error, if applicable. See above discussion.
Analog Logarithm or Exponential	Logarithm or exponential scales allow the presentation of a wide process range on a single scale. Radiation monitoring instruments commonly used an exponential scale. An uncertainty of ± ¼ of the specific largest division of interest should be assigned as the indication reading uncertainty. This requires an understanding of where on the scale that the operators will be most concerned regarding the monitored process, if applicable. See above discussion.
Analog Square Root	Square root scales show the correlation of differential pressure to flow rate. An uncertainty of ± $(1/4 \text{ of the specific largest division of interest})^{1/2}$ should be assigned as the indication reading uncertainty. This requires an understanding of where on the scale that the operators will be most concerned regarding the monitored process, if applicable. See above discussion.
Digital	The reading uncertainty is the uncertainty associated with the least significant displayed digit, which is usually negligible as an indication reading uncertainty. The digital display must be evaluated to confirm that the reading uncertainty is insignificant, if applicable. See above discussion.
Analog Recorder	Analog recorders have the same reading uncertainties, as do analog indicators. The only potential difference is that the indicator scale is fixed in place but the recorder chart paper can be readily replaced with a different scale paper. The chart paper used for the recorder should be checked to verify that the indication reading uncertainty can be estimated, if applicable. See above discussion.

C.3.14 Seismic Effects

Two types of seismic effects should be considered: 1) normal operational vibration and minor seismic disturbances, and 2) design basis seismic events in which certain equipment performs a safety function.

The effects of normal vibration (or a minor seismic event that does not cause an unusual event) are assumed to be calibrated out on a periodic basis and are considered negligible. Abnormal vibrations (vibration levels that produce noticeable effects) and more significant seismic events (severe enough to cause an unusual event) are considered abnormal conditions that require maintenance or equipment modification.

Design basis seismic events can cause a shift in an instrument's output. For the equipment that must function during and following a design basis seismic or accident event, the environmental qualification test report should be reviewed to obtain the bounding uncertainty. The seismic effect may be specified as a separate effect or, in some cases, may be included in the overall environmental allowance. A seismic event coincident with a LOCA is a design basis event per USAR 15.6.5. However, per USAR 15.6.5.1.1, there are no realistic, identifiable events which would result in a pipe break inside the containment of the magnitude required to cause a loss-of-coolant accident coincident with a safe shutdown earthquake. Therefore, each setpoint calculation should consider the effects of a seismic event and loss-of-coolant accident independently to establish the worst case scenario for the instrumentation being evaluated. Consideration should be given to the accident that the equipment is required to mitigate. For example, it is not necessary to impose LOCA conditions as worse case if no credit is taken to mitigate a LOCA condition (e.g. a trip function may activate prior to any harsh environment, thus calculation of LOCA is not required, whereas, indication may be required LOCA/post LOCA, therefore both seismic and LOCA would be calculated and the worst value used). This consideration should be documented in the calculation.

For well-designed and properly mounted equipment, the seismic effect will often contribute no more than ±0.5% to the overall uncertainty. This effect can be considered random and can be included within the uncertainty expression as a random term. Including a small allowance for seismic effects is considered a conservative, but not required, approach to the uncertainty analysis.

C.3.15 Environmental Effects - Accident

The environmental allowance is intended to account for the effects of high temperature, pressure, humidity, and radiation that might be present during an accident, such as a LOCA or HELB event. This allowance should include an evaluation of the timing of the event including the environmental condition existing at the time the function is designed to trip (See example in C.3.14 above). Some manufacturers do not distinguish the uncertainties due to each of the accident effects. In such cases, the accident uncertainty may be a single ± value given for all accident effects.

Qualification reports for safety-related instruments normally contain tables, graphs or both, of accuracy before, during and after radiation and steam/pressure environmental and seismic testing. Many times, manufacturers summarize the results of the qualification testing in their product specification sheets. More detailed information is available in the equipment qualification report. The manufacturer's specification sheet tends to be very conservative, as the worst-case performance result is normally presented.

Because of the limited sample size typically used in qualification testing, the conservative approach to assigning uncertainty limits is to use the bounding worst-case uncertainties. It is also recommended that discussions with the instrument manufacturer be conducted to gain insight into the behavior of the uncertainty (should it be considered random or bias?). This is important because if the uncertainty is random and of approximately the same magnitude as other random uncertainties, then SRSS methods might be used to combine the accident-induced uncertainty with other uncertainties. The environmental allowance should be of approximately the same size as the other random uncertainties if it is combined with other random terms in an SRSS expression. This consideration comes from the central limit theorem, which allows the combination of uncertainties by SRSS as long as they are of approximately the same magnitude. If not, then the accident uncertainty should be treated as an arbitrarily distributed uncertainty.

Using data from the qualification report in place of performance specifications, it is often possible to justify the use of lower uncertainty values that may occur at reduced temperatures or radiation dose levels. Typically, qualification tests are conducted at the upper extremes of simulated accident environments so that the results apply to as many plants as possible, each with different requirements. Therefore, it is not always practical or necessary to use the results at the bounding environmental extremes when the actual requirements are not as limiting. Some cautions are needed, however, to preclude possible misapplication of the data:

1. The highest uncertainties of all the units tested at the reduced temperatures or dose should be used. A margin should also be applied to the tested magnitude of the environmental parameter consistent with Institute of Electrical and Electronics Engineers 323-1975.
2. The units tested should have been tested under identical or equitable conditions and test sequences.
3. If data for a reduced temperature is used, ensure that sufficient "soak-time" existed prior to the readings at that temperature to ensure sufficient thermal equilibrium was reached within the instrument case.

The requirement in Item (1) above is a conservative method to ensure that bounding uncertainties are used in the absence of a statistically valid sample size. Item (2) above is an obvious requirement for validity of this method. Item (3) ensures that sufficient thermal lag time through the instrument case is accounted for in drawing conclusions of performance at reduced temperatures. In other words, if a transmitter case has a one-minute thermal lag time, then ensure that the transmitter was held at the reduced temperature at least one minute prior to taking readings.

Generally, the worst uncertainty is used from either the qualification report or the performance specification, unless more consideration is needed to preserve the existing AV or setpoint.

C.3.16 As-Left Tolerance Specification

The device as-left tolerance establishes the required accuracy band that a device or group of devices must be calibrated to within when periodically tested. If an instrument as-found value is found to be within the as-left tolerance, no further re-calibration is required for the instrument and calculations should assume that an instrument might be left anywhere within this tolerance.

See Section 4.3.3 for establishing the calibration as-left tolerance for a device. For all existing CPS instruments, an as-left tolerance is already specified by the applicable surveillance calibration procedure. CPS typically calibrates non-safety related instruments to a generic calibration procedure with tolerances per the Instrument Data Sheet (IDS). This as-left tolerance is recommended for use in the calculation unless other conditions suggest that a different tolerance is warranted. For example, a tighter tolerance is easily achievable for most electronic equipment and a tighter tolerance might provide needed margin for a setpoint calculation. Conversely, establishing a tighter tolerance than is achievable per the manufacturer ensures that it will routinely be found out of calibration.

The as-left tolerance should be specified for all instruments covered by the associated calculation, even if the as-left tolerances are unchanged from the values already specified in the applicable calibration procedures. The as-left tolerance is treated as a random term in the uncertainty analysis.

For all instrument loops, the loop as-left tolerance is calculation per Section 4.4.5.

C.3.17 As-Found Tolerance Specification

The device as-found tolerance establishes the limit of error the defined devices can have and still be considered functional. The as-found tolerance will never be less than the as-left tolerance. The purpose of the loop as-found tolerance is to establish a level of drift within which the instrument loop is still clearly functional, but not so large that an allowable value determination is required. An instrument or loop found outside the as-left tolerance but still within the as-found tolerance requires a recalibration but no further evaluation or response.

The as-found tolerance is generally defined to include the effects of M&TE, ALT, and vendor drift. Reference Section 4.3.3 for calculating the as-found tolerance.

The as-found tolerance should be specified for all instruments covered by the associated calculation.

For all instrument loops, the loop as-found tolerance is calculation per Section 4.4.5. For Technical Specifications, the loop as-found tolerance as defined at CPS, impacts the setpoint determination.

C.4 Uncertainty Analysis Methodology

An uncertainty calculation establishes a statistical probability and confidence level that bounds the uncertainty in the measurement and signal processing of a parameter such as system pressure or flow. Knowledge of the uncertainty in the process measurement is then used to establish an instrument setpoint or provide operators with the expected limits for process measurement indication uncertainty.

The basic approach used to determine the overall uncertainty for a given channel or module is to combine all terms that are considered random using the Square Root of the Sum of the Squares (SRSS) methodology, then adding to the result any terms that are considered nonrandom.

Note that the bias terms do not all operate in the same direction. Although it could be argued that some bias terms operate in opposite directions and therefore should be somewhat self-canceling, the standard practice is to treat the positive and negative channel uncertainty separately, if bias terms are present. The reason for this approach is based on generally not knowing the actual magnitude of the bias terms at a particular instant; the bias terms are defined at bounding levels only. Accordingly, the maximum positive uncertainty is given by:

$$VA_i = \pm\sqrt{(VA_1 + VA_2)^2}$$

In the determination of the random portion of an uncertainty, situations may arise where two or more random terms are not totally independent of each other, but are independent of the other random terms (e.g. two instruments calibrated together as a rack). This dependent relationship can be accommodated within the SRSS methodology by algebraically summing the dependent random terms prior to calculating the SRSS. The uncertainty expression would be similar for all random terms for both devices developed by section 4.3.1.

C.5 Propagation of Uncertainty through Modules

If signal conditioning modules such as scalars, summers, square root extractors, multipliers, or other similar devices are used in the instrument channel, the module's transfer function should be accounted for in the instrument uncertainty calculation. The uncertainty of a signal conditioning module's output can be determined when 1) the uncertainty of the input signal, 2) the uncertainty associated with the module, and 3) the module's transfer function are known. Equations have been developed to determine the output signal uncertainties for several types of signal conditioning modules. Refer to Appendix K for additional information.

C.6 Calculating Total Channel Uncertainty

The calculation of an instrument channel uncertainty should be performed in a clear, straightforward process. The actual calculation can be completed with a single loop equation containing all potential uncertainty values or by a series of related term equations. Either way, a specific channel calculation should be laid out to coincide with a channel's layout from process measurement to final output module or modules, using the formulas described previously in Section 4.4.9 & 4.4.12 (setpoints) and 4.4.8 (indication).

Depending on the loop, the uncertainty may be calculated for a setpoint(s), indication function, or control function. In some cases, all three functions may be calculated. Because each function will typically use different end-use devices, the channel uncertainty is calculated separately for each function.

Components for these equations, generally are built as follows:

1. Per Section 4.3.1, an instrument loop may contain several discrete instruments (modules) that process the measurement signal from sensor to display, or from sensor to trip unit. An uncertainty calculation would determine the expected uncertainty for the selected instrument loop and each discrete component could have several uncertainty terms contributing to the overall expression. The overall uncertainty calculation for the device (A_i) may contain any or all (or other) of the following uncertainty terms.

2. Per Section 4.4.1, A_L is determined from analysis of loop device error (A_i). All individual device error must be determined on the basis of the environmental conditions (normal, trip, post accident, etc.) applicable to the event and function time for which the loop accuracy applies. Once all the accuracy error contributions for a particular instrument are identified they should be combined using the SRSS method to determine total device accuracy. In performing the SRSS combination, the individual level of confidence of each term (sigma Level) should be accounted for to ensure the resultant device accuracy error is a 2 sigma value.

3. C_L is determined from two basic components. These are As Left Tolerance (ALT) and Maintenance and Test Equipment (M&TE). Per Appendix H, M&TE error consists of the error associated with each calibration tool or device used to calibrate the individual devices in the loop (including reading error) and the error associated with the Reference Standards used to calibrate the calibration tools.

   Per Appendix I, all potential errors from M&TE are controlled by 100% testing and can therefore be assumed as 3 sigma values.

4. Per Section 4.4.4, D_L is determined from analysis of loop device drift error. All individual device drift error must be determined on the basis of the environmental conditions (normal, trip, post accident, etc.) applicable to the event and function time for which the loop accuracy applies and adjusted to a common drift interval. Once the drift error contribution for a particular instrument is identified it is combined with each loop device drift term using the SRSS method to determine total loop drift. In performing the SRSS combination, the individual level of confidence of each term (sigma Level) should be accounted for to ensure the resultant drift accuracy error is a 2 sigma value. Per section 4.4.4, D_L is determined as:

5. Per Sections 4.4.6, C.3.1, and C.3.2, PMA and PEA are established as uncertainties to account for measurement errors, which lie outside the normal calibration bounds of the channel.

6. Per Section 4.4.8.2, the biases for all modules should be accounted for and combined outside the square root radical.

Table C-1
Channel Uncertainty/Setpoint Calculation Checklist

	Task	**Completed? Yes**	**No**
(1)	Are purpose and objectives clearly defined.	☐	☐
(2)	Are standard assumptions used as appropriate and any new assumptions used clearly justified and/or identified, as confirmation required.	☐	☐
(3)	Are Inputs/Outputs/References appropriately used, identified to latest revisions, and attached if required.	☐	☐
(4)	Diagram instrument channel.	☐	☐
(5)	Identify functional requirements, including actuations, any EOP setpoint requirement.	☐	☐
(6)	Identify operating times for functions.	☐	☐
(7)	Identify environment associated with functions during defined operating times.	☐	☐
(8)	Identify limiting environment and function.	☐	☐
(9)	Identify Process Measurement Accuracy (PMA) and Primary element accuracy (PEA) associated with each function and all drawings/walkdowns/other references identified to calculate values.	☐	☐
(10)	Identify biases due to linear approximations of nonlinear functions (RTDs). Determine if the biases are of concern over the region of interest for the setpoint.	☐	☐
(11)	Identify any modules with non-unity gains.	☐	☐
(12)	Identify transfer function for each module with a non-unity gain.	☐	☐
(13)	For each module, identify normal environment uncertainty effects, as applicable:		
	Vendor Accuracy (VA)	☐	☐
	Vendor Drift (VD)	☐	☐
	Temperature effects (ATE)	☐	☐
	Radiation effects (RE)	☐	☐
	Power supply effects (PSE)	☐	☐
	Static pressure effects (SPE)	☐	☐
	Overpressure effects (OPE)	☐	☐

Table C-1 (continued)
Channel Uncertainty Calculation Checklist

Task		**Completed? Yes**	**No**
	Deadband (DB)	☐	☐
	Measuring and test equipment uncertainty (MTE)	☐	☐
	Turndown Ratio Effect (TD)	☐	☐
	Indicator Reading Error (IRE)	☐	☐
(14)	For each module, identify harsh environment uncertainty effects, as applicable.		
	Accident temperature effects (ATE)	☐	☐
	Accident radiation Effects (RE)	☐	☐
	Humidity effects (HE)	☐	☐
	Seismic effects (SE)	☐	☐
	Worst case between seismic and harsh environment used to establish AV and NTSP	☐	☐
(15)	For electrical penetrations, splices, terminal blocks, or sealing devices in a harsh environment, are current leakage effects (IRA) determined.	☐	☐
(16)	Classify each module and process effect as random or bias. Determine if any of the random terms are dependent. Combine dependent random terms algebraically before squaring in the SRSS.	☐	☐
(17)	Combine random effects for each module by SRSS. Add bias effects algebraically outside the SRSS.	☐	☐
(18)	If the instrument channel has a module with non-unity gain, the total uncertainties in the input signal to the module must be determined, the module transfer function effect on this uncertainty calculated, and the result combined with the non-unity gain module and downstream module uncertainties to determine total channel uncertainty.	☐	☐
(19)	Has the ALT and AFT been appropriately identified for each device.	☐	☐
(20)	Has M&TE been appropriately identified and values correctly calculated, using the guidance of calculation IP-C-0089 (Ref. 5.30), as a minimum.	☐	☐
(21)	Does the drift interval meet or exceed the calibration interval, for each device.	☐	☐

Table C-1 (continued)
Channel Uncertainty Calculation Checklist

Task	Completed? Yes	No
(22) Are the appropriate equations used for the type of calculation (i.e. setpoint or indication).	☐	☐
(23) Has values such as AV, NTSP, ALT, AFT, etc. been converted to the units required by the calibration procedure.	☐	☐
(24) Has the existing AV and Setpoint been preserved and if not has all efforts been made to minimize the terms that affect calculation of AV and NTSP.	☐	☐
(25) Does the conclusions verbalize that the objectives were met and are they graphically presented.	☐	☐
(26) Does Attachment 1, identify head correction for the loop and identified all drawings/walkdowns/other references required to calculate head correction.	☐	☐
(27) Does Attachment 2 present all the information required by C&I maintenance and calibration procedures. Examples are: M&TE model and ranges or equivalent identified AV, NTSP, ALT, AFT given in the appropriate units and precision required by calibration procedures.	☐	☐
(28) Has the Cover Pages and Table of Contents been prepared correctly	☐	☐

C.7 Nominal Trip Setpoint Calculation

An uncertainty calculation defines the instrument loop uncertainty through a specific arrangement of instrument modules. This calculation is then used to determine an instrument setpoint based upon the safety parameter of interest. The relationship between the setpoint, the uncertainty analysis, and normal system operation is shown in Figure C-10.

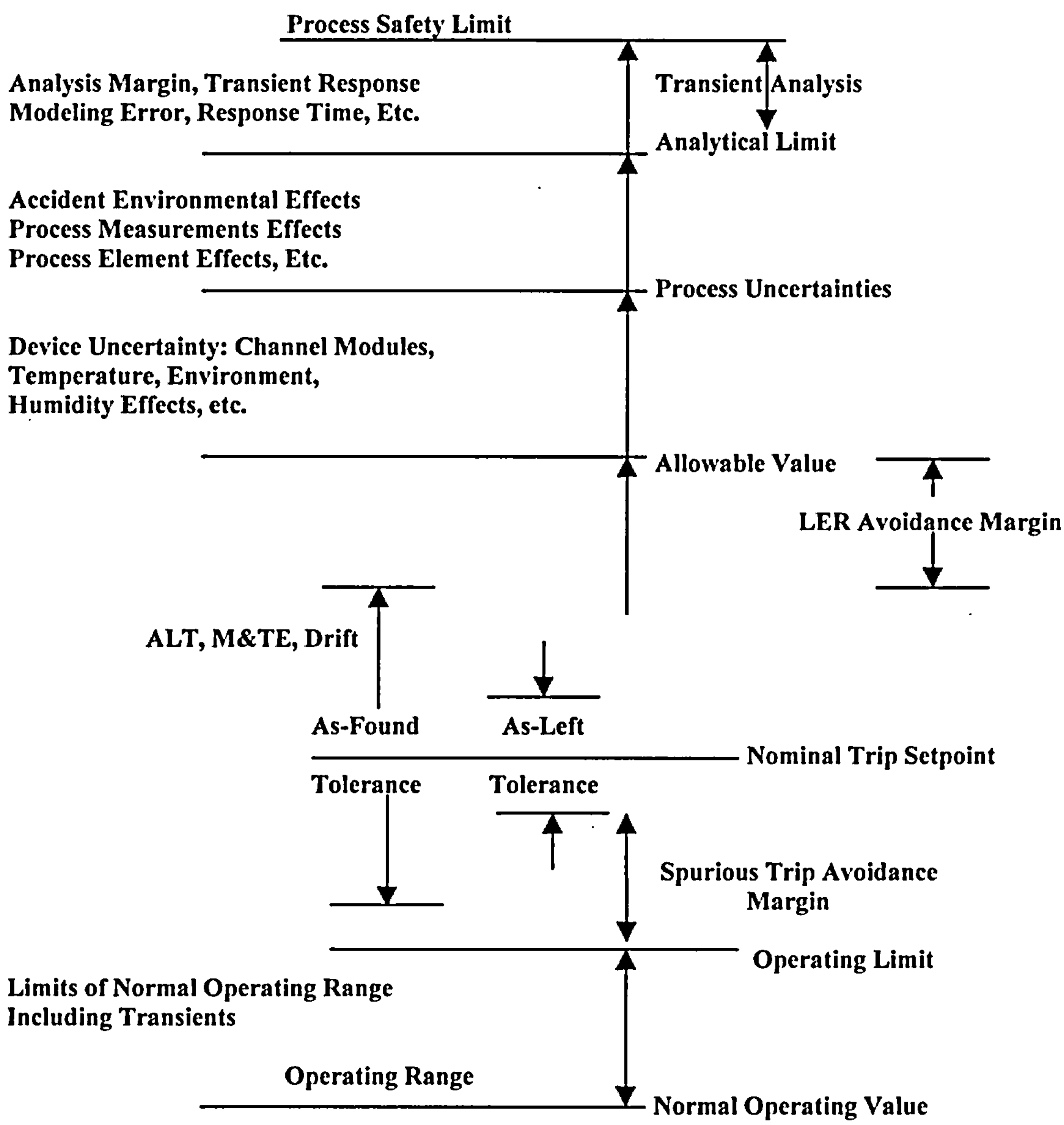


Figure C-10
Setpoint Relationships

The information provided in figure C-10, prompts several observations:

- The relationships shown can vary between applications or plants, and is provided for illustrative purposes only.

- The setpoint has a nominal value. The upper and lower limits for the setpoint shown represent the allowed AFT & ALT tolerances for the setpoint. Typically, an instrument found within the band defined by the as-left tolerance does not require an instrument reset.

- The setpoint relationship shown assumes that the process increases to reach the setpoint. If the process decreased towards the setpoint, the relationships shown in Figure C-10 would be reversed around the setpoint.

- The as-found tolerance is wider than the as-left tolerance and accounts for expected drift or certain other normal uncertainties during normal operation. Instruments found within the as-found tolerance, but outside the as-left tolerance require resetting with no further action. Instruments found outside the as-found tolerance require resetting and an evaluation to determine if the loop is functioning properly.

- Safety limits are established to protect the integrity of systems or equipment that guard against the uncontrolled release of radioactivity. Process limits may also be established to protect against the failure, catastrophic or otherwise, of a system.

- Analytical limits are established to ensure that the safety limit is not exceeded. The analytical limit includes the effects of system response times or actuation delays to ensure that the safety limit is not exceeded.

- The allowable value is a value that the trip setpoint should function on or before, when tested periodically due to instrument drift or other uncertainties associated with the test to protect the analytical limit. A calibrated or loop verified setpoint found within the allowable value region, but outside the instrument's as-found tolerance, is usually considered acceptable with respect to the analytical limit and allowable value. The instrument must be reset to return it within the allowed as-left tolerance. A setpoint, found outside it's as-found tolerance but with the allowable value, should be evaluated for functionality. A setpoint, found outside the allowable value region, requires an evaluation for operability. Normally, an allowable value is assigned to Technical Specifications parameters that also have an analytical limit.

- The trip setpoint is the desired actuation point that ensures, when all known sources of measurement uncertainty are included, that an analytical limit is not exceeded. Depending on the setpoint, additional margin may exist between the trip setpoint and the analytical limit. The trip setpoint is selected to ensure the analytical limit is not exceeded while also minimizing the possibility of inadvertent actuations during normal plant operation.

APPENDIX D
EFFECT OF INSULATION RESISTANCE ON UNCERTAINTY

D.1 Background

Under the conditions of high humidity and temperature associated with either a Loss of Coolant Accident (LOCA) or high energy line break (HELB), the insulation resistance (IR) may decrease in instrument loop components such as cables, splices, connectors, containment penetrations, and terminal blocks. A decrease in IR results in an increase in instrument loop leakage current and a corresponding increase in measurement uncertainty of the process parameters, defined in Section 2.2 as IRA.

Degraded IR effects during a LOCA or HELB are a concern for instrumentation circuits due to the low signal current levels. A decrease in IR can result in substantial current leakage that should be accounted for in instrument setpoint and post accident monitoring uncertainty calculations. The NRC expressed concern with terminal block leakage currents in Information Notice 84-47. More recently, the NRC stated in Information Notice 92-12 (Ref. 5.12) that leakage currents should be considered for certain instrument setpoints and indication.

This Appendix provides an overview of IR effects on standard instrumentation circuits and provides examples of the effect of IRA on instrument uncertainty. Specifically, this Appendix addresses the following:

- Qualitative effects of temperature and humidity on IR
- Analytical methodology for evaluating IR effects on instrument loop performance
- Technical information needed to perform an evaluation
- Application of results to uncertainty calculations
- Consideration of inherent margins in the analytical methodology

D.2 Environmental Effects on Insulation Resistance

IR is affected by changes in the environment. ASTM Standard D257-91 (Ref. 5.31), provides a discussion of the factors that affect the resistance of a material. This ASTM standard discusses material properties in general; it does not limit itself to cables or any other type of particular construction. Factors that affect the resistance or the ability to measure resistance include:

- Temperature
- Humidity
- Time of electrification (electrical measurement of resistance)
- Magnitude of voltage
- Contour of specimen
- Measuring circuit deficiencies
- Residual charge

Temperature and humidity effects are of particular interest for circuits that may be exposed to an accident harsh environment. The resistance of an organic insulating material changes exponentially with temperature. Often, this variation can be represented in the form:

$$R = Be^{-(m/T)}$$

where,

R =Resistance of an insulating material
B =Proportionality constant
m =Activation constant
T =Absolute temperature in degrees Kelvin

One manufacturer predicts a similar exponential variation of IR with respect to temperature for their cable; the manufacturer provides the following equation, for determining IR at a given temperature:

$$IR = (4 \times 10^{15}) \log (D/d)\ e^{(-0.079 \times T)}$$

where,

IR = Calculated cable insulation resistance, megohm for 1,000 ft
T = Temperature, degrees Kelvin
d = Diameter of conductor
D = Diameter of conductor and insulation

Example D-1

Using the above expression, a sample IR will be calculated at 300°F (422°K). Cable heatup due to current flow will be neglected for instrument cables since they carry no substantial current. Typical values for d and D are 0.051 in. and 0.111 in., respectively, for a 16 awg conductor.

$$IR = (4 \times 10^{15}) \log (0.111/0.051)\ e^{(-0.079 \times 422)} =$$
$$4.5 \text{ megohms per } 1{,}000\text{ft}$$

Using the above equation, a graph of the cable IR variation with temperature is provided in Figure D-1. This figure is illustrative only and does not necessarily apply to other configurations or materials.

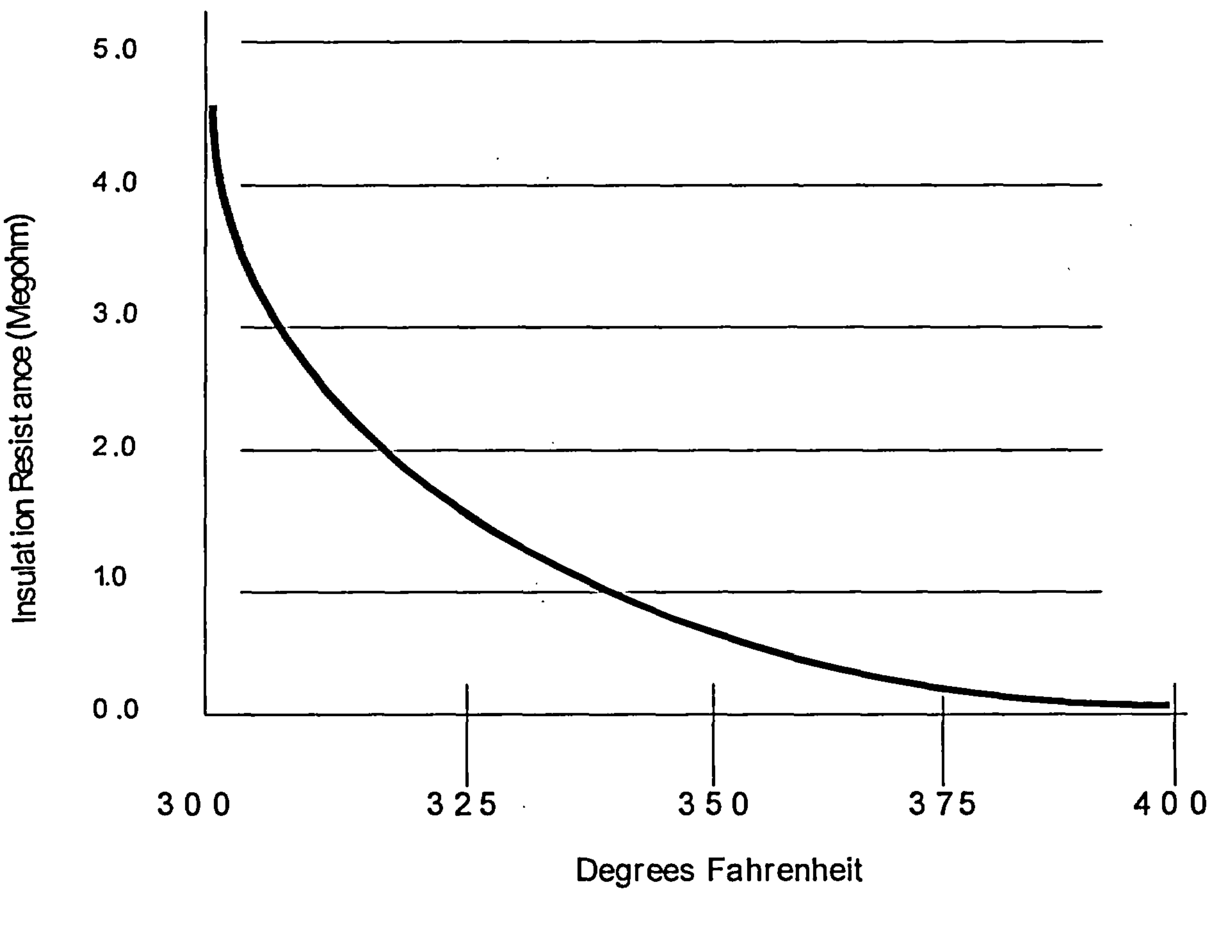


Figure D-1
Typical Cable Insulation Resistance Variation with Temperature

Insulation resistance of solid dielectric materials decreases with increasing temperature and with increasing humidity. Volume resistance of the insulating material is particularly sensitive to temperature changes. Surface resistance changes widely and very rapidly with humidity changes. In both cases, the change in IR occurs exponentially.

ASTM D257, Reference 5.31, discusses temperature and humidity as a combined effect on IR. In some materials, a change from 25°C to 100°C may change IR by a factor of 100,000 due to the combined effects of temperature and humidity. The effect of temperature alone is usually much smaller.

IR is a function of the volume resistance as well as the surface resistance of the material. In the case of an EQ test that includes steam and elevated temperatures, the minimum IR is expected near the peak of the temperature transient in a steam environment. Condensation of steam and chemical spray products will reduce the surface resistance substantially.

D.3 Analytical Methodology

D.3.1 Floating Instrument Loops (4 - 20 mA or 10 - 50 mA)

Instrument loops for pressure, flow or level measurement normally use a 4 to 20 mA (or 10 to 50 mA) signal. The instrument circuit typically consists, as a minimum, of a power supply, transmitter (sensor), and a precision load resistor from which a voltage signal is obtained for further signal processing. A typical current loop (without IR current leakage) is shown in Figure D-2.

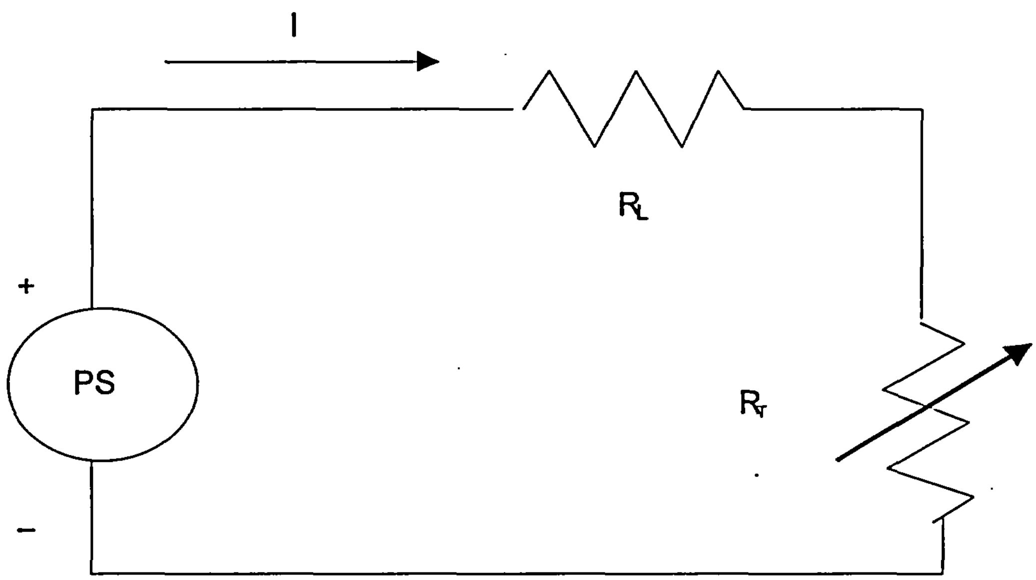


Figure D-2

Typical Instrument Circuit

In a current loop, the transmitter adjusts the current flow by varying its internal resistance, R_T, in response to the process. The transmitter functions as a controlled current source for a given process condition. The signal processor load resistor, R_L is a fixed precision resistor. Under ideal conditions, the voltage drop across R_L is directly proportional to the loop current and normally provides the internal process rack signal.

If current leakage develops in an instrument loop due to a degraded insulation resistance, the path is represented as a shunt resistance, R_S, in parallel to the transmitter as shown in Figure D-3.

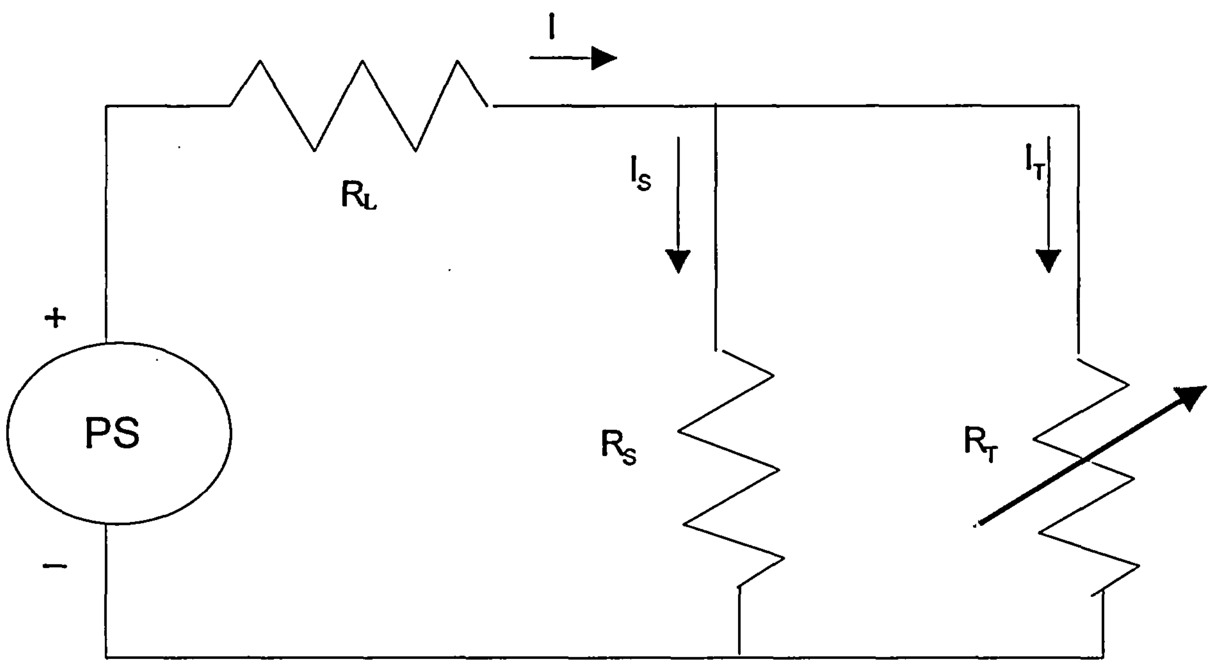


Figure D-3

Instrument Circuit with Current Leakage Path

Note that Figure D-3 applies only to floating instrument loops. In a floating instrument loop, the signal is not referenced to instrument ground. Thus, even if there is a low IR between cables or other instrument loop components to ground, the effect on instrument loop performance will be negligible as long as there is not a return path to ground for current flow. In this case, the only potential current leakage path is from conductor to conductor across the transmitter as shown in Figure D-3. See Section D.3.2 for necessary analytical methodology if the signal negative is grounded.

Leakage current disrupts the one-to-one relationship between the transmitter current and load current, such that a measurement error is introduced at the load. For a standard 4 - 20 mA (or 10 to 50 mA) instrument loop, the error is always in the higher-than-actual direction, meaning that the load current will be higher than the transmitter output current. The magnitude of the error in percent span ($I_S(\%)$) caused by leakage is defined as the ratio of leakage current to the 16mA span of a 4 - 20mA loop, or,

$$I_S(\%) = (I_s/16mA) \times 100$$

Where I_s = shunt current

From figure D-3, I_S can be expressed in terms of voltage, current and resistance in the current loop consisting of a power supply, load resistance and IR (shunt resistance) as follows:

$$V = I_L R_L + I_S R_S$$

where,

V	=	Power supply voltage
I_L	=	Current through the load resistor
I_S	=	Shunt current
R_L	=	Rack load resistance
R_S	=	Equivalent shunt (IR) resistance

Solving for I_S,

$$I_S = (V - I_L R_L)/R_S$$

Converting mA to Amps and normalizing for a 16mA span yields the following result:

$$I_S(\%\ span) = [(V - I_L R_L)/(R_S \times 0.016)] \times 100$$

The error due to current leakage is inversely proportional to the IR, or R_S in the above equation. As R_S decreases, the loop error due to current leakage increases. Note that equation to determine "V" has been simplified to provide an error in terms of percent span. For this case, the total instrument span is 16 mA for a 4 to 20 mA instrument loop.

R_S is an equivalent shunt resistance obtained from several parallel shunt paths. A typical circuit inside containment, showing all potential parallel current leakage paths, is shown in Figure D-4.

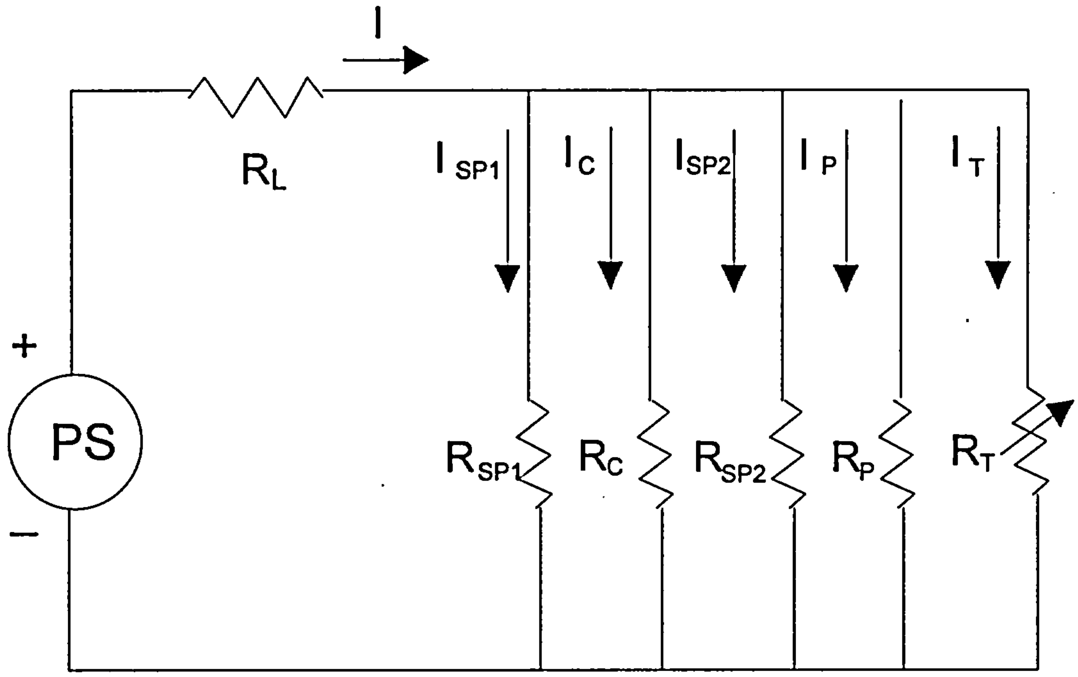


Figure D-4
Potential Current Leakage Paths

As depicted in Figure D-4, the current leakage paths include the following:

R_{SP1} Splice at sensor
R_C Field cable
R_{SP2} Splice between field cable containment penetration
R_P Containment penetration

Figure D-4 is intended to provide a feel for the various current leakage paths that might be present inside containment or a steam line break area; however, it is not necessarily complete. The containment penetrations might include the use of an extension (or jumper) cable to accomplish the transition from the field cable to the electrical penetration pigtail. Additional cables and splices may also be installed in the circuit, and each additional component should be included in the model.

Example D-2

Suppose we want to determine the IR that will affect the instrument loop uncertainty by 5%. The instrument loop conditions that yield the worst-case conditions for this example are as follows:

V = 50 VDC (highest typical loop power supply voltage)
I_L = 4 mA (0.004 A) (lowest possible loop current)
R_L = 250 ohm (lowest typical total load resistance)

Using the last equation from D.3.1 above,

$$5\% = [(50 - (0.004 \times 250))/(R_S \times 0.016)]$$
$$R_S = 61{,}250 \text{ OHM}$$

For a 10 to 50mA loop, the result is as follows:

$$5\% = [(50 - (0.010 \times 100))/(R_S \times 0.040)]$$
$$R_S = 24{,}500 \text{ OHM}$$

The interpretation of the above result is that any combination of current leakage paths with an equivalent IR of 61,250 ohm can cause an error of 5% of span in a 4 to 20 mA loop. Note that the above example is based on a worst-case configuration. Any decrease in power supply voltage, or an increase in total load resistance or current, will result in a smaller percent error for a given shunt resistance. Note that leakage current is a bias, causing the load current to always be higher than the transmitter current.

D.3.2 Ground Referenced Instrument Loops (4 - 20 mA or 10-50 mA)

The methodology provided in Section D.3.1 can be used if the signal negative is connected to ground; however, the circuit model is different in this case since there are additional current leakage paths than for a floating circuit. As discussed in Section D.3.1, a floating circuit is not ground-referenced; therefore, current leakage to ground is not likely since there is not a return path for current flow at the instrument power supply. In the case of an instrument loop with the signal current grounded at the instrument power supply, leakage paths to ground are possible since there is a return path to ground. This configuration is shown in Figure D-6.

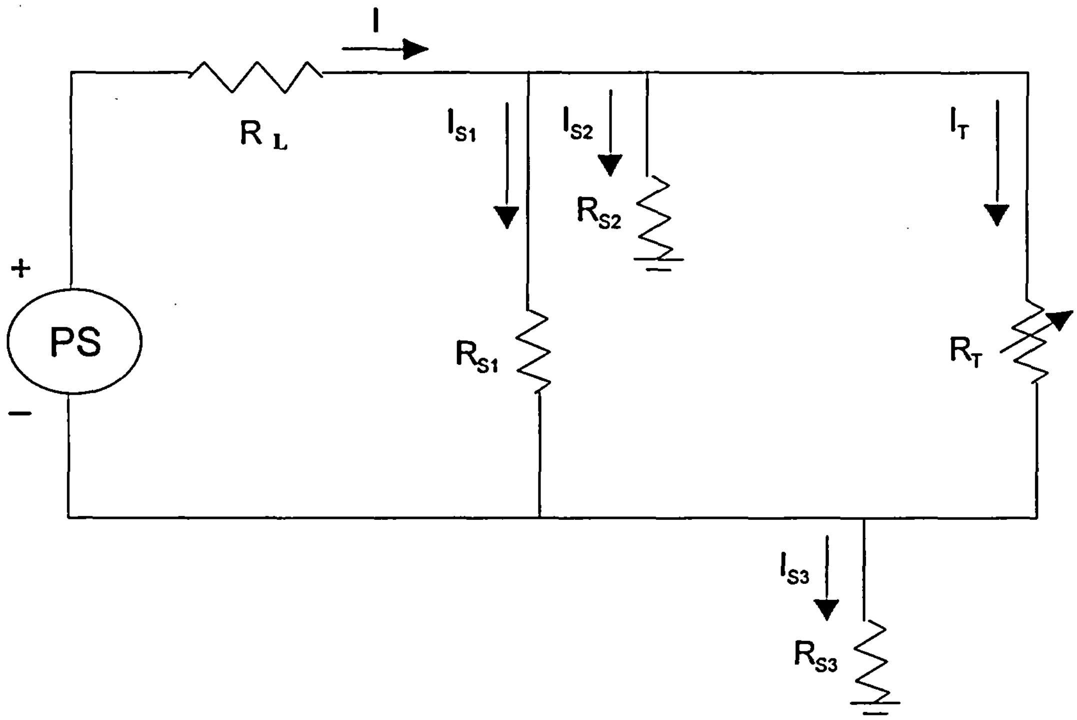


Figure D-6
Current Leakage Paths for a Ground-Referenced Instrument Loop

As shown in Figure D-6, the current leakage paths are as follows:

R_{S1} Conductor-to-conductor for equivalent IR per Section D.3.1
R_{S2} Positive conductor to ground IR equivalent resistance
R_{S3} Negative conductor to ground IR equivalent resistance

All of the above terms are parallel equivalent resistances that are calculated from cables, connectors, splices, etc., in accordance with the equations from Section D.3.1. Note that current leakage path R_{S3} can be neglected since it is effectively grounded at each end. The final configuration for analysis purposes is shown in Figure D-7.

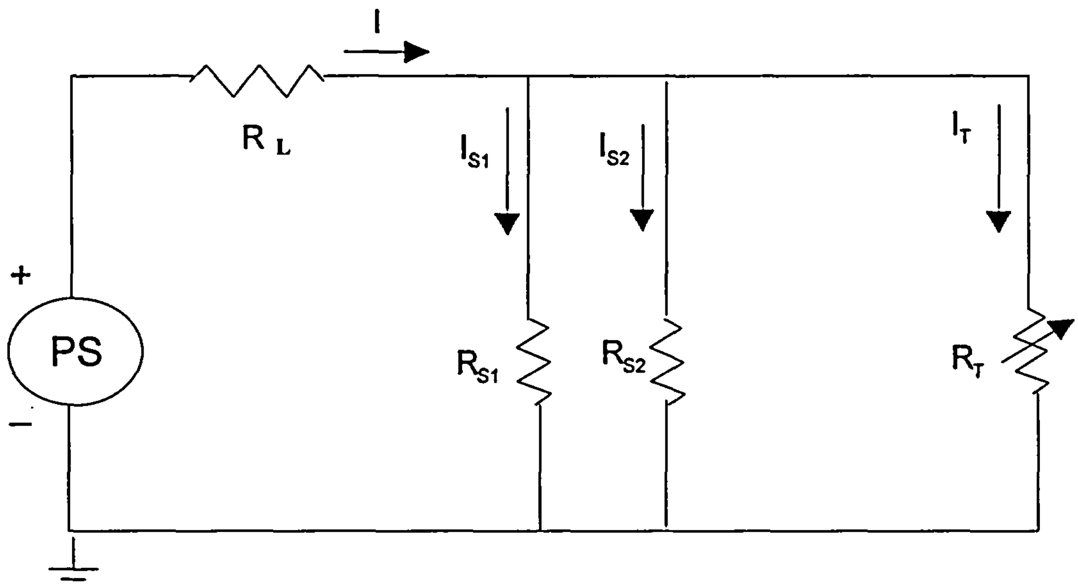


Figure D-7
Circuit Model for a Ground-Referenced Instrument Loop

The analysis of this circuit is identical to the methodology presented in Section D.3.1. Note that since there are additional current leakage paths, a ground-referenced instrument loop may be more susceptible to instrument uncertainty when its components are exposed to high temperature and humidity.

D.3.3 Resistance Temperature Detector Circuits (RTDs)

Resistance temperature detectors (RTDs) provide input to the Reactor Protection System and the Engineered Safety Features Actuation System. RTDs are also used for several post-accident monitoring functions. Because of these applications, the effect of degraded insulation resistance must be considered for RTD circuits. However, because of the difference in signal generation and processing, the analysis methodology is different than for 4 to 20 mA instrument loops.

An RTD circuit measures temperatures by the changing resistance of a platinum RTD, rather than a change in current. A typical 3-lead RTD circuit is shown in Figure D-8 (bridge and resistance to current [R/I] signal conditioner circuitry not shown for simplicity). Shunt resistances R_S and R_{SS} represent possible leakage current paths for this configuration.

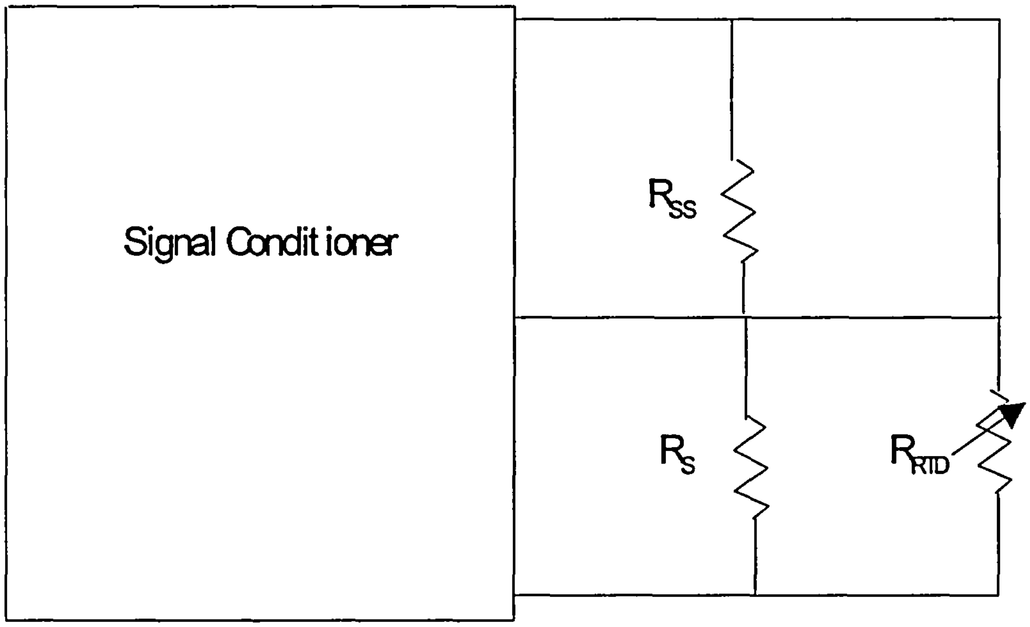


Figure D-8
RTD Circuit with Insulation Resistance Shown

The compensating lead wire resistance is approximately 0 ohms compared to the associated IR, R_{SS}. Therefore, R_{SS} is effectively shorted by the lead wire and will have no effect on the resistance signal received at the signal conditioner. This concept applies to 4-lead RTD circuits also. Shunt resistance (R_S) is in parallel with the RTD. The R/I signal conditioner will detect the equivalent resistance of the parallel resistances R_S and R_{RTD}. For this configuration, the equivalent resistance is R_E.

$$R_E = R_{RTD} \times R_S / (R_{RTD} + R_S)$$

The error, E, in °F introduced by the shunt resistance is defined as the difference between the temperature corresponding to the RTD resistance and the temperature corresponding to the equivalent resistance. In equation form,

$$E\,(^{\circ}F) = Temp\,(R_E) - Temp\,(R_{RTD})$$

Expressed in percent span,

$$E(\%) = [(Temp(R_E) - Temp(R_{RTD}))/Span] \times 100\%$$

Because the equivalent resistance seen by the signal conditioner will always be less than the RTD resistance, the resulting error will always be in the lower-than-actual temperature direction. In other words, the indicated temperature will always be lower than the actual temperature by the error amount.

Example D-3

As an example, calculate the IR in an RCS wide-range RTD instrument loop that will cause a 5% error in temperature measurement. The instrument span is 700°F. Perform the evaluation at an RTD temperature of 700°F.

$$-5\% = [(Temp\ (R_S) - 700)/700] \times 100\%$$

or,

$$Temp\ (R_E) = 665°F$$

From standard 200Ω RTD tables, the corresponding resistance is approximately 466 ohm. This is the equivalent resistance R_E. The RTD resistance for 700°F is approximately 480 ohm. So, the IR shunt resistance can be calculated by equation D-6.

$$466 = 480\ R_S/(480 + R_S)$$

or,

$$R_S = 15{,}977\ \Omega$$

D.4 Information Required to Perform Analysis

The following information is normally obtained to complete an analysis of current leakage effects:

- Cable length and type in the area of interest
- Number of splices in the area of interest
- List of all potential current leakage sources, e.g., cables, containment penetrations, etc.
- EQ test report information providing measured insulation resistance for each component
- Instrument circuit power supply maximum rated output voltage
- Total instrument loop loading for the circuits of interest
- Instrument loop span (4 - 20 mA, 0-700°F, etc.)
- Power supply configuration, e.g., floating or grounded

Example D-4

Assuming the following design inputs, calculate the maximum uncertainty associated with IR current leakage effects. *Note: This is an example only and does not apply to a particular configuration.*

Containment electrical penetration IR: $4.4 \times 10^6\ \Omega$ (obtained from EQ file)

Cable IR: $120 \times 10^6\ \Omega$/ft (obtained from EQ file)

Cable length inside containment is 250 ft (from design documents)

Note that cable IR is modeled as parallel resistances, or in this case, as 250 parallel resistances, each with a resistance of $120 \times 10^6\ \Omega$

Or, cable IR = $120 \times 10^6/250 = 0.48 \times 10^6\ \Omega$

Cable splices: $2.9 \times 10^6\ \Omega$ (obtained from EQ file)

Perform calculation at maximum power supply voltage (assume 48 VDC) and minimum loading (4 mA on a floating loop).

First, calculate equivalent shunt resistance due to all IR paths:

$$1/R_S = 1/(4.4 \times 10^6) + 1/(0.48 \times 10^6) + 1/(2.9 \times 10^6)$$

or,

$$R_S = 0.38 \times 10^6\ \Omega$$

The error in percent span is calculated by:

$$[48 - (0.004 \times 250)]/[(0.38 \times 10^6) \times 0.0016] = 0.77\%\ \text{of span}$$

This is the worst case configuration consisting of the minimum IR values from EQ test reports at the minimum loop loading. The uncertainty could be improved by including the actual instrument loop load. Also, the uncertainty could be calculated at the setpoint which often will have a higher loop current than the assumed 4 mA above.

D.5 Application of Results to Uncertainty Calculations

Current leakage due to IR is a bias defined as IRA in Section 2.2 and used in equations described in Section 4.5.4. The direction of the bias depends on the type of circuit as follows:

- Instrument loops, e.g., 4 to 20 mA or 10 to 50 mA circuits, will indicate higher than actual. The bias term is positive.
- RTD circuits will indicate lower than actual. The bias term is negative.

D.6 Additional Considerations

Depending on the instrument loop components, the circuit configuration, and the existing margins in a calculation, the first pass on a calculation may indicate less-than-desired setpoint margins. In this case, the input parameters to the calculation can be reviewed for any inherent margin that can be justifiably removed from the analysis. The following should be considered:

- Worst case IR values from the EQ test report are typically used. If the worst case IR values are based on IR to ground measurements and the instrument loop of concern is floating, then only conductor-to-conductor leakage need be considered. This effectively doubles the IR to use for the calculation since the current leakage depends on the series IR of both conductor's insulation.
- If the EQ test attempted to envelope all plants and all postulated accidents with a high peak temperature, e.g., 450°F, but the plant requirement is to a lesser value, such as 300°F, then margin is contained in the test report. The IR of an insulating material decreases exponentially with temperature. The EQ test report should be reviewed to determine the measured IR at lower temperatures.
- The calculations, References 5.22, 5.23, & 5.24, may have been performed for the worst-case circuit configuration for the sake of simplicity. In this case, the calculation probably assumed the following circuit conditions:
- Maximum power supply voltage
- Minimum instrument loop loading
- Minimum instrument loop current, e.g., 4 mA or 10 mA

If the actual circuit configuration and desired current corresponding to the actual setpoint differs from the above assumptions, then the CI-01-00 calculation can calculate IRA per Appendix D, for the actual loop configuration and required setpoint to eliminate unnecessary conservatism.

- Consider the time during which the process parameter is required. If the instrument loop performs a trip function prior to the peak accident transient conditions or if the instrument loop provides a post-accident monitoring function after the peak accident transient conditions have passed, a lower value of IRA may be defendable based upon a review of the appropriate EQ test reports.

- Consider the signal cable routing in each environmental zone. If the signal cable routes through multiple zones each with a unique peak temperature, a lower value of IRA may be defendable based upon calculation of the effect for each zone.

D.7 Concluding Remarks

The effect of IRA on instrument uncertainty is easily in a setpoint or indication uncertainty calculation. This Appendix provides an analytical basis for current leakage calculations and discusses options to consider when the calculated results exceed the available margin. If a bounding IRA value for a given device has been established per References 5.22, 5.23, and 5.24 and the values are acceptable for use in the setpoint or indication uncertainty calculation, then no further action is required.

Current leakage due to IR is not expected during normal operation. However, the methodology presented in this Appendix D could be used to determine IR effects during normal environmental conditions. Cable insulation resistance typically exceeds 1 megohm during normal operation, which results in a negligible contribution to the overall uncertainty.

APPENDIX E
FLOW MEASUREMENT UNCERTAINTY EFFECTS

E.1 Uncertainty of Differential Pressure Measurement

Differential pressure transmitters are generally used for flow measurement. The differential pressure measurement is normally obtained across a flow restriction such as a flow orifice, nozzle, or venturi. Each type of flow measurement device is briefly described below:

- A flow orifice is a thin metal plate clamped between gaskets in a flanged piping joint. A circular hole in the center, smaller than the internal pipe diameter, causes a differential pressure across the orifice plate that is measured by the differential pressure transmitter. A flow orifice is inexpensive and easy to install, but it has the highest pressure drop of all flow restrictor types.

- The flow nozzle is a metal cone clamped between gaskets in a flanged piping joint so that the cone tapers in the direction of fluid flow. The nozzle does not cause as large a permanent reduction in pressure as does the orifice because the entrance cone guides the flow into the constricted throat section, reducing the amount of turbulence and fluid energy loss.

- A flow venturi is a shaped tube inserted in the piping as a short section of pipe. The venturi has entrance and exit cones that serve as convergent and divergent nozzles, respectively, guiding the flow out of, as well as into, the constricted throat area. The venturi design is the most efficient and accurate of the flow restrictors. However, it is also the most expensive and difficult to maintain.

Regardless of how the pressure drop is created, flow transmitters measure the differential pressure across the flow restrictor. The high-pressure connection is always made upstream of the flow restrictors. The low-pressure connection is made downstream of orifices and nozzles (the exact location can vary), based on the constricted throat section of a venturi.

Flow is proportional to the square root of the differential pressure. This means that flow and differential pressure have a nonlinear relationship. The uncertainty also varies as a function of the square root relationship. The following example considers flow accuracy as a function of flow rate.

Example E-1

This example is illustrative only and does not directly correlate to any particular system flow rates or designs. However, the relative change in accuracy as a function of flow is considered representative of expected performance. A flow transmitter is used to monitor system flow. The instrument loop diagram is shown in Figure E-1.

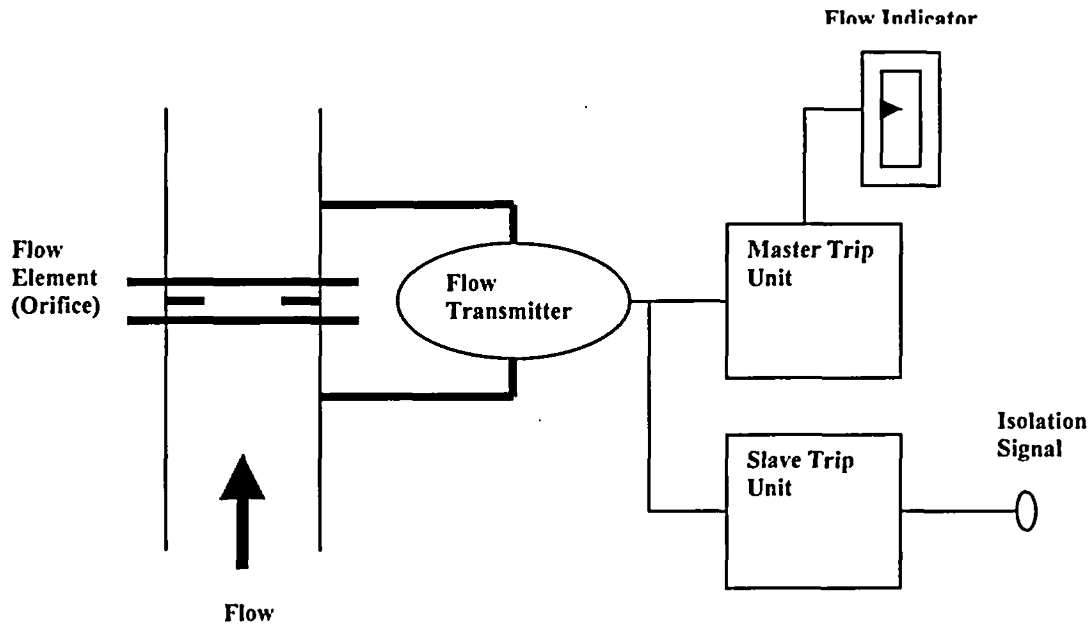


Figure E-1
Flow Monitoring Instrument Loop Diagram

The flow transmitter measures the differential pressure across the flow orifice. The relationship between flow in gpm and the differential pressure in inches is given by:

$$Flow = k\sqrt{\rho \Delta P}$$

The constant, k, is the flow constant for a specified configuration and the term, ρ, is the density of water at the design operating temperature (refer to ASME MFC-3M-1989, reference 5.7 for a detailed explanation of the flow equation). If we assume that the fluid temperature is essentially constant, the density can be incorporated into the flow constant and the above expression simplifies to:

$$Flow = k\sqrt{\Delta P}$$

For this example and assuming constant fluid temperature, the maximum flow will be given as 1,500 gpm when differential pressure is 100 inches. Therefore, the flow constant is:

$$k = \frac{Flow}{\sqrt{\Delta P}} = \frac{1{,}500}{\sqrt{100}} = 150$$

Assume that the various manufacturers provided the following measurement uncertainties:

Flow Orifice
Accuracy (PEA) - ±1.5%

Flow Transmitter
Accuracy (VA_T) - ±0.5%
Drift (VD_T) - ±1.0%
Temperature Effects (ATE_T) - ±0.5%

Indicator
Accuracy (VA_I) - ±0.5%
Drift (VD_I) - ±1.5%

Input Resistor
Accuracy (VA_R) - ±0.1%

Assume that all of the above uncertainty terms are random and independent for this example. The transmitter is providing an output signal proportional to the differential pressure across the flow orifice.

For this reason, we should first determine the uncertainty in our differential pressure measurement. The flow uncertainty can be estimated by taking the square root of the sum of the squares of the individual component uncertainties. The following equation is shown for example only AND does not replace the equations presented in Section 4.5.4:

$$Z = (PEA^2 + VA_T^2 + VD_T^2 + ATE_T^2 + VA_I^2 + VD_I^2 + VA_R^2)^{1/2}$$

$$Z = \sqrt{1.5^2 + 0.5^2 + 1.0^2 + 0.5^2 + 0.5^2 + 1.5^2 + 0.1^2}$$

$$= \pm 2.5\% = \pm 2.5 \text{ inches } \Delta P$$

Now, remember that our understanding of flow is based on the square root relationship between flow and differential pressure. Because, the relationship is not linear, we must consider the flow uncertainty at specific points. We already determined that flow for this particular application is related to differential pressure by the following expression:

$$\text{Flow} = 150\ (\Delta P)^{1/2}$$

Table E-1 provides the flow-to-ΔP relationship at different flow points:

Percent of Full Scale Flow	Flow (gpm)	Differential Pressure (inches)
100%	1,500	100.00
75%	1,125	56.25
50%	750	25.00
25%	375	6.25
10%	150	1.00

Table E-1
Flow Versus Differential Pressure for Example E-1

Now, let's estimate our uncertainty in flow for each of the above flow rates based on the ±2.5 inches of measurement uncertainty in differential pressure.

$$100\%: \mathit{Flow} = 150\ \sqrt{100 \pm 2.5} = 1{,}500\ {}^{+19}_{-19}\ \mathit{gpm}$$

$$75\%: \mathit{Flow} = 150\ \sqrt{56.25 \pm 2.5} = 1{,}125\ {}^{+25}_{-25}\ \mathit{gpm}$$

$$50\%: \mathit{Flow} = 150\ \sqrt{25 \pm 2.5} = 750\ {}^{+37}_{-38}\ \mathit{gpm}$$

$$25\%: \mathit{Flow} = 150\ \sqrt{6.25 \pm 2.5} = 375\ {}^{+69}_{-85}\ \mathit{gpm}$$

$$10\%: \mathit{Flow} = 150\ \sqrt{1.00 \pm 2.5} = 150 -\ {}^{+130}_{-150}\ \mathit{gpm}$$

If the flow versus the uncertainty of that flow measurement is graphed, the relative uncertainty at low flow conditions is readily apparent (see Figure E-2). This example shows the problem of obtaining accurate flow measurements by differential pressure at low flow conditions. The use of more accurate instrumentation would change the magnitude of the uncertainty, but would not affect the relative difference in uncertainty at low flow versus high flow conditions.

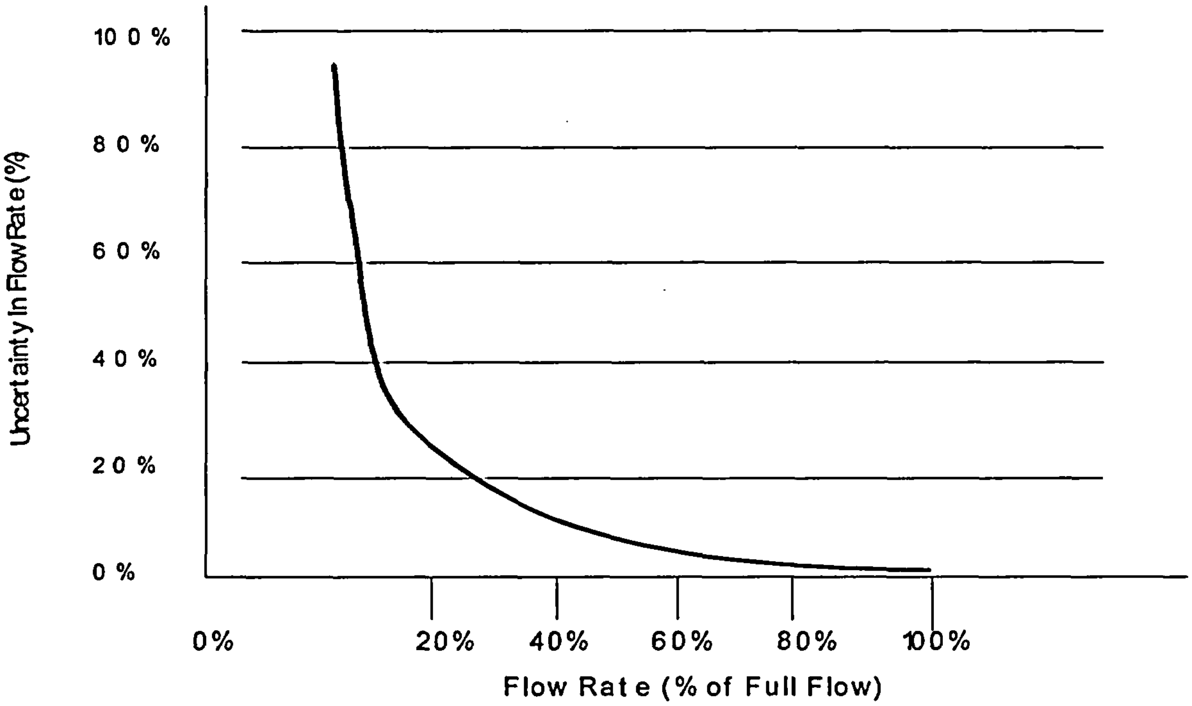


Figure E-2
Flow Uncertainty as a Function of Flow Rate

E.2 Effects of Piping Configuration on Flow Accuracy

Bends, fittings and valves in piping systems cause flow turbulence. This can cause process measurement uncertainties to be induced in flow elements. ASME has published guidance for various types of installation examples to show the minimum acceptable upstream/downstream lengths of straight pipe before and after flow elements. Following this ASME guidance helps reduce the effect of this turbulence. The piping arrangement showing locations of valves, bends, fittings, etc. can usually be obtained from piping isometric drawings. Reference 5.7,ASME MFC-3M-1989, states that, if the minimum upstream and downstream straight-pipe lengths are met, the resultant flow measurement uncertainty for the piping configuration (not including channel equipment uncertainty) should be assumed to be 0.5%. If the minimum criteria cannot be met, additional uncertainty (at least 0.5%) should be assumed for conservatism based on an evaluation of the piping configuration and field measurement data, if available.

E.3 Varying Fluid Density Effects on Flow Orifice Accuracy

In many applications, process liquid and gas flows are measured using orifice plates and differential pressure transmitters. The measurement of concern is either the volumetric flow rate or the mass flow rate. Many reference books and standards have been written using a wide variety of terminology to describe the mathematics of flow measurement, but in basic form, the governing equations are:

$$Q = k\ A\ (\Delta P\ /\rho)^{1/2}$$

and

$$W = k\ A\ ((\Delta P)(\rho))^{1/2}$$

where,

Q = Volumetric flow rate
W = Mass flow rate
A = Cross-sectional area of the pipe
ΔP = Differential pressure measured across the orifice
ρ = Fluid density
K = Constant related to the beta ratio, units of measurement, and various correction factors

As shown above, the density of the fluid has a direct influence on the measured flow rate. Normally, a particular flow-metering installation is calibrated or sized for an assumed normal operating density condition. As long as the actual flowing conditions match the assumed density, additional related process errors should not be present

If the flow-measuring system has been calibrated for the normal low-temperature condition, significant process uncertainties can be induced under accident conditions when the higher-temperature (lower-density) water is flowing. Of course, the flow measurement could be automatically compensated for density variations, but this is not the usual practice except on systems such as steam flow measurement.

To examine the effects of changing fluid density conditions, a liquid flow process shall be discussed. For most practical purposes, K and A can be considered constant. Actually, temperature affects K and A due to thermal expansion of the orifice, but this is assumed to be constant for this discussion to quantify the effects of density alone. If the volumetric flow rate, Q, is held constant, it is seen that a decrease in density will cause a decrease in differential pressure (ΔP), causing a measurement uncertainty. This occurs because the differential pressure transmitter has been calibrated for a particular differential pressure corresponding to a specific flow rate. A lower ΔP due to a lower fluid density causes the transmitter to indicate a lower flow rate.

Assuming the actual flow remains constant between a base condition (the density at which the instrument is calibrated, ρ_1) and an actual condition (ρ_2), an equality may be written between the base flow rate (Q_1) and actual flow rate (Q_2), as shown below:

$$Q_1 = Q_2$$

or

$$k\ A\ (\Delta P_2/\rho_2)^{1/2} = k\ A\ (\Delta P_1/\rho_1)^{1/2}$$

or

$$\Delta P_2/\rho_2 = \Delta P_1/\rho_1 \qquad \Delta P_2/\Delta \rho_1 = \rho_2/\rho_1$$

Density is the inverse of specific volume, SV. Accordingly, the above expression can be restated in terms of specific volume.

$$\frac{\Delta P_2}{\Delta P_1} = \frac{SV_1}{SV_2}$$

E.4 Effects of cavitating flows, ß ratios, and fluid velocity on Flow Orifice Accuracy

There are three elemental considerations to analyze when evaluating errors in flow measurement. First is the uncertainty of the coefficients used to determine the differential pressure of flow rate. This can be termed as flow element error or accuracy. Second is a temperature variation, which occurs during normal operation, which was discussed in Section E.3 for density effects but may also create material property effects such as pipe size variations from thermal expansion. The third is flow rate variation, which will cause the discharge coefficient to vary slightly.

The three primary components of flow element error are:

(1) uncertainty of the discharge coefficient

(2) bore diameter uncertainty and

(3) pipe diameter uncertainty. The diameter ratio is represented as the bore diameter relative to the pipe diameter or ß ratio and is given as: diameter ratio = d/D

Where :

d = uncertainty of orifice bore diameter
D = uncertainty of upstream pipe diameter

As stated, the discharge coefficient can vary with flow rate and cause the flow coefficient to vary. Flow element installation assumes design condition and therefore a constant flow coefficient (K). Flow Variations decreasing from design flow will lower the flow element Reynolds number and as Reynolds number falls the discharge coefficient, C, will rise above the value that existed for design flow such that the relative error is predicted by:

$$\frac{\Delta P_A - \Delta P_D}{\Delta P_D} = \left(\frac{C_D}{C_A}\right)^2 - 1$$

Therefore, flow below design flow induces a small negative bias error.

APPENDIX F
LEVEL MEASUREMENT TEMPERATURE EFFECTS

F.1 Level Measurement Overview

Differential pressure transmitters are typically used for level measurement involving an instrument loop. One side of a d/p cell is connected to a water column of fixed height (often called a reference leg) and the other side is connected to the fluid whose level is to be measured (see Figure F-1).

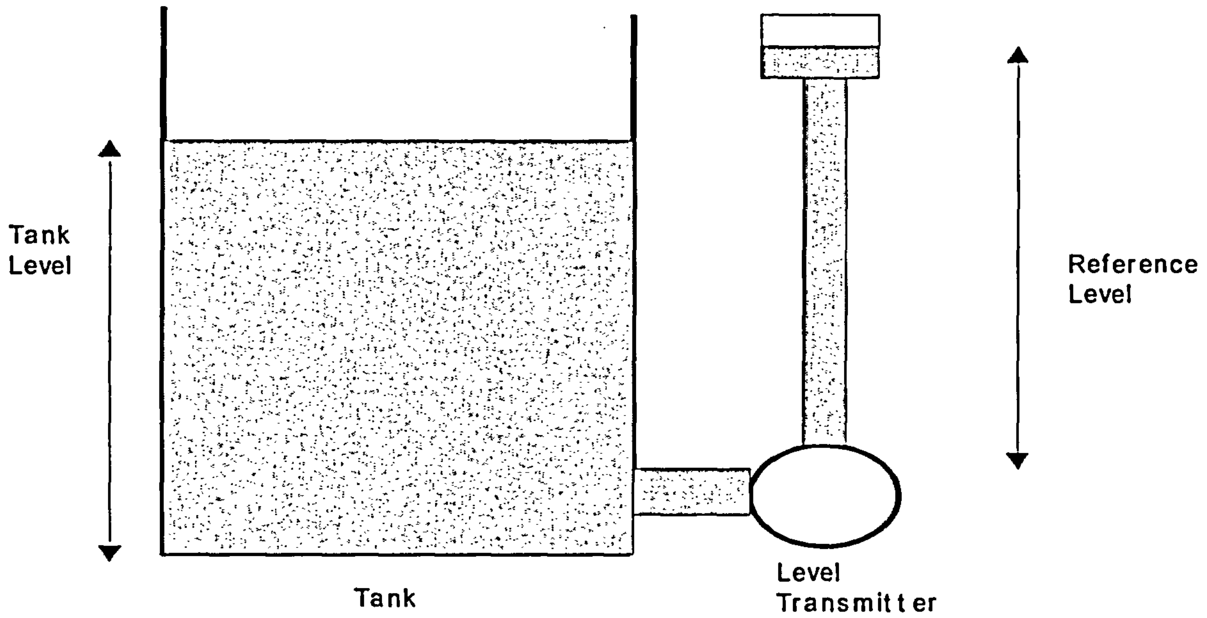


Figure F-1
Simplified Level Measurement in a Vented Tank

The measured level in Figure F-1 is determined by the pressure caused by the column of water in the reference leg minus the pressure caused by the water level in the tank:

$$\Delta P = (L_{ref} \times \gamma_{ref}) - (L_{tank} \times \gamma_{tank})$$

where,

L_{ref}	=	Height of liquid in reference leg
γ_{ref}	=	Specific weight of liquid in reference leg
L_{tank}	=	Height of liquid in tank
γ_{tank}	=	specific weight of liquid in tank

Notice in this case that tank level and differential pressure are inversely related. Maximum differential pressure occurs at minimum tank level.

As implied by the above expression, the specific weight of the liquid in the reference leg may not equal the specific weight of liquid in the tank. The two liquids might be at different temperatures (or might even be different liquids in the case of sealed reference legs).

F.2 Uncertainty Associated with Density Changes

Density changes in the reference leg fluid or the measured fluid can add to the uncertainty of a level measurement by a differential pressure transmitter. Differential pressure transmitters respond to the hydrostatic (head) pressure caused by a height of a liquid fluid column; for a given height, the response varies as the liquid density varies. The density changes as a function of temperature which then potentially changes the differential pressure measured by the transmitter. The transmitter cannot distinguish between the difference caused by a level change and the difference caused by a fluid density change.

Two types of level measurement system uncertainties are presented here. Section F.2.1 provides the methodology if no temperature compensation is provided for the vessel level measurement. Section F.2.2 provides the methodology for those cases in which the vessel temperature is measured to provide automatic compensation of the vessel liquid density, but the reference leg is still not compensated.

F.2.1 Uncompensated Level Measurement Systems

The methodology developed and described in this section assumes that vessels are closed and contain a saturated mixture of vapor and water. For this discussion, the reference leg is water-filled and also saturated. Note that the reference leg liquid may well be compressed (subcooled). Figure F-3 shows a closed vessel containing a saturated vapor/water mixture. The symbols used to explain the effect of density variations are provided immediately below Figure F-3.

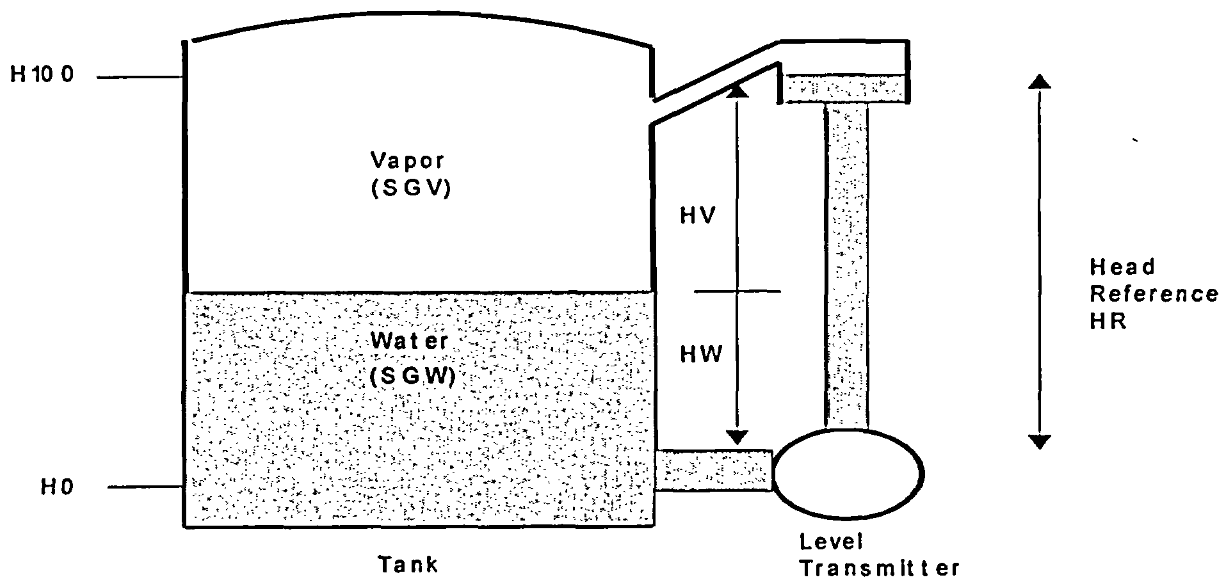


Figure F-3
Saturated Liquid/Vapor Level Measurement

Table F-1 provides the list of symbols used in a level measurement analysis and their explanation.

HW:	Height of water
SVW:	Specific volume of water at saturation temperature
HV:	Height of vapor
SVV:	Specific volume of vapor
HR:	Height of reference leg
SVR:	Specific volume of reference leg fluid
H0:	Height of 0% indicated level
SGW:	Specific gravity of water at saturation temperature
H100:	Height of 100% indicated
SGV:	Specific gravity of vapor level
ΔP:	Differential pressure
SGR:	Specific gravity of reference leg fluid (inches H_2O)

Any vapor higher than the entrance to the reference leg has an equal effect on both sides of the differential pressure transmitter and can be ignored.

Table F-1
Symbols Used in a Level Measurement Density Effect Analysis

All heights in Table F-1 are referenced to the centerline of the lower level sensing line. HV and HR are measured to the highest possible water column that can be obtained by condensing vapor. Specific gravity, is calculated by the specific volume of water at 68°F divided by the specific volume of the fluid at the stated condition.

Referring to Figure F-3, the differential pressure applied to the transmitter is the difference between the high pressure and the low pressure inputs:

$$\Delta P = \text{Pressure } (Hi) - \text{Pressure } (Lo)$$

The individual terms above are calculated by:

$$\text{Pressure (Hi)} = (\text{HR})(\text{SGR}) + \text{Static Pressure}$$

$$\text{Pressure (Lo)} = (\text{HW})(\text{SGW}) + (\text{HS})(\text{SGS}) + \text{Static Pressure}$$

Substituting the above equations into the general expression for differential pressure yields:

$$\Delta P = (HR)(SGR) - (HW)(SGW) - (HS)(SGS)$$

Referring to Figure F-3, it can be seen that the height of the vapor (HV) is equal to the height of the reference leg (HR) minus the height of the water (HW). Substituting (HR - HW) for HS yields:

$$\Delta P = (HR)(SGR) - (HW)(SGW) - (HR - HW)(SGS)$$

or

$$\Delta P = [(HR)(SGR - SGS)] + [(HW)(SGS- SGW)]$$

Using Equation F.1 and substituting for HW the height of water at 0% level (H0) and at 100% level (H100), the differential pressures at 0% (ΔP0) and at 100% (ΔP100) can be determined. Note that HR, H0, and H100 are normally stated in inches above the lower sensing line tap centerline. It is normally assumed that the fluid in both sensing lines below the lower sensing line tap are at the same density if they contain the same fluid and are at equal temperature. The specific gravity or specific weight terms (SGW, SGR, and SGV) are unit-less quantities, which means that ΔP, ΔP0, and ΔP100 are normally stated in "inches of water."

The transmitter is calibrated for proper performance at a given operating condition. Before the transmitter calibration requirements can be expressed, it is necessary to define the reference operating conditions in the vessel and reference leg from which SGW, SGR, and SGV may be determined by the use of thermodynamic steam tables. After the specific gravity terms are known, they can be used in Equation F.1 along with HR, H0, and H100 and the equation solved for the minimum and maximum level conditions, ΔP0 and ΔP100.

Provided that the actual vessel and reference leg conditions remain unchanged, the indicated level is a linear function of the measured differential pressure; no density error effects are present. Under this base condition, the following proportionality can be written.

$$\frac{HW - H0}{H100 - H0} = \frac{\Delta P - \Delta P0}{\Delta P100 - \Delta P0}$$

Solving for HW yields:

$$HW = [(H100 - H0)\ (\Delta P - \Delta P0)/(\Delta P100 - \Delta P0)] + H0$$

Now, assess the effects of varying the vessel and reference leg conditions from the assumed values. Let an erroneous differential pressure, ΔPU, and erroneous water level. HU, be developed because of an operating condition different from that assumed for the transmitter calibration. The uncertainty in the water level is given by:

$$HW \pm HU = [(H100 - H0)(\Delta P \pm \Delta PU - \Delta P0)/(\Delta P100 - \Delta P0)] + H0$$

Or, the uncertainty HU is given by:

$$HU = (H100 - H0)\ (\Delta PU)/(\Delta P100 - \Delta P0)$$

And,

$\Delta P100 - \Delta P0$ can be expressed by:

$$\Delta P100 - \Delta P0 = [(HR)(SRG - SGS) + (H100)(SGS - SGW)] - [(HR)(SGR - SGS) + (H0)(SGS - SGW)]$$

or

$$\Delta P100 - \Delta P0 = (H100 - H0)(SGS - SGW)$$

Thus, the uncertainty HU is given by:

$$HU = \frac{\Delta PU}{SGS - SGW}$$

The term ΔPU is just the difference between the differential pressure measured at the actual conditions, ΔPA, minus the differential pressure measured at the base condition, ΔPB:

$$\Delta PU = \Delta PA - \Delta PB$$

Assuming that HR and HW are constant (only the density is changing, not the actual levels), ΔPA and ΔPB can be expressed as:

$$\Delta PA = (HR)\ (SGRA - SGSA) + (HW)\ (SGSA - SGWA)$$

$$\Delta PB = (HR)\ (SGRB - SGSB) + (HW)\ (SGSB - SBWB)$$

Substituting into the expression for ΔPU yields:

$$\Delta PU = (HR)\ (SGRA - SGSA - SGRB + SGSB) + (HW)\ (SGSA - SGWA - SGSB + SGWB)$$

Returning to the expression for the uncertainty in measured level, HU, the substitution of the above expression for ΔPU yields:

$$HU = [(HR)\ (SGRA - SGSA - SGRB + SGSB) + (HW)(SGSA - SGWA - SGSB + SGWB)]/(SGSB - SGWB)$$

The above expression for level measurement uncertainty describes the uncertainty caused by liquid density changes in the vessel, reference leg, or both.

F.2.2 Temperature-Compensated Level Measurement System

The previous section describes the analysis methodology for the case in which no temperature compensation is provided to the level measurement system. The next section describes how to account for varying density effects on a differential pressure measurement. This section clarifies the methodology for a system in which the vessel temperature is monitored and the level measurement system includes automatic temperature compensation to account for the vessel's liquid density changes.

If the temperature inside the vessel is monitored, then the specific gravity of the steam and the water inside the vessel can be corrected as a function of temperature. In the analysis methodology for the water level measurement uncertainty, HU, the following terms become effectively equal because of the automatic correction for temperature:

$$SGSA = SGSB \quad and \quad SGWA = SGWB$$

In this case, the vessel density effects are eliminated, but note that the reference leg density changes are not monitored and still require consideration. The uncertainty of the differential pressure measurement reduces to:

$$\Delta PU = (HR)\ (SGRA - SGRB)$$

The above equation shows that the differential pressure uncertainty becomes increasingly negative as the actual temperature increases above the reference temperature. As the temperature in the reference leg increases above the reference temperature, the fluid density decreases, causing a negative ΔPU. Returning to Figure F-3, note that a lower differential pressure means that a higher level will be indicated, or a negative ΔPU will cause a positive level uncertainty HU. The magnitude of the error can be estimated by:

$$HU = (HR)\ (SGRA - SGRB)/(SGSB - SGWB)$$

If the transmitter connections were reversed (high pressure connection reversed with low pressure connection to reverse the ΔP), the above discussion would still apply, but the uncertainty would change direction:

$$\Delta PU = (HR)\ (SGRB - SGRA)$$

The above equations calculate uncertainties in actual engineering units. If desired, the quantities HU and ΔPU can be converted to percent span units by dividing each term by (H100 - H0) or (ΔP100 - ΔP0), respectively, and multiplying the results by 100%. As discussed above, the sign (or direction of the uncertainty) for ΔPU depends on which way the high- and low-pressure sides of the transmitter are connected to the vessel.

F.2.3 Example Calculation for Uncompensated System

For this example, assume that a level measurement is not compensated for density changes and has the following configuration:

1. HR = 150 in.
2. H0 = 50 in.
3. H100 = 150 in.
4. HW = 100 in.
5. Reference conditions:
   Vessel temperature = 532°F (saturated water)
   Reference leg temperature = 68°F (assume saturated, but could be compressed)
6. Actual conditions:
   Vessel temperature = 500°F (saturated water)
   Reference leg temperature = 300°F (assume saturated, but could be compressed)

Determine the level measurement uncertainty for this operating condition.

First, calculate the specific gravity terms for each condition by using steam table specific volumes of water (SVW) and specific volumes of vapor (SVV). The following values are calculated:

$$SGWA = \frac{SVW\ (68^{\circ}F)}{SVW\ (500^{\circ}F)} = \frac{0.016046\ ft^3/lbm}{0.02043\ ft^3/lbm}\ \ 0.78541$$

$$SGSA = \frac{SVW\ (68^{\circ}F)}{SVS\ (500^{\circ}F)} = \frac{0.016046\ ft^3/lbm}{0.67492\ ft^3/lbm}\ \ 0.02377$$

$$SGRA = \frac{SVW\ (68^{\circ}F)}{SVW\ (300^{\circ}F)} = \frac{0.016046\ ft^3/lbm}{0.01745\ ft^3/lbm}\ \ 0.91954$$

$$SGWB = \frac{SVW\ (68^{\circ}F)}{SVW\ (532^{\circ}F)} = \frac{0.016046\ ft^3/lbm}{0.02123\ ft^3/lbm}\ \ 0.75582$$

$$SGSA = \frac{SVW\ (68^{\circ}F)}{SVW\ (532^{\circ}F)} = \frac{0.016046\ ft^3/lbm}{0.50070\ ft^3/lbm}\ \ 0.03205$$

$$SGRB = \frac{SVW\ (68^{o}F)}{SVW\ (68^{o}F)} = \frac{0.016046\ ft^3/lbm}{0.016046\ ft^3/lbm}\ 1.0$$

Next, substitute HW = 100 in. and HR = 150 in., as well as the above quantities, into the expression for HU:

HU = [(HR) (SGRA - SGSA - SGRB + SGSB) + (HW) (SGSA - SGWA - SGSB + SGWB)]/(SGSB - SGWB)

= [150(0.91954 - 0.02377 - 1.0 + 0.03205) + 100 (0.02377 - 0.78541 - 0.03205 + 0.75582)]/(0.03205 - 0.75582)

$= +20.2\ inches$

In percent of span, the uncertainty is given by:

HU% = [(HU)/(H100 - H0)](100%) = [(20.2)/(150 - 50)](100%) = +20.2% span

APPENDIX G
STATIC HEAD AND LINE LOSS PRESSURE EFFECTS

The flow of liquids and gases through piping causes a pressure drop from Point A to some Point B due to fluid friction (see Figure G-1). Many factors are involved, including piping length, piping diameter, pipe fittings, fluid viscosity, fluid velocity, etc. If a setpoint is based on pressure at a point in the system that is different from the point of measurement, the pressure drop between these two points must be taken into account.

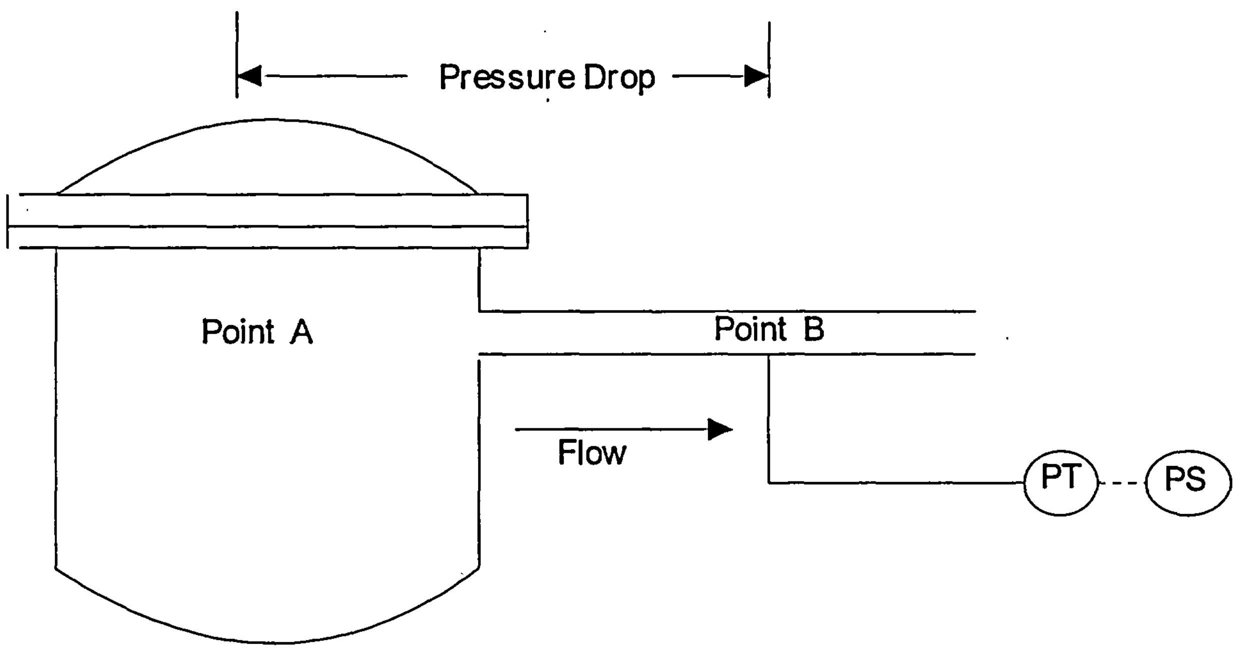


Figure G-1
Line Pressure Loss Example

<u>Example G-1</u>

Refer to Figure G-1 for this example. If protective action must be taken during an accident when the pressure at Point A exceeds the analysis limit (AL) = 1060 psig, the pressure switch setpoint needs to be adjusted to account for the line loss (30 psig) and channel equipment errors (10 psig) as shown below (it is assumed that the sensing line head effect for the accident condition is negligible in this case).

Setpoint = AL - Line Loss - Total Channel Equipment Uncertainty

= 1060 - 30 - 10

= 1020 psig

Note that if the line loss had been neglected and the setpoint adjusted to the analysis limit minus equipment error (1050 psig), the resultant setpoint would be non-conservative. In other words, when the trip occurred, the pressure at Point A could be equal to 1050 + 30 = 1080 psig, which non-conservatively exceeds the analysis limit

Example G-2

If the pipe had dropped down vertically to Point B, the result would be a head effect plus line loss example. Assume the head pressure exerted by the column of water in the vertical section of piping is 5 psig and that the line loss of Point A to Point B is still equal to 30 psig. Also, assume that the pressure at Point A is not to drop below 1,500 psig without trip action. For this example, the setpoint is calculated as follows:

Setpoint = AL + Head + total Channel Equipment Uncertainty

= 1,500 + 5 + 10 = 1,565 psi

In this case, the 30 psig line loss was neglected for conservatism.

Note that the head effect/line loss errors are bias terms, unless they can be calibrated out in the transmitter, in which case this effect can be removed from the channel uncertainty calculation. CPS C&I department typically calibrates the effects of head out during transmitter calibration testing, this must be verified for each channel during analysis. If head effects are included in the channel uncertainty calculation, the effect must be added or subtracted from the analytical limit, depending on the particular circumstances, to ensure that protective action occurs before exceeding the analytical limit.

APPENDIX H
MEASURING AND TEST EQUIPMENT UNCERTAINTY

M&TE uncertainty is the inaccuracy introduced by the calibration process due to the limitations of the test instruments. M&TE uncertainty includes three principal components: (1) vendor accuracy of the test equipment, (2) effect of temperature on the test equipment, and (3) accuracy of the test equipment calibration process. The first two components are included directly in the M&TE uncertainty and the third is assumed to be included in the conservatism of the vendor accuracy of the test equipment.

All (100%) of test equipment is certified to pass the calibration requirements, not just 95%, the common confidence level used for uncertainty calculations. Discussion with vendors shows that the actual accuracy of the test equipment is better than the vendor published values. Both of these provide conservatism in the accuracy of the test equipment and, therefore conservatism in the M&TE determination. As discussed in H.1 below the standards used to calibrate the test equipment are generally rated 4:1 better than the equipment being calibrated. For these reasons it is generally accepted that the published vendor accuracy of the test equipment includes the uncertainty of the calibration standard since vendor accuracy divided by 4 is negligible in the relation to other uncertainties. For the purposes of setpoint and uncertainty calculations, the total M&TE uncertainty for any module should be based on test equipment, which has been calibrated using 4:1 reference standards.

The module calibration also includes an As-Left tolerance (ALT) which can be related to the test equipment uncertainty. An instrument does not provide an exact measurement of the true process value; there is always some level of uncertainty or error in our measurement. The As-Left tolerance is (1) a reflection of the best accuracy that we can realistically obtain or (2) the minimum accuracy that we feel is needed to assure that the process is properly controlled.

For example, a pressure transmitter may have vendor accuracy (VA) of ±0.1%, but its As-Left tolerance may be allowed to be ±0.5%. Thus, the instrument technician is allowed to leave the instrument as-is if it is found anywhere within ±0.5% of the calibration check point. Without any other considerations, we would have to conclude that the calibrated condition of the instrument is only accurate to ±0.5% rather than the device's VA of ±0.1%. If greater accuracy is needed, the calibration procedure should be revised for the tighter As-Left tolerance.

Appendix H provides the details for calculation preparers to consider when evaluating the M&TE uncertainty for a module.

H.1 General Requirements

The control of measuring and test equipment (M&TE) is governed at CPS, by procedure CPS 1512.01, Reference 5.14. This procedure requires the M&TE accuracy to be at least a 4:1 ratio, greater than the Reference Standards used. In discussion with NSED, loop M&TE is specified as the statistical combination of all of the pieces of input and output M&TE. Instrument and loop calibration procedures, CPS 8801.01 and 8801.02, References 5.15 and 5.16 required the M&TE to be at least as accurate as the device being calibrated (1:1 ratio). CPS does have an M&TE calculation (IP-C-0089, Ref. 5.30) supporting both maintenance selection activities and engineering assumptions used in calculations.

The following discusses specific requirements of this procedure:

1. Reference standards used for calibrating M&TE shall have an uncertainty (error) requirement of not more than ¼ of the tolerance of the M&TE equipment being calibrated. A greater uncertainty may be acceptable as limited by "State of the Art."

2. Total SRSS of M&TE accuracy used for calibrating a loop or component shall have an uncertainty (error) requirement of no more than a 1:1 ratio of the tolerance of the loop or component being calibrated.

3. No measurement and test equipment shall be used if the record date for recalibrating the test equipment has been exceeded.

CPS 1512.01, does not address the accuracy of M&TE equipment with respect to the loop or component being checked for calibration. The accuracy of M&TE equipment is addressed by calculation, CPS (IP-C-0089, Reference 5.30). SRSS of M&TE device(s) accuracy uncertainty will be considered in terms of the VA of the loop or component to be calibrated.

For the purposes of setpoint and uncertainty calculations, the total M&TE uncertainty should be based on CPS Standard Assumption (Section I.11) that a 4:1 ratio exists between M&TE and references standards, thus CSTD = 0. If the test equipment accuracy is not based on 4:1 reference standards, the required total M&TE uncertainty should be met by using better test equipment for calibration.

In general, it is desirable to minimize the contribution of M&TE to the uncertainty of the loop. Every effort should be made to use the most accurate M&TE available during calibration.

H.2 Uncertainty Calculations Based on Plant Calibration Practices

The M&TE uncertainty included in an uncertainty calculation is based on historical practices and the uncertainty assigned to the M&TE by calculation, IP-C-0089, Ref. 5.30. The implicit design assumption is that M&TE used in the future will be equal to or better than the M&TE used in the past (due to improvements in State of the Art test equipment). In order to ensure this assumption is not invalidated by future calibrations, review the M&TE specified in the applicable C&I procedures. Verify the uncertainty of the M&TE specified (including calibration standards) is bounded by VA used in the calculation as shown in the following sections for each type of instrument or configuration.

NOTE: ALT does not have to equal VA. It can be greater or smaller based on the needs of C&I maintenance.

H.2.1 Loop Component

For all components, the M&TE reference accuracy used for calibration should be no greater than VA of that component.

The calculation of Calibration uncertainty should include both the input and output M&TE. M&TE errors are present with the input signal provided to the input of the sensor as well as with the instrumentation used to measure the output of the sensor (see Figure H-1). The input M&TE is independent from the output M&TE. Additionally, it should include any other affects on the M&TE equipment such as ATE and/or IRE.

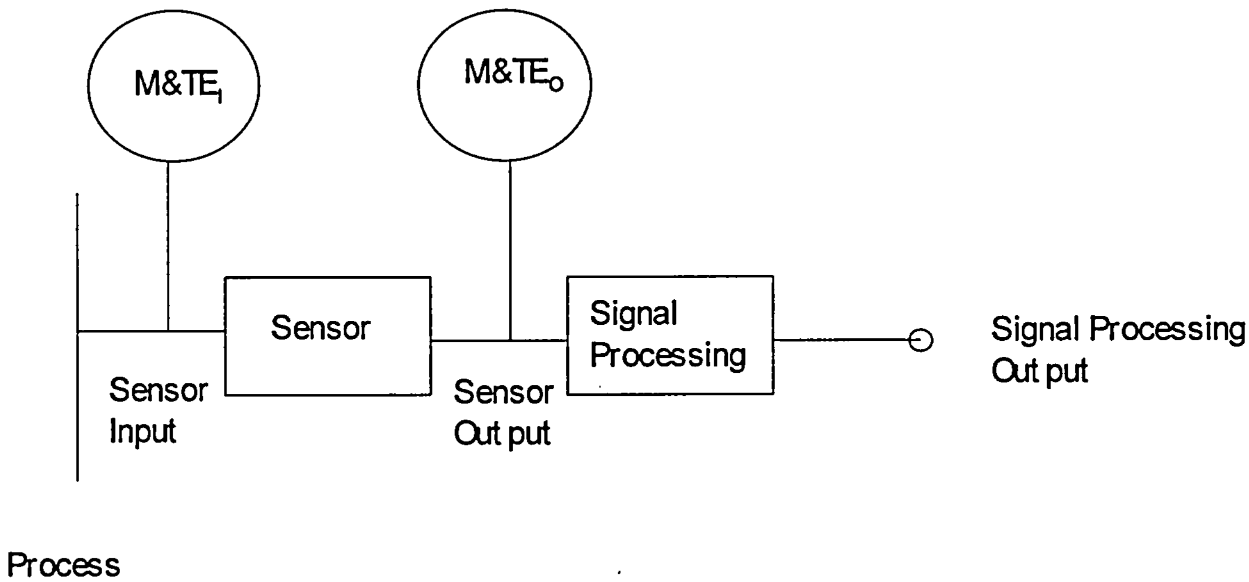


Figure H-1
Measuring and Test Equipment Uncertainty

An example is given for Figure H-1. In the case of a transmitter (sensor), where VA = ±0.5%. The 1:1 criteria for M&TE would be met by the statistical combination of the input and output MTE reference accuracies.

$$VA_{sensor} \geq (MTE_I^2 + MTE_O^2)^{1/2}$$

This comparison should be made for all components in the loop regardless of whether they have M&TE on both input and output, or multiple M&TE on input, output, or both.

H.2.2 Instrument Loops

For an entire instrument loop, the Calibration Error used should be the statistical combination of the As-Left tolerance (ALT), Calibration Device Error (C_i), and Calibration Standard Error (CSTD). C_i should be the statistical combination of all of the pieces of input and output M&TE including all uncertainties associated with the M&TE (example: temperature effect and readability). CPS calculation IP-C-0089, "M&TE Uncertainty Calculation", provides uncertainty values for the most commonly used M&TE.

H.2.3 Example Channel Loop Error Section for a Typical Transmitter, ATM Loop

7.6 Loop Calibration Error (C_L)

Loop Calibration Error is determined by the SRSS of As-Left Tolerance (ALT_i), Calibration Tool Error (C_i), and Calibration Standards Error ($C_{i\,STD}$) for the individual devices in the loop. The equation below is used to calculate this effect.

From Section 7.3.3:

$$C_L = \pm N\sqrt{\sum\left(\frac{ALT_i}{n}\right)^2 + \sum\left(\frac{C_i}{n}\right)^2 + \sum\left(\frac{C_i STD}{n}\right)^2} \quad (2\sigma)$$

7.6.1 As-Left Tolerance (ALT_L)

From Section 7.5

$$ALTi_{PT} = \pm 0.25\% \quad (2\sigma)$$

$$ALTi_{ATM} = \pm 0.25\% \quad (2\sigma)$$

$$\mathbf{ALT_L = \pm\, 0.354\%\ Span} \quad (2\sigma)$$

7.6.2 Calibration Tool Error (C_i)

7.6.2.1 Transmitter Calibration Tool Error (Ci_{PT})

The 1B21NXXXA, B, C, D transmitters located in the Aux. Bldg. (Refer to Section 7.2) are calibrated with a Fluke Model 45 DC voltmeter on the slow response setting that is capable of measuring 1-5 Vdc and a 250-ohm precision resistor, accurate to ±0.02 ohms. The calibration also requires a test gauge with a range of 0-2000 psig. This information is from Section 7.0 of Output [calibration procedure listed in output section]. Per Assumption [ ], all M&TE equipment is a 3σ value.

Per Section 7.4.1:
Transmitter span is 0-1500 psig
$VA_{PT} = \pm\, 0.25\%$ span. (2σ)

Per Reference [IP-C-0089], VA for the M&TE devices are:

Heise (0-2000 psig) = 0.1% FS (3σ)

Fluke 45 (1-5 Vdc, Slow) = 0.065% reading, where max reading is 5 Vdc. (3σ)

The accuracy of the precision resistor is calculated as follows:

$C_{PR} = \pm 0.02/250 * 100$
$C_{PR} = \pm 0.008\%$ Span (3σ)

Per Ref. [CI-01.00, Appendix H, Section H.2.1]

$VA_{PT} \geq (MTE_I^2 + MTE_O^2)^{1/2}$
$0.25\%\ \text{span} \geq ((0.1\%FS/SP)^2 + (0.065\%R/SP)^2 + (0.008\%Span)^2)^{1/2}$
$(0.0025*1500) \geq ((0.001*2000/1500^2 + (0.00065*5/4)^2 + (0.00008*1500)^2)^{1/2}$

$3.75 \geq 0.12$ /

The total M&TE error for the Heise gauge (C_{PG}) is therefore:

Per Reference [IP-C-0089], Total error M&TE devices are:
$C_{PG} = \pm 1.187$ FS
Converting to the 1500 psig span of the transmitter:
$C_{PG} = \pm 1.187\%$ (2000 psig/1500 psig)
$C_{PG} = \pm 1.583\%$ Span (3σ)

The M&TE error for the voltmeter (C_{VM}) is therefore:

$C_{VM} = \pm 0.097\%$ R/SP
$= \pm 0.097\%$ 5/4
$= \pm 0.121\%$ Span (3σ)

The M&TE error for the precision resistor (C_{PR}) is therefore:

$C_{PR} = \pm 0.008\%$ Span (3σ)

Substituting terms:

$$C_{PT} = \pm\sqrt{C_{PG}^2 + C_{VM}^2 + C_{PR}^2}$$

$$C_{PT} = \pm\sqrt{1.583\%span^2 + 0.121\%span^2 + 0.008\%span^2}$$

$C_{PT} = \pm 1.588\%$ Span (3σ)

7.6.3 ATM Calibration Tool Error (C_{ATM})

The ATM's are calibrated using a DAC, which uses a readout assembly. This assembly does introduce some error into the calibration. Per Reference [IP-C-0089], Total error M&TE devices are 0.195%FS.

$C_{Res} = \pm 0.195\% * 20\ mA/16mA$

$C_{ATM} = \pm 0.0901$ % Span **(3σ)**

7.6.4 Calibration Standard Error (C_{STD}):

Per Assumption[ ], Calibration Standard Error is considered negligible for the purposes of this analysis.

$C_{STD} = 0$

7.6.5 Loop Calibration Error (C_L):

Per Outputs [ ], the loop calibration is performed using a pressure gauge only. Therefore, C_i for the loop will be C_{PG}.

From Section 7.6 above:

$$C_L = \pm N\sqrt{\sum\left(\frac{ALT_i}{n}\right)^2 + \sum\left(\frac{C_i}{n}\right)^2 + \sum\left(\frac{C_iSTD}{n}\right)^2}$$

From above:

ALT_L = 0.354% Span	(2σ)	Section 7.6.1
C_{PG} = 1.583% Span	(3σ)	Section 7.6.2.1
$C_iSTD = 0$		Section 7.6.3

Substituting terms for the pressure loop:

$$C_L = \pm 2\sqrt{\left(\frac{0.354\ \%\,span}{2}\right)^2 + \left(\frac{1.583\ \%\,span}{3}\right)^2 + 0^2}$$

$C_L = \pm 1.622\%$ Span **(2σ)**

H.2.4 Special Considerations

C_L is used in the development of AFT_L, which is used to calculated NTSP. In order to preserve an existing setpoint, C_L can be reduced as follows:

1. Reduce the M&TE temperature uncertainty by reducing the temperature band from maximum (Bldg Temp. Band) to a lower Room Temp. Band for the location of the component. This will require calculating new M&TE uncertainty values consistent with calculation IP-C-0089.

Discussion and agreement with C&I Maintenance is required for the below options, but these may be considered as well;

2. Specify a more accurate M&TE, such as digital heise, which are temperature compensated. Also, there are some regular heise gauges, which are temperature compensated.

3. Reduce or change the range specified for M&TE. For the example above, specify a 1500 psig Heise (if it exists). However, the upper Cardinal Point(typically 100% span)used in the calibration procedure will have to be reduced such that the range of the M&TE is not exceeded when allowing for As Found and As Left calibration tolerances.

APPENDIX I
NEGLIGIBLE UNCERTAINTIES / CPS STANDARD ASSUMPTIONS

The uncertainties listed and discussed in sections I.1 through I.6 below. The CPS Standard Assumptions are listed in I.11. Personnel performing an uncertainty calculation must evaluate the calculation with respect to this Appendix to verify that any special circumstances or unusual configurations do not invalidate any of these negligible uncertainties or CPS Standard Assumptions.

I.1 Normal Radiation Effects

DC-ME-09-CP, Ref. 5.36, defines the normal and harsh environments for areas within the plant. There is not a substantial increase in radiation during normal operating conditions. In these areas, radiation changes during normal operation do not exist and/or are minimal, with no impact to vendor equipment. Normal radiation induced errors shall be incorporated when provided by the manufacturer. Otherwise, it is assumed that any accumulative effects of $<10^4$ RAD TID radiation are calibrated out on a periodic basis. For these reasons, the uncertainty introduced by any radiation effect during normal operation is assumed to be negligible.

I.2 Humidity Effects

Most manufacturers' literature and technical manuals do not address the effect of humidity (10% RH to 95% RH) on their equipment. The uncertainty introduced by humidity changes during normal operation is assumed to be negligible unless the manufacturer specifically discusses humidity effects in the technical manual. The effects of humidity changes are assumed to be calibrated out on a periodic basis. A condensing environment is considered an abnormal event that would require equipment maintenance. A humidity below 10% is considered to occur very infrequently.

I.3 Seismic/Vibration Effects

The effects of normal vibration (or a minor seismic event that does not cause an unusual event) on a component are assumed to be calibrated out on a periodic basis. As such, the uncertainty associated with this effect is assumed to be negligible. Abnormal vibrations, e.g., levels that produce noticeable effects on equipment, are considered abnormal events that require maintenance or equipment modification.

I.4 Normal Insulation Resistance Effects

The uncertainties associated with insulation resistance are assumed to be negligible during normal plant operating (non-accident) conditions. Typical insulation resistances are greater than 1,000 megohm. As an example, assume that the total IR is only 10 megohm and assume minimum instrument loop loading. Using the methodology provided in Appendix D, the expected uncertainty attributable to IR is given by:

$$(48 - (0.004)(250))/((10\times10^{6})(0.016)) = 0.03\%$$

As can be seen, the IR can be considered negligible as long as the environment remains mild.

I.5 Lead Wire Effects

Since the resistance of a wire is equal to the resistivity times the length divided by the cross-sectional area, it is assumed that the very small differences in wire lengths between components do not contribute to any significant resistance differences between wires. The uncertainty associated with these insignificant resistance variations is assumed to be negligible.

If a system design includes lead wire effects that must be considered as a component of uncertainty, the requirement must be included in the design basis. The general design standard is to eliminate lead wire effects as a concern both in equipment design and installation. Failure to do so is a design fault that should be corrected. Unless specifically identified to the contrary, lead wire effects are to be assumed to be negligible. An exception to this is thermocouples and RTDs. These cases require individual evaluation of lead wire effects.

I.6 Calibration Temperature Effects

Calibration temperature is not recorded at CPS, however, the temperature at which an instrument is calibrated is within the normal operating range of the instrument and generally reasonably close to one another between calibrations. Although, the ambient temperature effects cannot be determined, they are considered small. Therefore, the uncertainty associated with the temperature variations during calibration is assumed to be included within the instrument drift errors. Note that this applies only to temperature changes for calibration. Temperature effects over the expected range of equipment operation and M&TE temperature effects must be considered.

I.7 Atmospheric Pressure Effects

Assuming that the atmospheric pressure might change as much as one inch of mercury, this equates to approximately 0.5 psi. Because this change is small, this effect will be assumed negligible for pressures of 5 psi and larger, unless the pressure transmitter is measuring a relatively small pressure.

I.8 Dust Effects

Any uncertainties associated with dust are assumed to be compensated for during normal periodic calibration and are assumed to be negligible.

I.9 RTD Self Heating Errors

To determine a typical RTD self heating error, the following computation is provided:

RTD: Rosemount Model 104 RTD
Self Heating Effect: 0.1°C or less
Resistance @ 400°C: 249.61 Ω
Resistance @ 380°C: 242.58Ω
Resistance/°C around 400°C = (249.61 - 242.58)/20
= 0.35 Ω/°C
Self Heating Error = 0.1°C x 0.35 Ω/°C = 0.035 Ω

At 400°C = 0.035/249.61 = 0.014%

The above results show that the RTD self heating error can be assumed to be negligible.

I.10 Digital Signal Processing

An accuracy of 0.1% of full scale or less is often specified. Additionally, linearity and repeatability are often specified as 1 least significant bit (LSB). When this 0.1% uncertainty is compared to the percent uncertainty for the rest of the instrument loop, it is clear that this uncertainty can be neglected.

I.11 Assumptions

As defined in Section 2.2, these assumptions are considered to be defendable and should be used in Section 2.0 for any new or revised calculation, performed under this methodology. All standard assumptions shall be listed first without modification, except for where an assumption points to another assumption, which may not be the same number as listed (see assumptions 2.10 & 2.11 below). The Setpoint Program Coordinator may provide corrections and/or new standard assumptions that may have not been incorporated into the latest revision of CI-01.00. It may be necessary to modify some of the CPS Standard Assumptions listed below during the development or revision of calculations. The preparer and reviewer of a calculation must ensure the assumptions used are valid and applicable to their calculation.

2.1 Published instrument vendor specifications are considered to be 2σ values unless specific information is available to indicate otherwise

2.2 Temperature, humidity, power supply, and ambient pressure errors have been incorporated when provided by the manufacturer. Otherwise, these errors are assumed to be included in the manufacturer's accuracy or repeatability specifications

2.3 Changes in ambient humidity are assumed to have a negligible effect on the uncertainty of the instruments used in these loops.

2.4 Normal radiation induced errors have been incorporated when provided by the manufacturer. Otherwise, these errors are assumed to be small and capable of being adjusted out each time the instrument is calibrated. Therefore, unless specifically provided, normal radiation errors can be assumed to be included within the instrument drift errors.

2.5 If the manufacturers instrument performance data does not specify Span, Calibrated Span, Upper Range Limit, etc. the calculation will assume URL because it will result in the most conservative estimate of instrument uncertainty. In all cases the URL is greater than or equal to the calibrated span (CS) and it is conservative to use the URL in calculating instrument uncertainties. This is because, by definition, URL is the maximum upper calibrated span limit for the device.

2.6 This analysis assumes that the instrument power supply stability (PSS) is within ±5% (±1.2 Vdc) of a nominal 24 Vdc.

2.7 The effects of normal vibration (or a minor seismic event that does not cause an unusual event) on a component are assumed to be calibrated out on a periodic basis. As such, the uncertainty associated with this effect is assumed to be negligible and included within the instrument drift errors. Abnormal vibrations, e.g., levels that produce noticeable effects on equipment, are considered abnormal events that require maintenance or equipment modification.

2.8 Evaluation of M&TE errors is based on the assumption that the test equipment listed in Analysis Section 7.0 is used. Use of test equipment less accurate than that listed will require evaluation of the effect on calculation results.

2.9 It is assumed that the M&TE listed in Section 7.0 is calibrated to the required manufacturer's recommendations and within the manufacturer's required environmental conditions. Temperature related errors are based on the difference between the Calibration Lab temperature and the worst case temperature at which the device is used.

2.10 It is assumed that the reference standards used for calibrating M&TE or Calibration tools shall have uncertainty requirements of not more than ¼ of the tolerance of the equipment being calibrated. A greater uncertainty may be acceptable as limited by "State of the Art". It is generally accepted that the published vendor accuracy of the M&TE or Calibration tool includes the uncertainty of the calibration standard M&TE when the 4:1 accuracy standard is satisfied. Hence, Calibration Standard uncertainty is considered negligible to the overall calibration error term and can be ignored. This assumption is based primarily upon inherent M&TE conservatism built into the calculation. Per assumption [2.11], this calculation considers the combined M&TE vendor or reference accuracy used for calibration satisfies 1:1 accuracy ratio to the instrument under calibration. This ratio bounds the upper accuracy limit on Calibration tool equal to the Vendor's Accuracy (VA) specification for the device under calibration. Use of M&TE more accurate than 1:1 is conservative to this assumption and thereby acceptable without impacting the results of this calculation.

2.11 It is assumed that when M&TE is not specified uniquely in a controlling calibration procedure (e.g., Surveillance Procedure or Preventive Maintenance Procedure), the combined M&TE vendor or reference accuracy used for calibration satisfies a 1:1 accuracy ratio to the instrument under calibration. This accuracy ratio establishes the limit on selected M&TE equal to the Vendor's Accuracy (VA) requirement. Further, M&TE uncertainty assumed per this discussion, is considered a 3σ value regardless of the confidence associated with the related VA term.

2.12 The effects of EMI and RFI are considered negligible for panel mounted meters in administratively controlled EMI/RFI environments, unless a specific uncertainty term is provided by the vendor.

2.13 If the instrument vendor provides no drift information and there is no clear basis for assuming drift is zero, it may be conservatively assumed that the drift over the entire calibration period equals Vendor Accuracy (i.e., VD = VA 2σ).

2.14 Data from comparable but different instruments may be used when vendor specification is not available or is lacking. This comparison should evaluate like applications in like environment with the instrument analyzed consistent for form, fit, and function.

APPENDIX J
DIGITAL SIGNAL PROCESSING UNCERTAINTIES

This Appendix presents a discussion on digital signal processing and the uncertainties involved with respect to determining instrument channel setpoints for a digital system. This Appendix assumes that a digital signal processing system exists that receives an analog signal and provides either a digital or analog output. In many respects, the digital processor is treated as a black box; therefore, the discussion that follows is applicable to many different types of digital processors.

The digital processor is programmed to perform a controlled algorithm. Basic functions performed are addition, subtraction, multiplication and division, as well as data storage. The digital processor is the most likely component to introduce rounding and truncation errors.

In general, an analog signal is received by the digital processor, filtered, digitized, manipulated, converted back into analog form, filtered again and sent out. The analog input signal is first processed by a filter to reduce aliasing noise introduced by the signal frequencies that are high relative to the sampling rate. The filtered signal is sampled at a fixed rate and the amplitude of the signal held long enough to permit conversion to a digital word. The digital words are manipulated by the processor based on the controlled algorithm. The manipulated digital words are converted back to analog form, and the analog output signal is smoothed by a reconstruction filter to remove high-frequency components.

Several factors affect the quality of the representation of analog signals by digitized signals. The sampling rate affects aliasing noise, the sampling pulse width affects analog reconstruction noise, the sampling stability affects jitter noise and the digitizing accuracy affects the quantization noise.

J.1 Sampling Rate Uncertainty

If the sampling rate is higher than twice the analog signal bandwidth, then the sampled signal is a good representation of the analog input signal and contains all the significant information. If the analog signal contains frequencies that are too high with respect to the sampling rate, aliasing uncertainty will be introduced. Anti-aliasing band limiting filters can be used to minimize the aliasing uncertainty or else it should be accounted for in setpoint calculations.

J.2 Signal Reconstruction Uncertainty

Some information is lost when the digitized signal is sampled and held for conversion back to analog form after digital manipulation. This uncertainty is typically linear and about ±½ Least Significant Bit (LSB).

J.3 Jitter Uncertainty

The samples of the input signal are taken at periodic intervals. If the sampling periods are not stable, an uncertainty corresponding to the rate of change of the sampled signal will be introduced. The jitter uncertainty is insignificant if the clock is crystal controlled, which it is in the majority of cases.

J.4 Digitizing Uncertainty

When the input signal is sampled, a digital word is generated that represents the amplitude of the signal at that time. The signal voltage must be divided into a finite number of levels that can be defined by a digital word *n* bits long. This word will describe 2*n* different voltage steps. The signal levels between these steps will go undetected. The digitizing uncertainty (also known as the quantizing uncertainty) can be expressed in terms of the total mean square error voltage between the exact and the quantized samples of the signal. An inherent digitizing uncertainty of ±½ the least significant bit (LSB) typically exists. The higher the numbers of bits in the conversion process the smaller the digitizing uncertainty.

J.5 Miscellaneous Uncertainties

Analog-to-digital converters also introduce offset uncertainty, i.e., the first transition may not occur at exactly ±½ LSB. Gain uncertainty is introduced when the difference between the values at which the first transition and the last transition occurs is not equal. Linearity uncertainty is introduced when the differences between the transition values are not all equal.

As a rule of thumb, use ±½ LSB for relative uncertainty for the analog-to-digital conversion. For digital-to-analog conversion, the maximum linearity uncertainty occurs at full scale when all bits are in saturation. The linearity determines the relative accuracy of the converters. Deviations from linearity, once the converters are calibrated, is absolute uncertainty. As a rule of thumb, use ±½ LSB for absolute uncertainty and ± LSB for linearity uncertainty.

J.6 Truncation and Rounding Uncertainties

The effect of truncation or rounding depends on whether fixed-point or floating-point arithmetic is used and how negative numbers are represented. For the sign-and-magnitude one's compliment and two's compliment methods, the numbers are represented identically. The largest truncation error occurs when all bits discarded are one's.

For negative numbers, the effect of truncation depends on whether sign-and-magnitude, two's compliment or one's compliment representation is used. Rounding is used on the magnitude of the numbers, and uncertainty is independent of the method of negative numbers representation.

For positive numbers and two's compliment negative numbers, the truncation uncertainty is estimated by:

$$-2^{-b} < E_T \leq 0$$

For sign-and-magnitude and one's compliment negative numbers, the truncation uncertainty is estimated by:

$$0 \leq E_T < 2^{-b}$$

where b is the number of bits to the right of the binary point after truncation or rounding.

Estimation for rounding uncertainty is:

$$(-1/2)(2^{-b}) < E_R \leq (1/2)(2^{-b})$$

Where b, is the number of bits to the right of the binary point after truncation or rounding. Truncation and rounding Effects the mantissa in floating point arithmetic. The relative uncertainty is more important than the absolute uncertainty, i.e., floating-point errors are multiplicative.

For floating point arithmetic, the relative uncertainty for rounding is estimated by:

$$-2.2^{-b} < E \leq 0$$

For one's compliment and sign-and-magnitude, truncation uncertainty is estimated by:

$$-2.2^{-b} < E \leq 0, \text{ for } X < 0$$

$$0 \leq E < 2.2^{-b}, \text{ for } X > 0$$

Where X is the sign and magnitude value prior to truncation.

APPENDIX K
PROPAGATION OF UNCERTAINTY THROUGH SIGNAL CONDITIONING MODULES

This Appendix discusses techniques for determining the uncertainty of a module's output when the uncertainty of the input signal and the uncertainty associated with the module are known. Using these techniques, equations are developed to determine the output uncertainties for several common types of functional modules.

For brevity, error propagation equations (See Table K-1) will not be derived for all types of signal-processing modules. Equations for only the most important signal-processing functions will be developed; however, the methods discussed can be applied to functions not specifically addressed here. The equations derived are applicable to all signal conditioners of that type regardless of the manufacturer.

The techniques presented here are not used to calculate the inaccuracies of individual modules; they are used to calculate uncertainty of the output of a module when the module inaccuracy, input signal uncertainty and module transfer function are known.

This section discusses only two classifications of errors or uncertainties: those, which are random and independent and can be combined statistically, and those, which are biases, which must be combined algebraically. The methods discussed can be used for both random and biased uncertainty components.

It is important to note that the method of calibration or testing may directly affect the use of the information presented in this section. If, for example, all modules in the process electronics for a particular instrument channel are tested together, they may be considered one device. The uncertainty associated with the output of that device should be equal to or less than the uncertainty calculated by combining all individual modules.

K.1 Error Propagation Equations Using Partial Derivatives and Perturbation Techniques

There are several valid approaches for the derivation of equations, which express the effect of passing an input signal with an error component through a module that performs a mathematical operation on the signal. The approaches discussed here, which are recommended for use in developing error-propagation equations, are based on the use of partial derivatives or perturbation techniques, i.e., changing the value of a signal by a small amount and evaluating the effect of the change on the output. Either technique is acceptable and the results, in most cases, are similar.

For simplicity, this discussion assumes that input errors consist of either all random or all biased uncertainty components. The more general case of uncertainties with both random and biased components is addressed later in this Appendix.

K.2 Propagation of Input Errors through a Summing Function

The summing function is represented by the equation:

$$C = k_1 A + k_2 B$$

where,

C = Output signal

A, B = Input signals

k_1 and k_2 = Constants representing gain or attenuation of the input signals

The summing function is shown on Figure K-1.

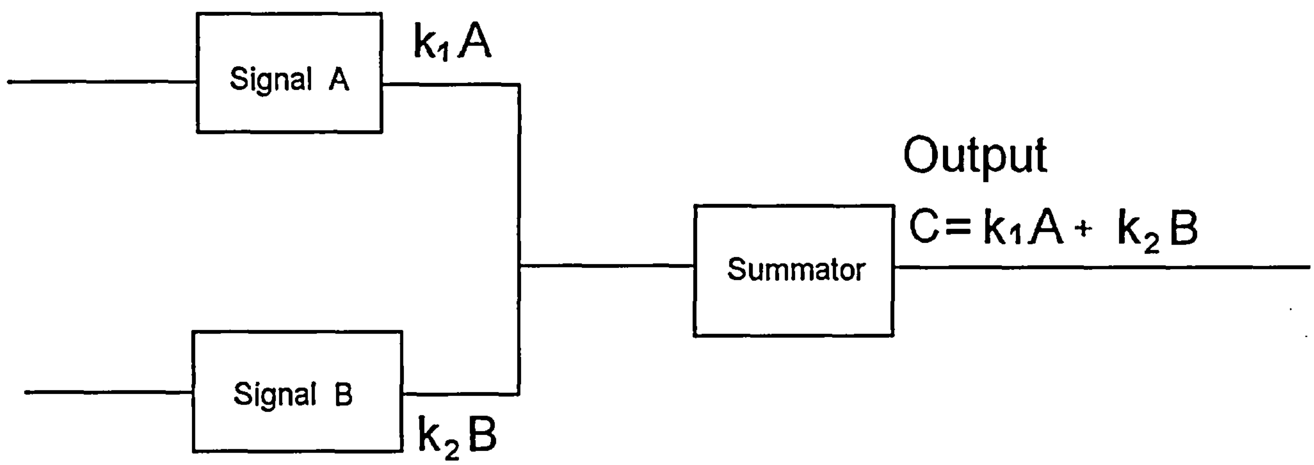


Figure K-1
Summing Function

The input signals are summed as shown above to provide an output signal. If the input signals A and B have errors, a and b, the output signal including propagated error is given by:

$$C + c = k_1(A + a) + k_2(B + b)$$

Or

$$C + c = k_1A + k_1a + k_2B + k_2b$$

where c is the error of the output signal C. Subtracting Equation K.1 from Equation K.2 provides the following estimate of the output signal uncertainty:

$$c = k_1a + k_2b$$

Equation K.3 is appropriate if the errors, a and b, are bias errors. If the input errors are random, they can be combined as the square root of the sum of the squares to predict the output error:

$$c = ((k_1a)^2 + (k_2b)^2)^{1/2}$$

The above expressions for uncertainty can also be derived using partial derivatives. Start by taking the partial derivative of Equation K.1 with respect to each input:

$$\Delta C = (\partial C/\partial A)\Delta A + (\partial C/\partial B)\Delta B$$

$$\partial C/\partial A = k_1(\partial A/\partial A) + k_2(\partial B/\partial A)$$

$$= k_1 + 0 = k_1$$

$$\partial C/\partial B = k_1(\partial A/\partial B) + k_2(\partial B/\partial B)$$

$$= 0 + k_2 = k_2$$

The input signals are independent. The input errors, a and b, represent the change in A and B, or $\Delta A = a$ and $\Delta B = b$. If c represents the change in C, then $\Delta C = c$, yielding:

$$c^2 = (k_1a)^2 + (k_2b)^2$$

or

$$c = ((k_1a)^2 + (k_2b)^2)^{1/2}$$

K.3 Propagation of Input Errors through a Multiplication Function

The summing function is represented by the equation:

$$C = (k_1A)(k_2B)$$

where,

C	=	Output signal
A, B	=	Input signals
k_1 and k_2	=	Constants representing gain or attenuation of the input signals

The multiplication function is shown on Figure K-2.

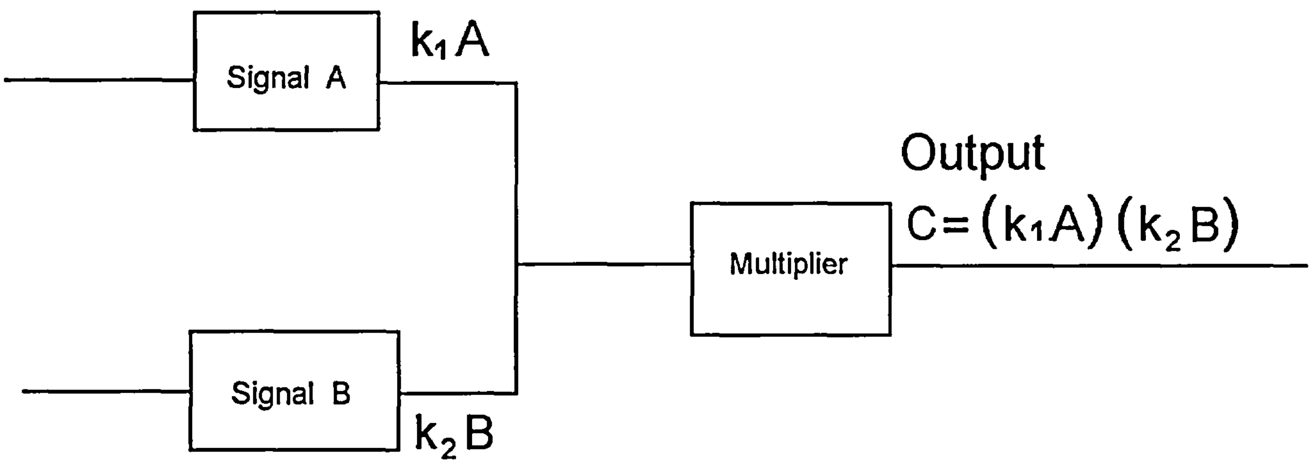


Figure K-2
Multiplication Function

The input signals are multiplied as shown above to provide an output signal. If the input signals *A* and *B* have errors, *a* and *b*, the output signal including propagated error is given by:

$$C + c = k_1(A + a)k_2(B + b)$$

where *c* is the error of the output signal *C*. Equation K.11 can be expanded as shown:

$$C + c = k_1Ak_2B + k_1Ak_2b + k_1ak_2B + k_1ak_2b$$

Subtracting Equation K.12 from Equation K.10 provides the following estimate of the output signal uncertainty:

$$c = k_1Ak_2b + k_1ak_2B + k_1ak_2b$$

or

$$c = k_1k_2(Ab + aB + ab)$$

If *a* and *b* are small with respect to *A* and *B*, the term *ab* is usually neglected to obtain the final result:

$$c = k_1k_2(Ab + aB)$$

If the input signals are random, they can be combined as the square root of the sum of the squares to predict the output error:

$$c = k_1k_2((Ab)^2 + (aB)^2)^{1/2}$$

K.4 Error Propagation Through Other Functions

Below are equations for other functions derived by the same techniques presented in the previous sections. The *algebraic* expressions represent the more conservative approach assuming bias errors and the *SRSS* expressions apply to random errors. Refer to Table 1 in reference 5.3, ISA-RP67.04, Part II, for more information.

Function	Treatment of Error
Division $C = (k1 * A)/(k2 * B)$	
$C = k1/k2\ [(B * a) - (A * b)/B^2]$	Algebraic
$C = k1/k2\ [((B * a)^2 - (A * b)^2)^{1/2}/B^2]$	SRSS
Logarithmic $C = k1 + (k2 * \text{Log } A)$	
$C = [k2 * \text{Log } e/A] * a$	Algebraic
$C = [k2 * \text{Log } e/A] * a$	SRSS

Squaring $C = A^2$

$C = (2 * A * a) + a^2$	Algebraic
$C = 2 * A * a$	SRSS

Square Root Extraction $C = (A)^{1/2}$

$C = (A + a)^{1/2} - (A)^{1/2}$	Algebraic
$C = a/ (2 * (A))^{1/2}$	SRSS

APPENDIX L
GRADED APPROACH TO UNCERTAINTY ANALYSIS

L.1 Introduction

The methodology presented in this engineering standard is intended to establish a minimum 95% probability with a high confidence that a setpoint will actuate when required. The methodology is based, in part, on ISA -S67.04, Reference 5.3.

When a calculation is prepared in accordance with this engineering standard, it will accomplish a rigorous review of the instrument loop layout and design. Each element of uncertainty will be evaluated in detail and the estimated loop uncertainty justified at length. The setpoint will be carefully established with respect to the process analytical limit and channel uncertainty. A calculation prepared with this engineering standard will be comprehensive and can typically take an engineer at least two weeks to prepare. This level of effort is justified for those calculations involving reactor safety and integrity.

The importance of the various types of safety-related setpoints differ, and as such it may be appropriate to apply different setpoint determinations requirements. As described in Reference 5.3, for automatic setpoints that has a significant importance to safety. For example, those required by the plant safety analyses and directly related to Reactor Protection System, Emergency Core-Cooling Systems, Containment Isolation, and Containment Heat Removal, a stringent setpoint methodology should consider all sources of instrument error. However, for setpoints that may not have the same level of stringent requirements, for example, those that are not credited in the safety analyses or that do not have limiting values, the setpoint determination methodology could be less rigorous. The level of detail should be commensurate with the importance of the application.

Multiple setpoint methodologies for engineering calculations have been attributed to programmatic setpoint errors at other power stations. These stations have incorporated corrective actions that implement setpoint and loop uncertainty analysis that are balanced with the importance or significance of the related plant system safety function. This approach is acceptable and is consistent with a draft recommended practice by Instrument Society of America (ISA) standards, (ISA dTR 67.04.09, Graded Approaches to Setpoint Determination, Draft Technical Report, 1994 and the subsequent version Draft 4, May, 2000). This Appendix provides guidance regarding how to satisfy the needs for proper setpoint control while allowing for simpler approaches for less critical applications.

The CPS setpoint methodology will establish the basis of a graded setpoint program by grouping the instrument loops according to their safety significance. The graded approach to setpoint determination provides the maximum available tolerance to optimize the safety and reliability of the plant.

Graded approaches are based on fact that all the rigor and conservatism established in RP67.04-1994, Part II may not be warranted for all setpoints in a nuclear power plant. Per RP67.04-1994, a nuclear plant licensee may establish a multilevel classification scheme by documenting the rationale used to establish the classification. Implementation of a graded approach to setpoints requires the users to identify how critically important each setpoint is. For example, setpoints for RPS and ESFAS are to be maintained with a high degree of conservatism and a high level of confidence. Setpoints for Reg. Guide 1.97, Type C variables for post accident monitoring do not require the same level of confidence. Therefore, a graded approach, with classification for setpoints, will help proper maintenance of safety grade nuclear instrumentation without compromising the safe and reliable operation of the plant.

L.2 GRADED CLASSIFICATIONS

CPS Setpoint Control distinguishes between applications by providing the following classifications of setpoint categories in terms of safety significance. For example, Setpoint Category 1 instrument loops are deemed safety significant and calculations for this class of instruments would require full rigor and conservatism established in RP67.04-1994, Part II for safety related setpoints. The Setpoint Category Tables are presented in order of descending safety significance and therefore, calculation rigor.

CPS Graded Approach Recommendations	
SETPOINT CATEGORY	*FUNCTIONAL DESCRIPTION*
1	RPS (Reactor Protection System). ESF (Engineered Safety Features). ECCS (Emergency Core Cooling System). PCIS (Primary Containment Isolation System). SCIS (Secondary Containment Isolation System). Emergency Reactor Shutdown Containment Isolation Reactor Core Cooling Containment and Reactor Heat Removal Prevent/mitigate a significant release of radioactivity.
2	Ensure compliance with Tech Spec but are not Level 1 setpoints. Provide setpoints/limits for Reg. Guide 1.97 Type A variables.
3	Provide setpoints/limits for Reg. Guide 1.97, Type B, C, D variables. Provide setpoints/limits for other regulatory requirements or operational commitments. Provide setpoints/limits that are associated with personnel safety or equipment protection.
4	Provide setpoints/limits not identified with levels 1,2 & 3 above. Require documentation of engineering judgement, industry or station experience or other methods have been used to set or identify an operating limit. Provide setpoints/limits for station EOP requirements. GE BWR methodology for EOP's does not require or desire treatment for uncertainties.

The following guidelines should be followed with regard to the level of rigor required for a setpoint determination.

Cat. 1 and 2: A Calculation in accordance with NSED Procedure E.1 is required. Setpoints must be prepared in accordance with this standard and must account for all known sources of uncertainty. The expected results of these calculations are that they establish a well-documented basis for the 95% probability that the setpoint will actuate as desired

Cat 3: A Calculation in accordance with NSED Procedure E.1 is required. Setpoints need not meet all the requirements of this engineering standard, including the required level of detail or depth of analysis, unless they involve nuclear safety-related setpoints protecting a safety limit, initial condition or support a primary success path in any design basis accident or transient analysis functions. Cat. 3 Setpoints are normally associated with system control functions. Documented engineering judgement can be applied to those uncertainties that are not readily known or available.

Cat 4: Documented basis for the setpoint or limit is required but may be captured in ECN, Engineering Evaluation, or a Calculation. Engineering judgement can be applied to those uncertainties that are not readily known or available. Industry or station experience or other methods can be used to set the limit. Need not meet the requirements accounting for all known sources of uncertainty, including the required level of detail or depth of analysis.

L.3 Correction for Single-Sided Setpoints

The methodology presented in this engineering standard is intended to establish a 95% probability with a high confidence that a setpoint will actuate when required. Without consideration of bias effects, the probability is two-sided and symmetric about the mean as shown in Figure L-1.

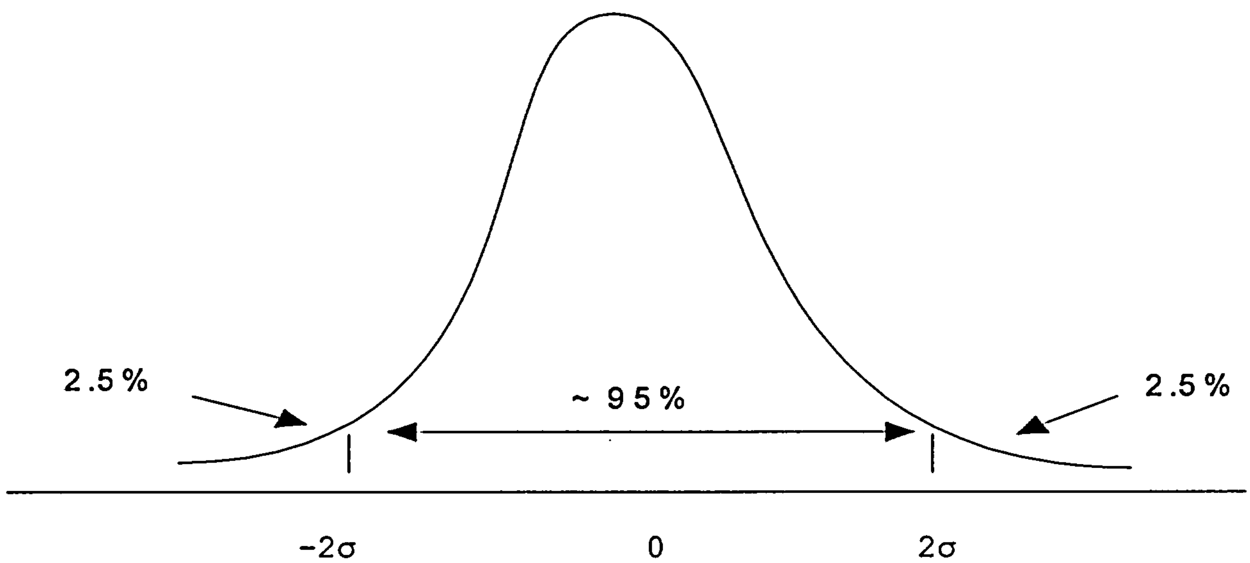


Figure L-1
Typical Two-Sided Setpoint at 95% Level

Figure L-1 shows the configuration in which there may be high and low setpoints with a single process. In some cases, there will only be a single setpoint associated with a particular sensor. For example, a pressure switch may actuate a high setpoint when steam dome pressure is too high. In this case a 95% probability is desired for the high pressure setpoint only as shown in Figure L-2.

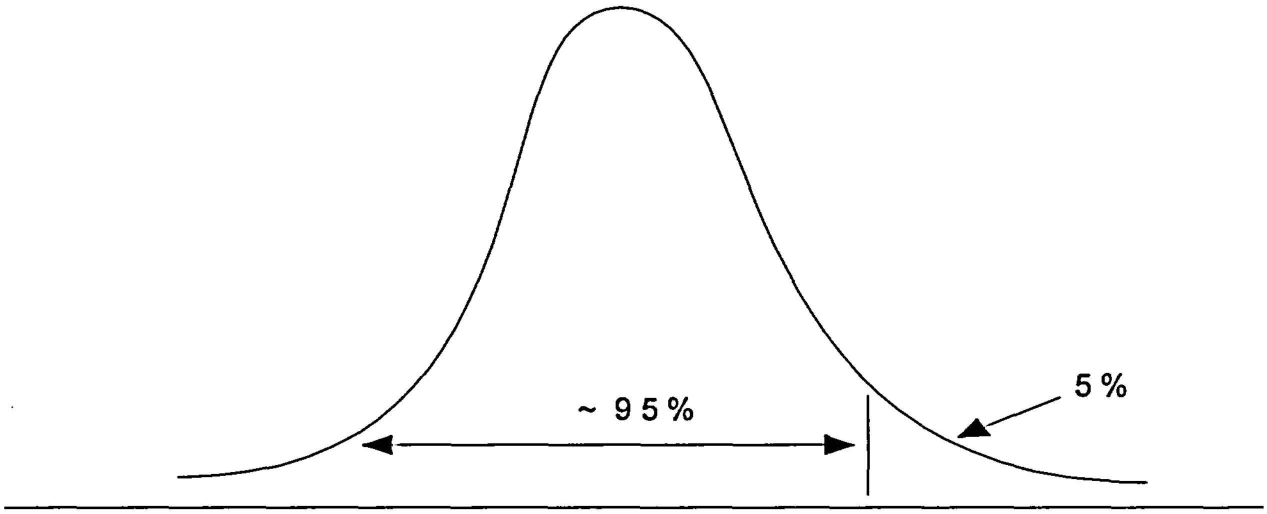


Figure L-2
Typical One-Sided Setpoint at 95% Level

A two-sided normally distributed probability at the 95% level will have 95% of the uncertainties falling within ± 1.96σ (see example L-1) with 2.5% below -1.96σ and 2.5% above 1.96σ. However, for one-sided normally distributed uncertainties, 95% of the population will fall below + 1.645σ (see Table M-2). If the concern is that a single value of the process parameter is not exceeded and the single value is approached only from one direction, the appropriate limit to use for the 95% probability is + 1.645σ (or - 1.645σ depending on the direction the setpoint is approached). Provided that the individual component uncertainties were approached at the 95% level, or greater, the final calculated uncertainty result can be corrected for a single side of interest by the following expression:

$$1.645/1.96 = 0.839$$

Example L-1

Suppose the calculated uncertainty for the High Steam Dome Pressure channel is ± 2% of span and this represents 95% probability for the expected uncertainty. Suppose the uncertainty applies only to the high pressure trip setpoint. In this case we are only concerned with what happens on the high end of span (near the setpoint). The setpoint can be established for a single side of interest by multiplying the Equation L.1 correction by the calculated channel uncertainty, or:
(0.839) (2%) = 1.68%

Hence, rather than require that the setpoint allowance include a 2% uncertainty value, only a 1.68% allowance needs to be considered. This correction can provide additional margin for normal system operations.

APPENDIX M

NOT USED

APPENDIX N
STATISTICAL ANALYSIS OF SETPOINT INTERACTION

Frequently, there is more than one setpoint associated with a process control system. For example, a tank may have high and low level setpoints that are designed to prevent overfilling or completely emptying the tank. Each setpoint has a lower and upper actuation uncertainty and, in some cases, two or more setpoints can be very close to one another (or overlap) when all uncertainties are included. A calculation that involves multiple setpoints should also confirm that the setpoints are adequate with respect to one another.

Setpoints that are prepared in accordance with this engineering standard represent a 95% probability with a high confidence (approximately 95%) that the setpoint will actuate within the defined uncertainty limit. The uncertainty variation about the setpoint, is assumed to be approximately normally distributed. If two setpoints are close together, it could appear that they have an overlap region as shown in Figure N-1.

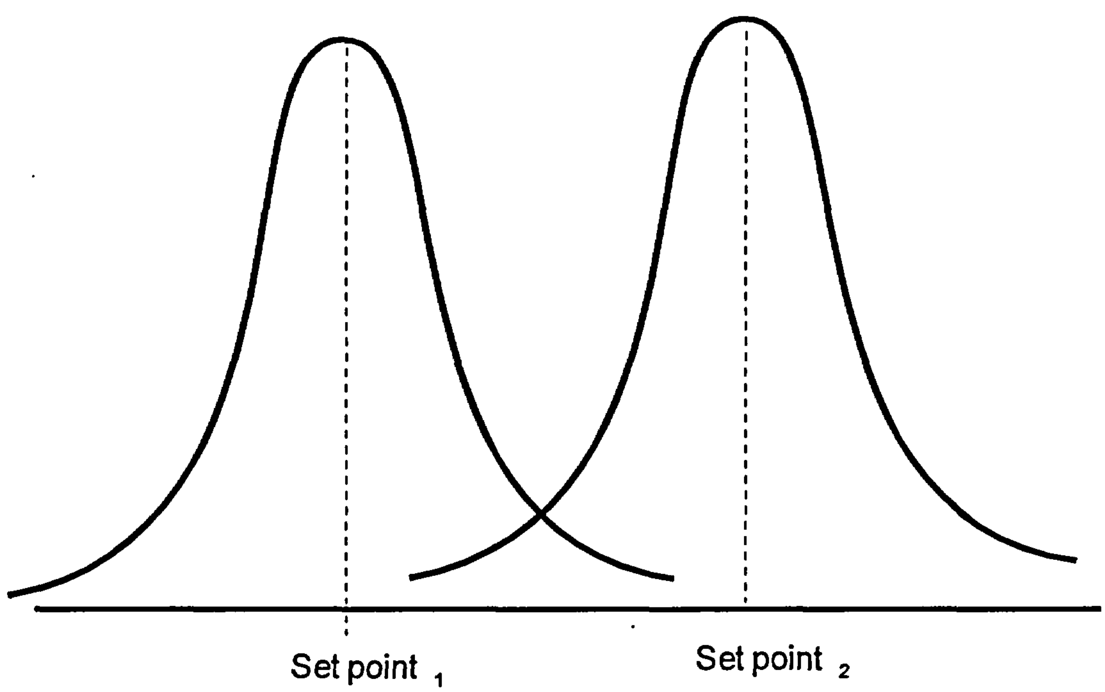


Figure N-1
Distribution of Uncertainty about Two Setpoints

As shown in Figure N-1, setpoint overlap can occur when Setpoint 1 drifts high at the same time that Setpoint 2 drifts low. The probability of this occurrence can be estimated based on the behavior of the normal distribution. For a normal distribution, 68.3% of the total probability is contained within $\pm 1.0\sigma$ of the mean, with 15.85% in either tail. Because the setpoints have been statistically determined, it is reasonable to evaluate the possibility of setpoint overlap statistically also. It is highly unlikely for one setpoint to drift by the 1.0σ value in the high direction when the other setpoint simultaneously drifts low by the 1.0σ value. The probability, P_T, of this occurring is:

$$P_T = (P_A)(P_B) = (0.1585)(0.1585) = 0.0251 = 2.51\%$$

The above probability readily shows the low likelihood of setpoint overlap even at the 1.0σ level. The probability becomes virtually insignificant at the 1.50σ level. In this case, 86.64% of the total probability is contained with $\pm 1.5\sigma$ level, with 6.68% in either tail. The probability of one setpoint to drift high by 1.5σ when the other setpoint drifts low by 1.5σ is:

$$P_T = (P_A)(P_B) = (0.0668)(0.0668) = 0.0045 = 0.45\%$$

The above approach can be used to demonstrate the low likelihood of setpoint overlap. If setpoints appear to have a higher-than-desired probability of overlap, the electrical circuits should be reviewed to determine the possible consequences of the overlap.

APPENDIX O
INSTRUMENT LOOP SCALING

O.1 Introduction

CPS Calibration Procedures and data sheets include head corrections and scaling. CPS procedure 8801.05, Reference 5.17, controls the method of instrument corrections. For calculations developed by this methodology, the scaling will be evaluated and documented in Attachment 1 of calculation. Scaling instrument loops and development of calibration correction values should be done in a consistent and correct manner. This vital instrument engineering function must be deliberately integrated into maintenance and engineering activities. This Appendix provides the guidance relative to the analysis of an instrument loop and preparation of scaling calculations.

A process instrumentation loop (circuit) typically consists of three distinct sections:

1. Sensing: The parameter to be measured is sensed directly by some mechanical device. Examples include a flow orifice for flow, a differential pressure cell for level, a bourdon tube for pressure, and a thermocouple for temperature measurement. The sensing element may include a transmitter that converts the process signal into an electrical signal for ease of transmission.

2. Signal Processing: The electrical signal sent by the sensor/transmitter may be amplified, converted, isolated, or otherwise modified for the end-use devices.

3. Display or Actuation: The process signal is used somehow, either as a display, an actuation setpoint above or below some threshold, or as part of some final actuation device logic.

Figure O-1 shows a typical instrument application. As shown, a level transmitter monitors a tank's water level. A power supply provides a constant voltage to the transmitter and the transmitter outputs a current proportional to the tank level. The indicator displays a tank level corresponding to the electrical current. If the electrical current is above (below) a predetermined level, indicative of a high (low) tank level, the trip unit actuates. The current is provided to the controller for some control action.

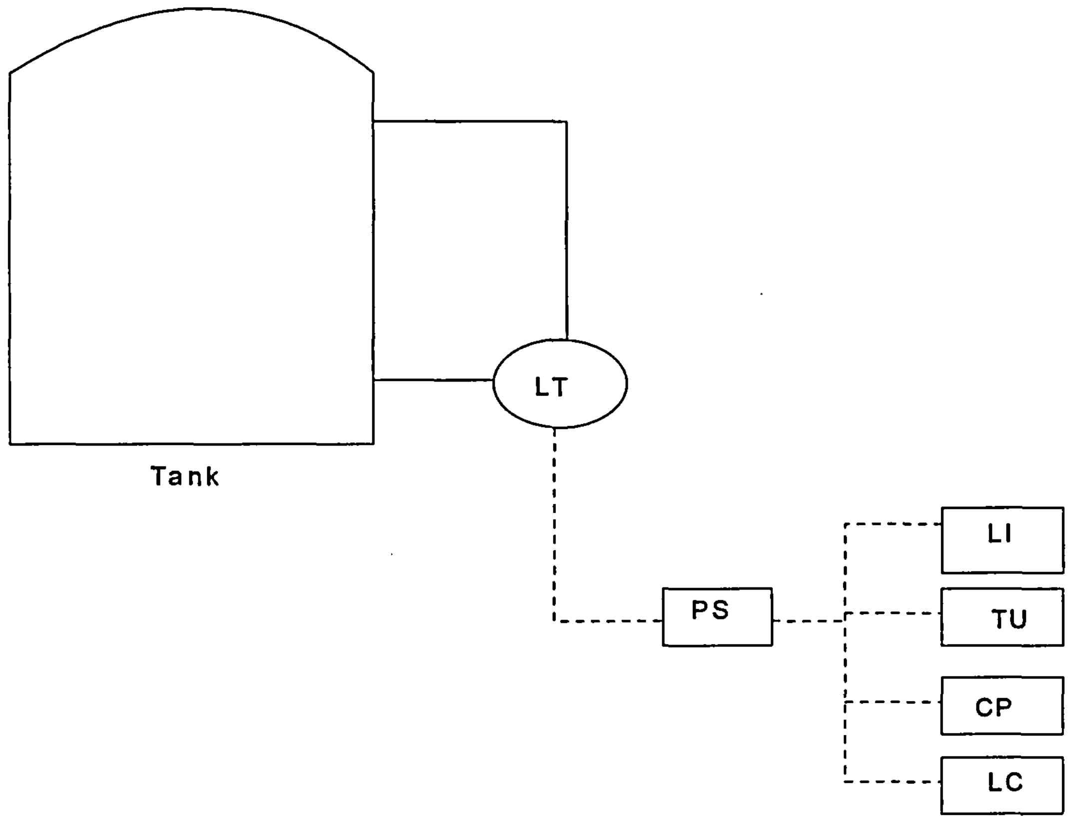


Figure O-1
Simple Instrument Loop for Level Measurement

The above example of a tank level measurement illustrates the various elements of an instrument loop. Regardless of the application, an instrument loop measures some parameter - temperature, pressure, flow, level, etc. - and generates signals to monitor or aid in the control of the process. The instrument loop may be as simple as a single indicator for monitoring a process, or can consist of several sensor outputs combined to create a control scheme.

An instrument and control engineer, will usually design an instrument circuit such that the transmitter (or other instrument) output is linearly proportional to the measured process. Consider the tank level instrument loop just described. As tank level varies from 0% to 100%, we want a transmitter electrical output that can be scaled in direct proportion to the actual tank level. A typical transmitter output signal is shown in Figure O-2. The output signal varies linearly with the measured process parameter with a low value of 4 milliamps (mA) to a high limit of 20 mA. Under ideal conditions, a zero tank level would result in a 4 mA transmitter output and a 100% level would correspond to a 20 mA output (or 10 to 50 mA, respectively).

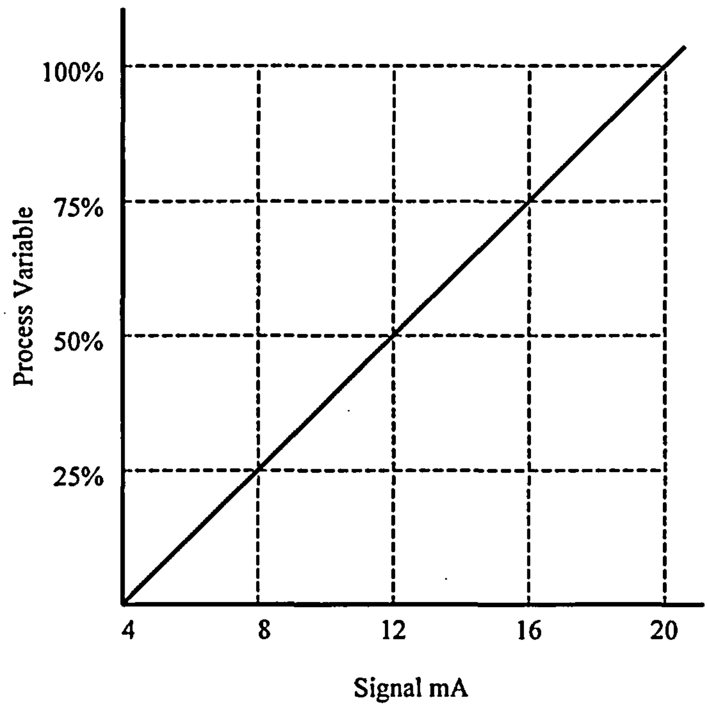


Figure O-2
Desired Relationship between Measured Process and Sensor Transmitter Output

Example O-1

Referring to Figure O-2, what is the expected transmitter output signal if tank level is 50%? The tank level varies from 0% to 100% for a transmitter output span of 16 mA (4 to 20 mA). The transmitter output signal should be:

$$Transmitter\ Output = 4\ mA + (0.50)(16\ mA) = 12\ mA$$

As expected, the transmitter output is at the half-way point of its total span. The above equation will be developed in more detail in the following section.

Example O-2

Referring again to Figure O-2, what is the expected tank level if the transmitter signal is 18 mA?

$$Tank\ Level = \frac{18\ mA - 4\ mA}{16\ mA\ span} 100\% = 87.5\%$$

O.2 Scaling Terminology

Instrument scaling, applied to a process instrumentation, is a method of establishing a relationship between a process sensor input and the signal conditioning devices that transmit/condition the sensor's output signal. The goal is to provide an accurate representation of the measured parameter throughout the measured span. In its simplest perspective, scaling converts process measurements (temperature, pressure, differential pressure, etc.) from engineering units (°F, psig, etc.) into analog electrical units (VDC, mADC, etc.).

A typical instrument loop consists of a sensor, power supply, and end-use instruments as shown in Figure O-3. Whereas Figure O-1 showed the functionality of the circuit, Figure O-3 shows the instrument loop as an actual circuit. All components are connected in a series arrangement. The power supply provides the necessary voltage for the pressure transmitter to function. In response to the measured process, the pressure transmitter provides a 4 to 20 mA output current.

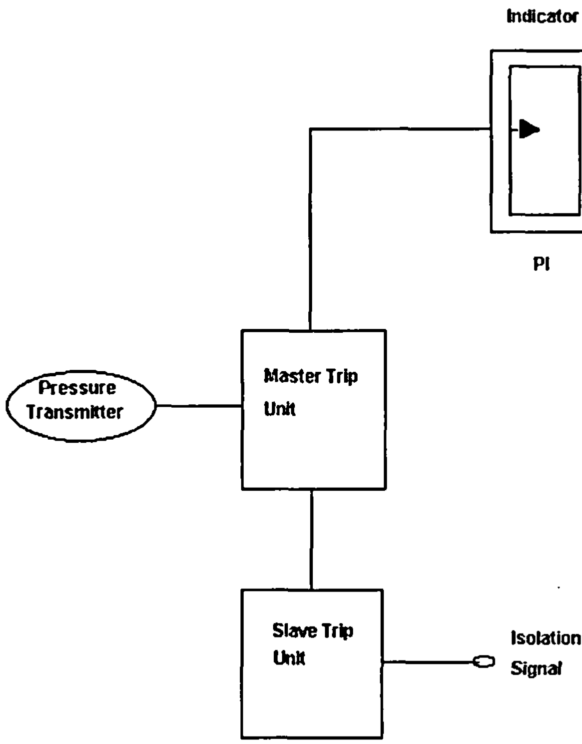


Figure O-3
Simplified Instrument Loop Schematic

Suppose the pressure transmitter shown in Figure O-3 monitors tank pressure and is designed to operate over a process range of 1700 to 2500. The transmitter has an elevated zero or *pedestal* of 1700 psig. The transmitter has an analog output signal of 4 to 20 mADC.

Other components in Figure O-3 include a pressure indicator and trip unit, each sensing the same 4 to 20 mA signal from the transmitter. The loop signal is developed from the transmitter input via the voltage developed across a 250 ohm input resistor; this arrangement is typical. As the current through the input resistors varies from 4 to 20 mA, the voltage developed across the resistor is 1 V to 5 V, maintaining a linear relationship between the measured process and the resultant output signal. The only purpose of the resistors is to convert the current signal to a voltage signal.

As configured in this example, the 1700 to 2500 psig process signal has a span of 800 psig which corresponds to the 1 to 5 VDC (or 4 VDC span) across the input resistor. The *scale factor* is defined as the ratio of the analog electrical signal span to the process span, or 4 VDC/800 psig = 0.005 VDC/psig. Accounting for the 1700 psig input pedestal and the 1 VDC output pedestal, the *scaling equation* that relates the input to the output is given by:

$$E_p = [(0.005V/psig)(P - 1700\ psig)] + 1V$$

where,

E_p =Voltage corresponding to the input pressure

P =Input pressure value between 1700 and 2500 psig

The above scaling equation provides an exact relationship between the process variable and the voltage developed across an input resistor for the stated configuration.

O.3 Module Equations

Module equations are commonly referred to as *transfer functions*. They define the relationship between a module's input and output signals and are just scaling equations that describe this input/output relationship. Transfer functions are typically classified as either static or dynamic.

Static transfer functions are time-independent and can be either linear or nonlinear. Modules that typically have static transfer functions include:

- Input resistors (I/V modules)
- Isolators
- Summators

The module equation of a static device will sometimes include a gain adjustment also. For example, a simple summator may have the following module equation:

$$E_{out} = G(k_1E_1 + k_2E_2 + k_BE_B) + 1\,V$$

where,

k_1, k_2	=	Input signal gains
k_B	=	Bias input gain
E_1, E_2	=	Input voltages
E_B	=	Bias voltage
G	=	Output gain
E_{out}	=	Output voltage

O.4 Scaling calculation

After the process algorithm, module equations, and required ranges have been determined, the scaling calculation can be completed. The scaling factor is used with the scaling equation to derive the voltage equation form the process equation. An overall system equation can be developed, by combining module equations, as applicable. For example, assume the use of two modules in an instrument loop.

The first module has two inputs, $E_1$and E_2, that are summed together with a module gain of G_1. The simplified equation for this module is given by:

$$E_A = G_1\,(E_1 + E_2)$$

Now, assume that the output, E_A, is summed with another input, E_3, which has a module gain of G_2. The resulting module equation is:

$$E_{out} = G_2(E_3 + E_A)$$

or, substituting in for E_A,

$$E_{out} = G_2\,[E_3 + G_1(E_1 + E_2)]$$

The expression for each voltage above can be complex also. But, the result is an overall scaling equation that defines the system operation. Once a scaling equation has been developed and the scaling calculation performed, the equation should be checked by inputting typical process values and determining if reasonable analog values are calculated. Each module should be tested separately to ensure its accuracy before combining it with other modules. As part of the test process, include minimum and maximum process values to ensure that the limits work as expected.

APPENDIX P
RADIATION MONITORING SYSTEMS

Radiation monitoring systems have unique features that complicate an uncertainty analysis. The system design, detector calibration, and display method all can reduce the system accuracy. Whenever evaluating a radiation monitoring system, review References 5.9 and 5.33, for additional information and:

Radiation monitoring system operation and maintenance manual

Radiation monitoring system calibration procedures

The following should be considered as part of any uncertainty analysis:

Detector Measurement Uncertainty

A radiation monitoring system detector's response varies with the following parameters:

- Energy level of the incident particles.
- Count rate of the detected particles.
- Type of particle being counted (depending on application, the particles may be gamma photons, neutrons, or beta particles).

Detector Count Rate Measurement Uncertainty

The detector's measurement uncertainty can be affected by the following:

- On the low end of scale, the uncertainty in count rate response is affected by signal to noise ratio effects.

- On the high end of scale, the uncertainty in count rate is affected by pulse pile-up in which discrete pulses are missed.

- Through the detection range, the alignment of the source to the detector geometry can impact the measurement uncertainty. For example, the containment high range radiation monitors need an unobstructed view of the containment dome. Blockages such as concrete walls can degrade the measurement capability of the detector.

Detector Energy Response Uncertainty

The detector energy response uncertainty can be affected by the following:

- On the low end, the discriminator setting and the energy sensitivity of the detector.
- On the high end, the point at which a rise in incident particle energy does not result in a change in pulse height output.
- Throughout the detection range, by a degrading failure of the system.

For most permanently installed radiation detectors, the detector is designed to respond to incident particles over a certain range of energies. The output of count rate is then correlated to a mR/hr

or μC/cc indication by the application of a conversion factor, without regard to differing incident particle energies.

When the plant is shutdown, the detector indicated count rate is generally derived from lower energy particles. When the plant is operating, the particle energy tends to be higher. In this case, a typical detector will display a higher count rate, even if the number of incident particles per unit time remains the same. As the incident particle energy level changes, the probability of detection changes, for a given count rate. During initial calibration, this difference is accounted for by exposing the detector sample streams of different radioisotopes and measuring the detector's response. After in-plant installation, the calibration is checked, by exposing the detector to fixed external sources of different radioisotopes.

The detector coefficient represents the sensitivity of the detector, which is typically specified in Amp/(R/hr). The sensitivity is provided by the vendor for each detector and can be different if the detectors are ever replaced.

Post Accident Radiation Measurement and Indication accuracy for containment area monitoring, is specified in Regulatory Guide 1.97, Table 2, Footnote 7. "Detectors should respond to gamma radiation photons, within any energy range from 60 keV to 3 MeV with an energy response accuracy of "20% at any specific photon energy from 0.1 MeV to 3 MeV". Overall system accuracy should be within a factor of 2 over the entire range." Revision 3 of R.G. 1.97 revised the above footnote to omit the "20% accuracy requirement for the detector. Now the containment area radiation monitors "should respond to gamma radiation photons within any energy range from 60 keV to 3 MeV with a dose rate response accuracy within a factor of 2 over the entire range". Considering the prior revision, it is clear the intent of the "factor of 2" current requirement applies to the "overall system accuracy" and not the detector accuracy alone. This interpretation is consistent with the requirements placed on other radiation monitoring devices in the same table.

The uncertainty terms identified in radiation monitoring technologies are either percent of reading or in Equivalent Linear Full Scale (ELFS), which is the same as percent of span provided the span and full scale are equivalent. The method for converting percent of reading uncertainties to percent ELFS using the "error factor" concept is based on the model from an example radiation trip calculation in Reference 5.3, ISA S 67.04 Part II. Conversion of this error to an ELFS error permits combining the percent of reading error with other string errors.

Consider the following example; A containment area monitor indicates R/Hr over an eight (8) decade range, uncertainty is calculated for the detector at 12.2%.

This detector accuracy error can be expressed as error factors of: (1.0 + 0.122)/1.0 = 1.122 and (1.0 - 0.122)/1.0 = 0.878. ELFS is calculated for both factors as:

ERROR FACTOR = 10^{DX}, where D = 8, the number of decades on the meter and X = ELFS as a decimal value.

$$X(+) = (\log(1.122)/8) * 100\% = +0.62\%\ \text{ELFS}$$
$$X(-) = (\log(0.878)/8) * 100\% = -\ 0.71\%\ \text{ELFS}$$

The error will be assumed to be symmetrical and set at the larger of two values, thus $E_{DET(ref)}$ = "0.71 % ELFS.

Whenever evaluating the uncertainty of a radiation monitoring system, the periodic calibration methods are particularly important to consider. EPRI TR-102644, Reference 5.33, provides additional guidance. Also, the applicable system engineer should be contacted for additional expertise.

APPENDIX Q

Rosemount Nuclear Instruments

Rosemount Nuclear Instruments. Inc.
12001 Technology Drive
Eden Prairie, MN 55344 USA
Tel 1 (612) 828-8252
Fax 1 (612) 828-8280

4 April 2000

Ref: Grand Gulf Nuclear Station message on INPO plant reports, subject Rosemount Instrument Setpoint Methodology, dated March 9, 2000

Dear Customer:

This letter is intended to eliminate any confusion that may have arisen as a result of the reference message from Grand Gulf. The message was concerned with statistical variation associated with published performance variables and how the variation relates to the published specifications in Rosemount Nuclear Instruments, Inc.(RNII) pressure transmitter models 1152, 1153 Series B, 1153 Series D, 1154 and 1154 Series H. According to our understanding, the performance variables of primary concern are those discussed in GE Instrument Setpoint Methodology document NEDC 31336, namely

1. Reference Accuracy
2. Ambient Temperature Effect
3. Overpressure Effect
4. Static Pressure Effects
5. Power Supply Effect

It is RNII's understanding that GE and the NRC have accepted the methodology of using transmitter testing to insure specifications are met as a basis for confirming specifications are $\pm 3\sigma$, The conclusions we draw regarding specifications being $\pm 3\sigma$ are based on manufacturing testing and screening, final assembly acceptance testing, periodic (e.g., every 3 months) audit testing of transmitter samples and limited statistical analysis. Please note that all performance specifications are based on zero-based ranges under reference conditions. Finally, we wish to make clear that no inferences are made with respect to confidence levels associated with any specification.

1. Reference Accuracy.

All (100%) RNII transmitters, including models 1152, 1153 Series B, 1153 Series D, 1154 and 1154 Series H, are tested to verify accuracy to ±0.25% of span at 0%, 20%, 40%, 60%, 80% and 100% of span. Therefore, the reference accuracy published in our specifications is considered $\pm 3\sigma$.

2. Ambient Temperature Effect

All (100%) amplifier boards are tested for compliance with their temperature effect specifications prior to final assembly. All sensor modules, with the exception of model 1154, are temperature compensated to assure compliance with their temperature effect specifications. All (100%) model 1154, model 1154 Series H and model 1153 gage and absolute pressure transmitters are tested following final assembly to verify compliance with specification. Additionally, a review of audit test data performed on final assemblies of model 1152 and model 1 153 transmitters not tested following final assembly indicate

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conformance to specification. Therefore, the ambient temperature effect published in our specifications is considered $\pm 3\sigma$

3. Overpressure Effect

Testing of this variable is done at the module stage. All (100%) range 3 through 8 sensor modules are tested for compliance to specifications. We do not test range 9 or 10 modules for overpressure for safety reasons. However, design similarity permits us to conclude that statements made for ranges 3 through 8 would also apply to ranges 9 and 10. Therefore, the overpressure effect published in our specifications is considered $\pm3\sigma$.

4. Static Pressure Effects

All (100%) differential pressure sensor modules are tested for compliance with static pressure zero errors. Additionally, Models 1153 and 1154 Ranges 3, 6,7 and 8 are 100% tested after final assembly for added assurance of specification compliance. Audit testing performed on ranges 4 and 5 have shown compliance to the specification. Therefore, static pressure effects published in our specifications are considered $\pm3\sigma$.

5. Power Supply Effect

Testing for conformance to this specification is performed on all transmitters undergoing sample (audit) testing. This variable has historically exhibited extremely small performance errors and small standard deviation (essentially a mean error of zero with a standard deviation typically less than 10% of the specification). All transmitters tested were found in compliance with the specification. Therefore, power supply effect published in our specifications is considered $\pm3\sigma$.

Should you have any further questions, please contact Jerry Edwards at (612) 828-3951.

Sincerely,

Jerry L. Edwards Manager, Sales, Marketing and Contracts Rosemount Nuclear Instruments, Inc.

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APPENDIX R
RECORD OF COORDINATION FOR COMPUTER POINT ACCURACY

Computer Point Accuracy (using single point data)

Hardware and software, considering that digital displays involve compression limits affect the accuracy of computer inputs. Taking into consideration the following errors, an accuracy of 0.25% of full range will be utilized. (Reference 5.28 and 5.29)

Gain Error	=	± 0.025% Full Range
Repeatability Error	=	± 0.025% Full Range
*Others	=	± 0.2% Full Range
Total	=	± 0.25% Full Range

* In accuracy of filter input card, Reference Junction Compensation, and any other loss due to conversions and scan frequency.