CAROLINA POWER AND LIGHT COMPANY
NUCLEAR ENGINEERING DEPARTMENT

INSTRUMENT SETPOINTS

DESIGN GUIDE NUMBER DG-VIII.50

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Reasons for Revision

Rev.	Description
1	Design Guide Rewritten.
2	Revised Section 6.3 and added Figure 3. Revised Page numbers for Appendix A. Added Reason for Revision Page and revised List of Effective Pages & Table of Contents.
3	Complete Rewrite of Design Guide.

I. INTRODUCTION

A. Purpose

The purpose of this document is to establish a consistent methodology for the preparation of instrument uncertainty and setpoint calculations for each of the three CP&L Nuclear Plants. This document is intended to provide CP&L's Engineering, and other interested organizations, with a description of the detailed rules and plant specific criteria involved in instrument loop uncertainty analysis and setpoint determination.

By standardizing the process of evaluating setpoint revisions, and their associated test and calibration procedure revisions, CP&L expects to enhance the effectiveness of each plant's overall design control program. Better design control will result in fewer Licensee Event Reports (LERs), reduced potential for spurious alarms and trips, and higher confidence in the capability of equipment and systems to perform in accordance within their design parameters.

B. Scope

This document should be used for the determination of uncertainty for any instrument loop at the Brunswick, H. B. Robinson, or Shearon Harris Nuclear Plants. Such instrument loops may be either safety related or nonsafety-related and encompass loops used for protection, control or indication functions. Since this document is intended to address all types of loops, portions of the methodology may not be necessarily applicable to every individual loop. For example, instruments that are not safety related or exposed to a harsh environment, do not need to incorporate accident environment uncertainties into their overall loop uncertainty. Conversely, instruments used for personnel safety, may include additional margins or conservatisms not needed for other applications. Each user of this document must evaluate individual uncertainties for their relevance to the user's application.

Although this document is intended to be utilized for process instrumentation, it may be applicable to other equipment as well. Specifically excluded from the scope of this methodology, however, are:

- Safety or Relief Valves
- Self Contained Regulating Valves
- Breaker Trip Settings
- Protective Relays (but not time delay relays)
- Valve Torque or Limit Switches

It is expected that this methodology will be applied to any new instrument designs, as well as revisions to existing designs. However, it is not proposed that this methodology supersede any calculations performed previously by CP&L or its vendors. Such calculations and analyses were performed in accordance with the guidelines and assumptions in effect at the time of their development. If the methodology described in this document should deviate from any previous methodology, the deviation should be identified to the appropriate NED I&C Supervisor for resolution.

C. Applicability

This document applies to NED personnel, NED managed contract personnel, and any plant personnel who require an understanding and/or use of the concepts involved in instrument loop uncertainty analysis and setpoint determination.

Deviations from this guide shall be approved by the Principal Engineer before the document in question is distributed. Documentation of this approval is at the discretion of the Principal Engineer.

II. GENERAL

A. Background

The need for a documented, consistent basis for calculating instrument uncertainties and setpoints is an emerging industry issue. Both INPO and the NRC have conducted audits/inspections of various nuclear facilities to ensure the adequacy of instrument setpoints and designs to be able to achieve their functions. Individual plant commitments relative to instrument uncertainties and setpoints are discussed in documents such as the FSAR, Technical Specifications, and DBDs; however, see attachments to this DG for site specific committments made to utilize a specific methodology. It is considered prudent at this time to establish a consistent methodology for determining and documenting instrument uncertainties and setpoints. This document sets forth the methodology to ensure CP&L's design practices remain compatible with the industry practices in this area.

B. References

1. Regulatory Guide 1.105, "Instrument Setpoints for Safety-Related Systems".

2. ANSI/ISA Standard S67.04-1988, "Setpoints for Nuclear Safety-Related Instrumentation", February 4, 1988.

3. ISA-dRP67.04, Part II, Draft Recommended Practice, "Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation", Draft 10, August, 1992.

4. INPO 84-026, "Setpoint Change Control Program", Revision 1, Good Practice TS-405, June, 1986.

5. Title 10, Part 50 of the Code of Federal Regulations (10CFR50), as of January 1, 1990.

6. IE Information Notice 82-11, "Potential Inaccuracies in Wide Range Pressure Instruments Used in Westinghouse Designed Plants", April 9, 1982.

7. IE Information Notice 84-54, "Deficiencies in Design Base Documentation and Calculations Supporting Nuclear Power Plant Design", July 5, 1984.

8. NRC Information Notice 89-68, "Evaluation of Instrument Setpoints During Modifications", September 25, 1989.

9. NRC Information Notice 91-29, "Deficiencies Identified During Electrical Distribution System Functional Inspections", April 15, 1991.

10. NRC Information Notice 91-75, "Static Head Corrections Mistakenly Not Included in Pressure Transmitter Calibration Procedures", November 25, 1991.

11. NRC Information Notice 92-12, "Effects of Cable Leakage Currents on Instrument Settings and Indications", February 10, 1992.

12. NRC Inspection Report of San Onofre Units 2 & 3, Report Numbers 50-361/91-01 and 50-362/91-01, dated April 12, 1991.

13. NRC Systems Based Instrumentation and Control Inspection at the Pilgrim Nuclear Power Station Unit 1, Report No. 50-293/91-201, dated January 6, 1992.

14. NRC Systems-Based Instrumentation and Control Inspection at the Haddam Neck Plant, Report No. 50-213/92-902, dated April 23, 1992.

15. ANSI/ISA-S51.1-1979, "Process Instrumentation Terminology".

16. ANSI/ASME PTC 19.1-1985, Part I, "Measurement Uncertainty", Instruments and Apparatus, Supplement to ASME Performance Test Code.

17. ASME PTC 19.5, Part II, "Application of Fluid Meters", Instruments and Apparatus, Sixth Edition, 1971.

18. ASME MFC-3M-1985, "Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi".

19. Considine, Douglas M., Process Instruments and Controls Handbook, McGraw-Hill, 1957.

20. Liptak, Bela G. and Venczel, Kriszta, Process Measurement Instrument Engineers Handbook, Chilton Book Company, 1982.

21. NED Guideline E-4, "Preparation, Documentation, and Control of Calculations".

22. Magison, E.C., Temperature Measureme..t in Industry, Instrument Society of America, 1990.

23. NUREG/CR-3659 - A Mathematical Model for Assessing the Uncertainties of Instrumentational Measurements for Power and Flow of PWR Reactors, February, 1985.

24. Fluid Meters - Their Theory and Application - 6th Edition, 1971.

C. Definitions

1. Abnormally Distributed Uncertainty - A term used by Reference II.B.3 to denote uncertainties that do not have a normal distribution. For the purpose of this document, abnormally distributed uncertainties are treated as biases.

2. Accuracy - A measure of the degree by which the actual output of a device approximates the output of an ideal device nominally performing the same function. Error, inaccuracy, or uncertainty represent the difference between the measured value and the ideal value.

3. Allowable Value - A limiting value that the trip setpoint may have when tested periodically, beyond which appropriate action shall be taken.

4. Ambient Temperature - The temperature of the medium surrounding a device. For field mounted devices, this is typically the room temperature at the device. For panel mounted devices, this is typically the temperature inside the panel which can be different from the room temperature.

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

6. As Found - The condition in which a channel, or portion of a channel, is found after a period of operations and before calibration (if necessary).

7. As Left - The condition in which a channel, or portion of a channel, is left after calibration or final actuation device setpoint verification.

8. Bias - The fixed or systematic error within a measurement. The bias error is the fixed difference between the true value and the actual measurement. The bias error can be of (1) known sign and known magnitude, (2) known sign but an unknown magnitude (with a maximum), or (3) unknown magnitude (with a maximum) and unknown sign. Often times the sign and magnitude vary in some relationship with another parameter.

9. Bistable - A device that changes state when a preselected signal value is reached. For example, for BWRs electronic trip units are considered bistables.

10. Calibration - The comparison of a standard (or device of known accuracy) with equal or better accuracy with a device under test to detect, record, or eliminate by adjustment any variation in the accuracy of the device under test.

11. Components - Discrete items from which a system is assembled. For example, wire, resistors, transmitters, converters, etc. would all be considered components.

12. Conformity - The closeness that the output of an instrument approximates (or conforms to) a specified preprogrammed curve (e.g., logarithmic, parabolic, cubic, etc.). Note: This measurement is usually determined in terms of non-conformity but expressed as conformity; e.g., the maximum deviation between an average curve and a specified curve. The average curve is determined after making two or more full range traverses in each direction. The value of conformity is referenced to the output unless otherwise stated.

13. Dead Band - The range through which an input can be varied upon reversal of direction without initiating an observable output response. See Figure II.C-1.

14. Dependent Uncertainty - Uncertainties are dependent on each other if they possess a significant correlation, for whatever cause, known or unknown. Typically, dependencies form when effects share a common cause.

15. Design Basis - Information which identifies the specific functions to be performed by a structure, system, or component of a facility, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design. These values may be (1) restraints derived from generally accepted "state of the art" practices for achieving functional goals, or (2) requirements derived from analysis (based on calculation and/or experiments) of the effects of a postulated accident for which a structure, system, or component must meet its functional goals.

16. Design Limit - The limit of a measured or calculated variable established to prevent undesired conditions (e.g., equipment or structural damage, spurious trip or initiation signals, challenges to plant safety signals, etc.). It is used in setpoint calculations for which there is no true Analytical Limit.

17. Device - An apparatus for performing a prescribed function (i.e., an instrument). The discrete items which make up an instrument loop/channel.

18. Drift - An undesired change in output over a period of time, which change is unrelated to the input, environment, or load.

19. Dynamic Response - The behavior of the output of a device as a function of the input, both with respect to time.

20. Effect - A change in output produced by some outside phenomena, such as elevated temperature, pressure, humidity, or radiation.

21. Error - The algebraic difference between the indication and the ideal value of the measured signal.

22. Final Actuation Device - A component or assembly of components that directly controls the motive power (electricity, compressed air, hydraulic fluid, etc.) for actuated equipment. Examples of final actuation devices are: bistables, relays, pressure switches, and level switches.

23. Foldover - A device characteristic exhibited when a further change in the input produces an output signal that reverses its direction from the specified input-output relationship.

24. Full Scale - The 100% value of the measured parameter on an instrument. Full scale is equal to the span for zero-based instruments.

25. Harsh Environment - This term refers to the worst environmental conditions to which an instrument is exposed during 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. It may also be referred to as the accident environment, or trip environment, and is the converse of mild environment.

26. Hysteresis - That property of an element evidenced by the dependence of the value of the output, for a given excursion of the input, upon the history of prior excursions and the direction of the current traverse. Note 1: This measure is usually determined by subtracting the value of dead band from the maximum measured separation between upscale going and downscale going indications of the measured variable (during a full range traverse, unless otherwise specified) after transients have decayed. This measurement is sometimes called hysteresis error or hysterectic error. See Figure II.C-1. Note 2: Some reversal of output may be expected for any small reversal of input; this distinguishes hysteresis from dead band.

27. Independent Uncertainty - Uncertainties are independent of each other if their magnitudes or algebraic signs are not significantly correlated, and they do not share a common source.

28. Indicated Value - A predetermined value of an indicator or recorder at which a manual action will be taken. An indicated value is similar to a setpoint except that a setpoint assumes an action will be taken by a device and an indicated value assumes an action will be taken by an individual.

29. Instrument - A single device that may be utilized alone or interconnected with other instruments for the purpose of observation, control and/or protection of a process or parameter.

30. Instrument Channel - An arrangement of components and modules as required to generate a single protective action signal when required by a plant condition. A channel loses its identity where single protective action signals are combined. For example, if three channels are input into a comparator, at the comparator the three individual signals lose their identity. Thus, the three channels are only channels up to the comparator.

31. Instrument Range - The region between the limits within which a quantity is measured, received, or transmitted, expressed by stating the lower and

upper range values.

32. Insulation Resistance (IR) Effect - The change in measurement signal due to an increase in leakage current between the conductors of instrument signal transmission components such as cables, connectors, splices, etc. The increased leakage is caused by the decrease of component insulation resistance due to extreme changes in environmental conditions.

33. Lead Wire Effect - The effect on measured RTD signals due to ambient temperature changes on the RTD signal wire.

34. Limiting Safety System Setting (LSSS) - Settings for automatic protective devices in nuclear reactors that are related to those variables having significant safety functions. A LSSS is chosen to begin protective action before the analytical limit is reached to ensure that the consequences of a design basis event are not more severe than the safety analysis predicted. Limiting Safety System Settings are identified in Section 2.0 of the Technical Specifications.

35. Linearity - The closeness to which a curve approximates a straight line. Note: The measurement determines non-linearity and expresses it as linearity; e.g., a maximum deviation between an average curve and a straight line. The average curve is determined after making two or more full range traverses in each direction. The value of linearity is referenced to the output unless otherwise stated.

36. Loop - A loop or instrument loop is the generic name given to a set of instrument devices which perform a specific function.

37. Loop Uncertainty - The instrument loop uncertainty is the combined effect of all instrument/device uncertainties in that loop. Depending on the function of the loop, this uncertainty could be an uncertainty in indication or an actuation uncertainty.

38. Lower Setpoint Limit - The lowest value for a setpoint which when used in conjunction with the upper setpoint limit, describes the tolerance band (no adjustment required) which allows for safe function operation and also minimizes the frequency of readjustment.

39. Margin - In setpoint determination, an allowance added to the instrument loop uncertainty. Margin moves the setpoint farther away from the analytical limit. Note: An additional expression, operating margin, should not be confused with margin. Adding or increasing operating margin has the effect of moving a setpoint closer to the analytical limit to increase the region of operation prior to reaching a setpoint.

40. Measurement and Test Equipment (M&TE) Effect - The effect on the uncertainty of a device or loop due to the accuracy ratings of reference measurement (test) equipment. When the accuracy rating of the reference measuring equipment is one tenth or less than that of the device under test, the accuracy rating of the reference measuring equipment may be ignored in the loop uncertainty calculation and in design of test/calibration procedures. When the accuracy rating of the measuring equipment is greater than one tenth that of the device under test, the accuracy rating of the reference measuring equipment shall be taken into account in the loop uncertainty calculation and in development of test/calibration procedures. Examples of measuring and test equipment are deadweight testers, resistor decade boxes, multimeters, current sources, etc.

41. Mild Environment - An environment that would at no time be more severe than the environment that would occur during normal plant operation, including any anticipated operational occurrences. It may also be referred to as the normal environment.

42. Module - Any assembly of interconnected components that constitutes an identifiable device, instrument, or piece of equipment. A module can be removed as a unit and replaced with a spare. It has definable performance characteristics that permit it to be tested as a unit. A module can be a card, a drawout circuit breaker, or other subassembly of a larger device, provided it meets the requirements of this definition. For the purpose of this document, a module is the same as a device.

43. Nuclear Safety-Related Instrumentation - That instrumentation which is essential to:

a) Provide emergency reactor shutdown
b) Provide containment isolation
c) Provide reactor core cooling
d) Provide for containment or reactor heat removal, or
e) Prevent or mitigate a significant release of radioactive material to the environment; or 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.

44. Operating Conditions - Conditions to which a device is subjected, other than the variable measured by the device. Examples of operating conditions include: ambient pressure, ambient temperature, electromagnetic fields, gravitational force, inclination, power supply variation (voltage, frequency, harmonics), radiation, shock, and vibration. Both static and dynamic variations in these conditions should be considered.

45. Operating Influence - The change in a performance characteristic caused by a change in a specified operating condition from a reference operating condition, all other conditions being held within the limits of reference operating conditions. Note: The specified operating conditions are usually the limits of the normal operating conditions. Operating influence may be stated in either of two ways: (1) As the total change in performance characteristics from reference operating condition to another specified operating condition, or (2) As a coefficient expressing the change in a performance characteristic corresponding to unit change of the operating condition, from a reference operating condition to another specified operating condition.

46. Percent Full Scale - Percent full scale is the ratio of a specific value compared to the full scale value, expressed as a percentage.

$$\frac{\text{Specific Value}}{\text{Full Scale Value}} * 100\% = \text{Percent Full Scale}$$

47. Primary Element - The system element that quantitatively converts the measured variable energy into a form suitable for measurement.

48. Process Effects - This is the general name given to all errors which affect the basic process measurements. The process effects are not instrument related but are due to characteristics of the process signal received by a sensor. The process effects include such things as fluid density variation effects, improper flow development effects, pressure variation effects, etc.

49. Process Measurement Instrumentation - An instrument, or group of instruments, that converts a physical process parameter such as temperature, pressure, etc. to a useable, measurable signal such as current, voltage, etc.

50. Random - A variable whose value at a particular future instant cannot be predicted exactly but can only be estimated by a probability distribution function. As used in this document, random means approximately distributed. The algebraic sign of a random uncertainty is equally likely to be positive or negative with respect to some median value. Thus, random uncertainties are eligible for square-root-sum-of-the-squares combination.

51. Range - The area between the upper and lower limits for which a device is designed to operate. A device may only be calibrated over a portion of its range (i.e its span) or calibrated over its entire range. For the latter case, the span would equal its range. Some vendors provide uncertainties in terms of span versus range, and clarification should be obtained as to whether the value is in range or calibrated span.

52. Reference Accuracy - A number or quantity that defines the limit that errors will not exceed when the device is used under reference operating conditions. Reference accuracy typically includes the combined effects of conformity (or linearity), hysteresis, dead band and repeatability. See Figure II.C-2.

53. Repeatability - The closeness of agreement among a number of consecutive measurements of the output for the same value of the input under the same operating conditions, approaching from the same direction, for full range traverses. Note: This measurement is usually determined as non-repeatability and expressed as repeatability in percent of span. It does not include hysteresis. See Figure II.C-3.

54. Reproducibility - The closeness of agreement among repeated measurements of the output for the same value of input made under the same operating conditions over a period of time, approaching from both directions. Note 1: This measurement is usually determined as non-reproducibility and expressed as reproducibility in percent of span for a specified time period. Normally, this implies a long period of time, but under certain conditions the period may be a short interval for which drift would not be included. Note 2: Reproducibility typically includes hysteresis, dead band, drift, and repeatability. Note 3: Between repeated measurements the input may vary over the range and operating conditions may vary within normal operating conditions.

55. Resolution - The smallest interval between two adjacent discrete details which can be distinguished one from the other. For instrument readout devices, the smallest discrete details are considered to be the minor scale divisions or 1/2 the least significant digit.

56. Response Time - The delay in the actuation of a trip function following the time when a measured process variable reaches the actual trip value due to the time response characteristics of the instrument loop, including the sensor. It may be expressed as the time taken by a device or loop to respond to a selected step input for testing or surveillance purposes.

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

58. Saturation - A device characteristic exhibited when a further change in the input signal produces no additional change in the output.

59. Sensor - The portion of an instrument loop that responds to changes in a plant variable or condition and converts the measured process variable into a signal, e.g., electric or pneumatic.

60. Setpoint - A predetermined value at which a device changes state to indicate that the quantity under surveillance has reached the selected value.

61. Signal Conditioning - One or more modules that perform signal conversion, buffering, isolation, or mathematical operations on the signal as needed.

62. Signal Interface - The physical means (cable, connectors, etc.) by which

the process signal is propagated from the process measurement module through the signal conditioning module of the instrument channel to the module which initiates the actuation.

63. Span - The algebraic difference between the upper and lower values of a calibrated range. If a device is calibrated over its entire range, the span equals its range.

64. Test Interval - The elapsed time between the initiation (or successful completion) of tests on the same sensor, load group, safety group, safety system, or other specified system of device.

65. Tolerance - The allowable deviation from a specified or true value.

66. Transient Overshoot - The difference in magnitude of a process variable over time, taken from the point of initial trip actuation to the point at which the magnitude is a maximum or minimum.

67. Turndown Factor - The upper range limit divided by the calibrated span of the device. Sometimes referred to as the turndown ratio.

$$\frac{\text{Upper Range Limit}}{\text{Calibrated Span}} = \text{Turndown Factor}$$

68. Uncertainty - The amount to which an instrument loop'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. For the purpose of this document, uncertainties shall include the broad spectrum of terms such as error, accuracy, effect, etc.

69. Upper Setpoint Limit - The highest value for a setpoint which when used in conjunction with the lower setpoint limit, describes the setpoint tolerance band which allows for safe function operation but minimizes the frequency of readjustment.

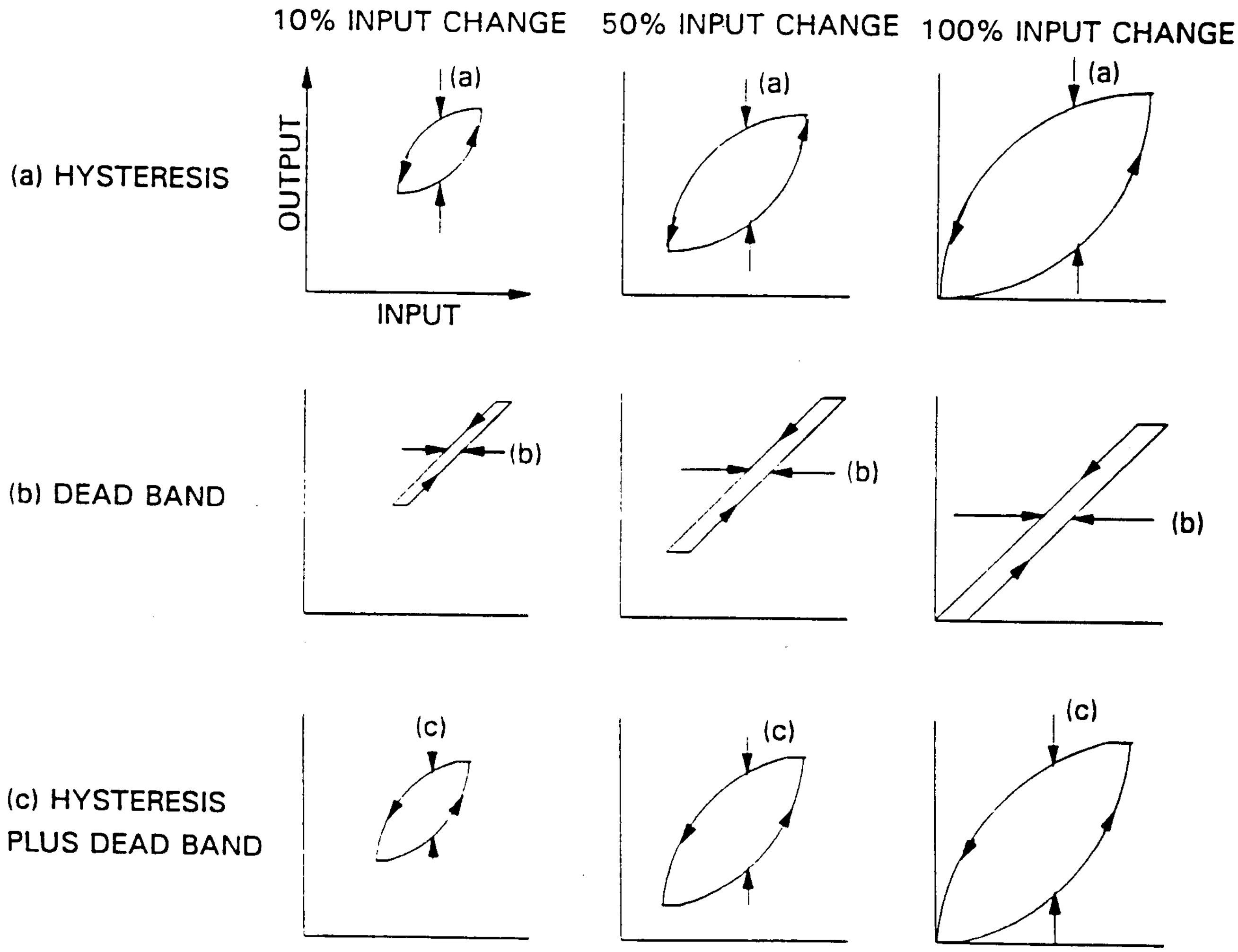


FIGURE II.C-1
HYSTERESIS AND DEAD BAND

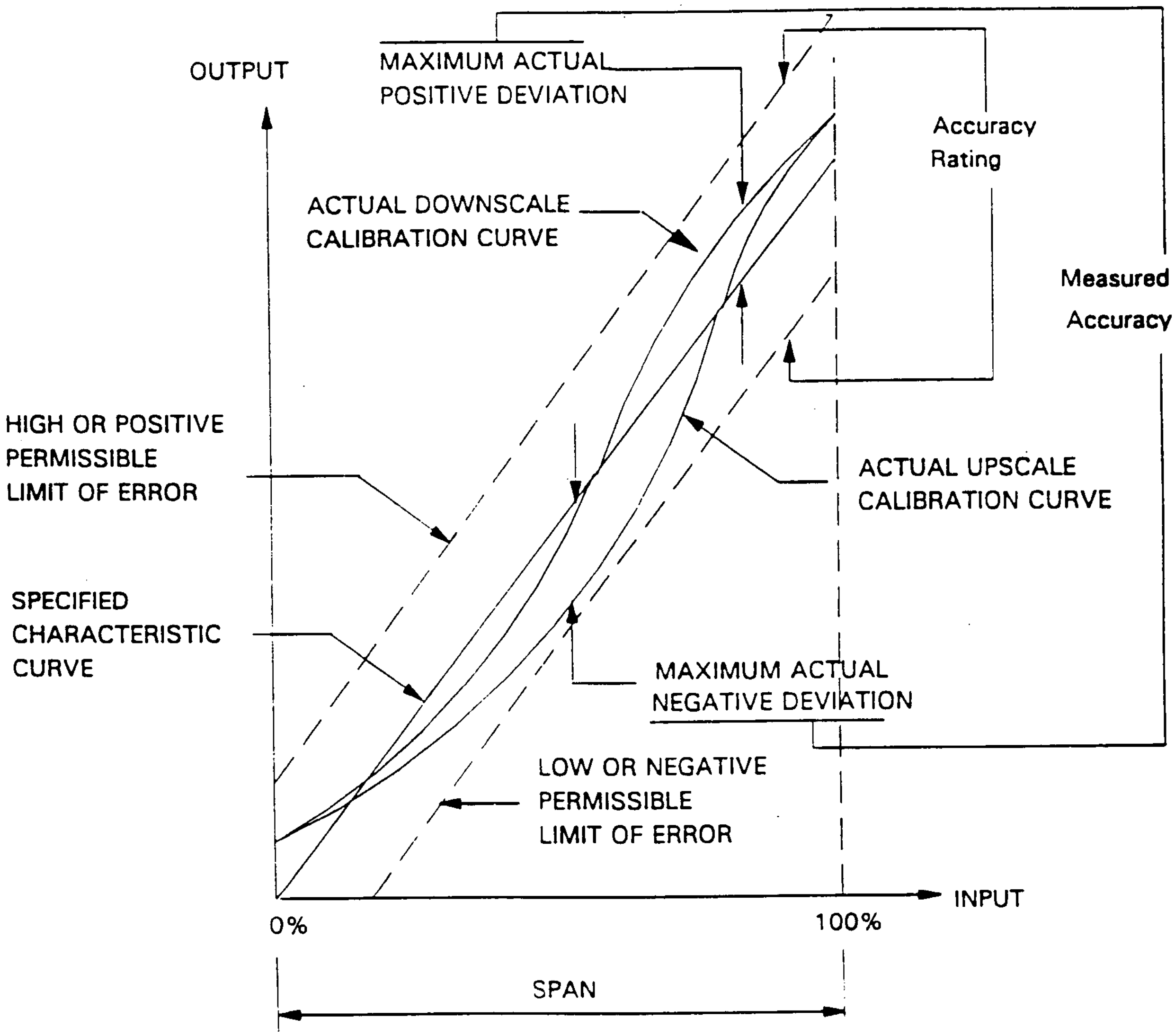


FIGURE II.C-2
REFERENCE ACCURACY

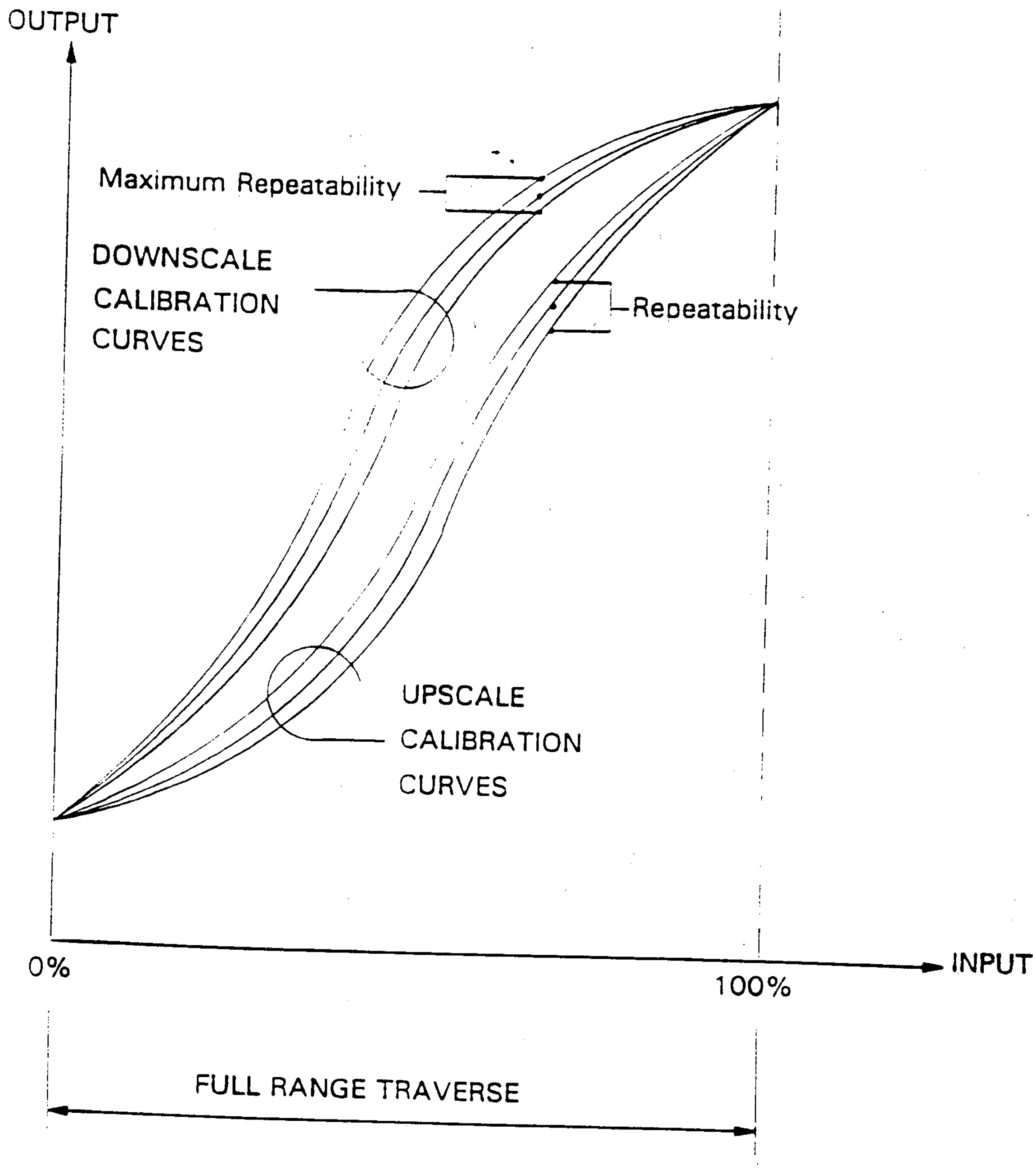


FIGURE II.C-3
REPEATABILITY

D. Acronyms

AE	-	Accident Effect
AL	-	Analytical Limit
AMMS	-	Automated Maintenance Management System
ANSI	-	American National Standards Institute
APE	-	Accident Pressure Effect
ARE	-	Accident Radiation Effect
ASME	-	American Society of Mechanical Engineers
ATE	-	Accident Temperature Effect
AV	-	Allowable Value
BSEP	-	Brunswick Steam Electric Plant
BWR	-	Boiling Water Reactor
CAL	-	Calibration Tolerance
CNAF	-	Calibration Nonconformance Action Form
COL	-	Channel Operability Limit
CSE	-	Conduit Seal Effect
DBA	-	Design Basis Accident
DBD	-	Design Basis Document
DL	-	Design Limit
DNBR	-	Departure from Nuclear Boiling Ratio
DP	-	Differential Pressure

DR	-	Drift
EDBS	-	Equipment Data Base System
EL	-	Elevation Difference
EOP	-	Emergency Operating Procedure
EQ	-	Environmental Qualification
EQDP	-	Environmental Qualification Data Package
ESFAS	-	Engineered Safety Features Actuation System
FSAR	-	Final Safety Analysis Report
GAFT	-	Group As-Found Tolerance
GPM	-	Gallons Per Minute
HBR	-	H. B. Robinson Unit 2 Nuclear Plant
HELB	-	High Energy Line Break
HL	-	Height of Liquid
HP	-	Hydrostatic Pressure
HPCI	-	High Pressure Coolant Injection
HR	-	Height of Reference Leg
HV	-	Height of Vapor
HVAC	-	Heating, Ventilatiing and Air Conditioning
I&C	-	Instrumentation & Controls
IE	-	Inspection and Enforcement
IND	-	Indicator
INPO	-	Institute of Nuclear Power Operations

IR	-	Insulation Resistance
ISA	-	Instrument Society of America
I/V	-	Current to Voltage Convertor
LAFT	-	Loop As-Found Tolerance
LER	-	Licensee Event Report
LOCA	-	Loss of Coolant Accident
LP	-	Loop Calibration Procedure
LSL	-	Lower Setpoint Limit
LSSS	-	Limiting Safety System Setting
LV	-	Loop Value
LW	-	Lead Wire Effect
M	-	Margin
M&TE	-	Measurement & Test Equipment
MFC	-	Measurement of Fluid Flow in Closed Conduits
MFR	-	Maintenance Feedback Report
MM	-	Multimeter
MMM	-	Maintenance Management Manual
MSLB	-	Main Steam Line Break
MST	-	Maintenance Surveillance Test Procedure
MTE	-	Material & Test Equipment Error
NBS	-	National Bureau of Standards
NED	-	Nuclear Engineering Department

NIST	-	National Institute of Standards and Testing
NRC	-	Nuclear Regulatory Commission
NUREG	-	Nuclear Regulation
OL	-	Operational Limit
OP	-	Overpressure Effect
P	-	Pressure
P&ID	-	Piping & Instrument Diagram
PB	-	Pressure Bistable
PE	-	Primary Element
PI	-	Pressure Indicator
PIC	-	Process Instrument Calibration Procedure
PME	-	Process Measurement Effect
PSE	-	Power Supply Effect
PT	-	Pressure Transmitter
PTC	-	Performance Test Code (ASME)
PWR	-	Pressurized Water Reactor
QDP	-	Qualification Data Report
RA	-	Reference Accuracy
RCS	-	Reactor Coolant System
RE	-	Readability
RPS	-	Reactor Protection System
RTD	-	Resistance Temperature Detector

SAR	-	Safety Analysis Report
SC	-	Signal Conditioner
SE	-	Seismic Effect
SG	-	Specific Gravity
SGL	-	Specific Gravity of Liquid
SGR	-	Specific Gravity of Reference Leg
SGV	-	Specific Gravity of Vapor (or Gas)
SH	-	Self Heating Effect
SI	-	Safety Injection
SHNPP	-	Shearon Harris Nuclear Power Plant
SL	-	Safety Limit
SP	-	Setpoint
SPE	-	Static Pressure Effect
SRSS	-	Square-Root-Sum-of-the-Squares
STP	-	Static Pressure and Temperature
STSS	-	Surveillance Test Scheduling System
SVF	-	Specific Volume of Fluid
TDF	-	Turndown Factor
TE	-	Temperature Effect
TID	-	Total Integrated Dose
TLU	-	Total Loop Uncertainty
TMM	-	Technical Support Management Manual

TRX	-	Transmitter
TV	-	True Value
URL	-	Upper Range Limit
USL	-	Upper Setpoint Limit
V/I	-	Voltage to Current Convertor
WC	-	Water Column

III. PRACTICE

A. Loop Error Analysis

1. Overview

Proper plant operation is achieved through the continuous monitoring and adjustment of process variables, either automatically or manually, via plant instrumentation and controls. The ability of the instrumentation and control (I&C) systems and equipment to properly monitor and control these variables is directly dependent upon the ability of the I&C systems to predictably and consistently measure and act on these processes. This ability is a measure of the accuracy of an I&C system.

The design of plant systems and equipment must take into account the realistic capabilities and limitations of the I&C systems available. The accuracy of an I&C system is affected by the system's ability to measure the process conditions and discern true variations in the process from a desired or set condition. This set condition, generally known as a setpoint, is the primary basis of process control. Setpoints can be actual process control settings, points of equipment actuation (commonly referred to as interlocks or trip setpoints), points of initiation of an alarm, etc. In other words, any predetermined point that requires an action to be initiated can be considered a setpoint.

Typically, setpoints are considered to be applicable to automatic devices such that upon reaching the predetermined value, an automatic action occurs. Sometimes setpoints are considered in a broader sense, and are considered to be points at which an automatic or manually initiated action occurs. When the term "setpoint" is used to describe a manually initiated action, it is usually used in conjunction with another descriptive term such as "EOP Setpoint" or "Operator Setpoint" to differentiate it from those setpoints that initiate automatic actions. For the purposes of this document, the term "indicated value" will be used to refer those points at which a manual action is expected. The following discussion is applicable to both setpoints and indicated values, although just the term "setpoint" is used for brevity. Whenever an issue only applies to just setpoints or just indicated values, it will be specifically noted.

Proper selection of setpoints is important to the safe, reliable and efficient operation of a plant. For proper determination of setpoints, a good understanding of system dynamic responses, interrelationships of system components, and analyses of anticipated abnormal occurrences (including accidents and environmental effects) is essential. In addition, the capabilities of the instrumentation must be considered. All instruments have limits to their accuracy, stability, and repeatability. These limits are also affected by external influences such as calibration, environment, power supply fluctuations, process conditions, etc. These external influences must be considered in the determination of a setpoint. The accuracy of an instrument is generally expressed in terms of inaccuracy, error, or uncertainty. These three terms are used interchangeably in industry to describe the limitations in the performance of an instrument.

In a nuclear power facility, special care must be taken in the development and selection of plant setpoints. This is especially true for setpoints which are related to plant quality-related systems and equipment. Setpoints which affect the safety of the plant must take into consideration all aspects of plant normal, and potentially abnormal, operations. For such setpoints, a specific detailed analysis should be performed and documented to ensure that all operational aspects are appropriately addressed.

Plant design is based on detailed system and equipment analyses which establish safety limits on important plant process variables. Safety limits are established to protect the integrity of the physical barriers that guard against the uncontrolled release of radioactivity. An example of a safety limit would be the absolute maximum pressure allowed in a piping system that carries potentially contaminated fluid. All safety limits applicable to a plant are typically documented in the plant's Technical Specifications and Safety Analysis Report (SAR).

Plant safety analyses, or accident analyses, are performed to model the interaction of plant systems, and to establish additional analytical or safety limits on specific process variables. These analytical limits are established such that, given the most severe operating or accident transient, the plant safety limits will not be exceeded. A typical analytical limit is the maximum operating pressure in a piping system. The piping system may have a safety limit maximum pressure equal to the pipe maximum design pressure. The analytical limit maximum pressure would be set below the safety limit to ensure that the safety limit is not reached during applicable design bases accidents (DBAs).

The plant safety analyses generally take into account the specific

thermodynamic, hydraulic, and mechanical interactions of systems. Response time assumptions for plant instrumentation are also modeled in the safety analyses, but the effects of instrument and measurement uncertainties are generally not explicitly quantified. Additional analyses are therefore necessary to ensure that all aspects of system and equipment design are taken into account when establishing the final plant process setpoints. These additional analyses are the primary subject of this document. The final plant setpoints must incorporate instrumentation uncertainties which, if not considered, could allow analytical limits, and possibly safety limits, to be exceeded.

Uncertainties which exist within an instrument device/loop are classified as either random or bias errors. Random errors are, as the name implies, the basic measurement uncertainties or variations which exist in any repeated measurement. The error is caused by the combination of numerous small effects which are within any such measurement. An exact value of random error cannot be predicted for a specific measurement. Instead, it can only be said that it will exist within a normal distribution about a true mean value. Therefore, in order to account for the random errors, these unsystematic errors are enveloped by upper and lower limits around the measured value. These limits bound the most probable value for the instrumentation output at any specific instance.

Unlike random errors, bias errors do not exhibit the random normal distribution characteristics. Rather, they exhibit a correlated, predictable, fixed, or systematic behavior. A bias exists where there is a known offset of a measurement from the ideal value or where there is a known relationship between the measured parameter and another parameter.

To establish the total uncertainty in an instrument or measurement, the various random and/or bias errors effects must be appropriately combined. This is accomplished through the application of basic statistical analysis. Those errors that are considered random are combined using statistical formulae such as Square-Root-Sum-of-the-Squares (SRSS). The bias errors, on the other hand, must be algebraically combined. Finally, the resultant random and bias errors are algebraically combined to yield a total uncertainty. Once the total uncertainty is known, the final plant setpoint can be established. It is calculated by placing it on the conservative side of the analytical limit by a value equal to, or greater than, the total uncertainty.

Consider again the example of the maximum piping system pressure analytical limit discussed earlier. The final plant setpoint would be

established at a valuc lower that the analytical limit, to ensure that neither the analytical limit nor the safety limit would be exceeded.

The source and magnitude of instrument uncertainties are governed by a number of system, equipment, and installation parameters. Process variations in temperature, pressure, fluid density, etc., can cause significant errors in the basic measurement. In addition, instrument support activities, such as the accuracy of the test equipment used to calibrate an instrument, and the calibration process itself, also influence instrument and measurement uncertainties.

Many instrument errors are influenced by the environmental conditions which surround an instrument. These conditions include among others, temperature, pressure, and radiation effects. The accuracy of an instrument must be evaluated for the ambient operating conditions under which it must function. In addition, a set of base or reference ambient conditions should be established to assist in instrument design and calibration. Typically, three specific ambient operating conditions are considered: (1) calibration (reference), (2) normal, and (3) accident conditions. These are discussed in detail in Section III.F.1.

2. Basic Concepts

The typical instrument loop consists of a field mounted transmitter or sensor connected by cabling to an instrument process cabinet containing the loop power supply and other signal conditioning modules. For loops with remote mounted devices (such as an indicator), the cabinet would contain modules to drive the remotely mounted device. Figure III.A-1 depicts a typical instrument loop containing both a remote mounted indicator and an actuation/setpoint device (bistable module), and Figure III.A-2 shows a block diagram for the typical loop.

Each device or component in the loop can affect the loop's performance (accuracy). These devices include the loop's power supply and interconnecting cabling. In general, the more components that exist in a loop, the greater the potential loop uncertainty since each component has a discrete uncertainty associated with it. In addition, the component uncertainties can be greatly affected by the ambient conditions under which the components function.

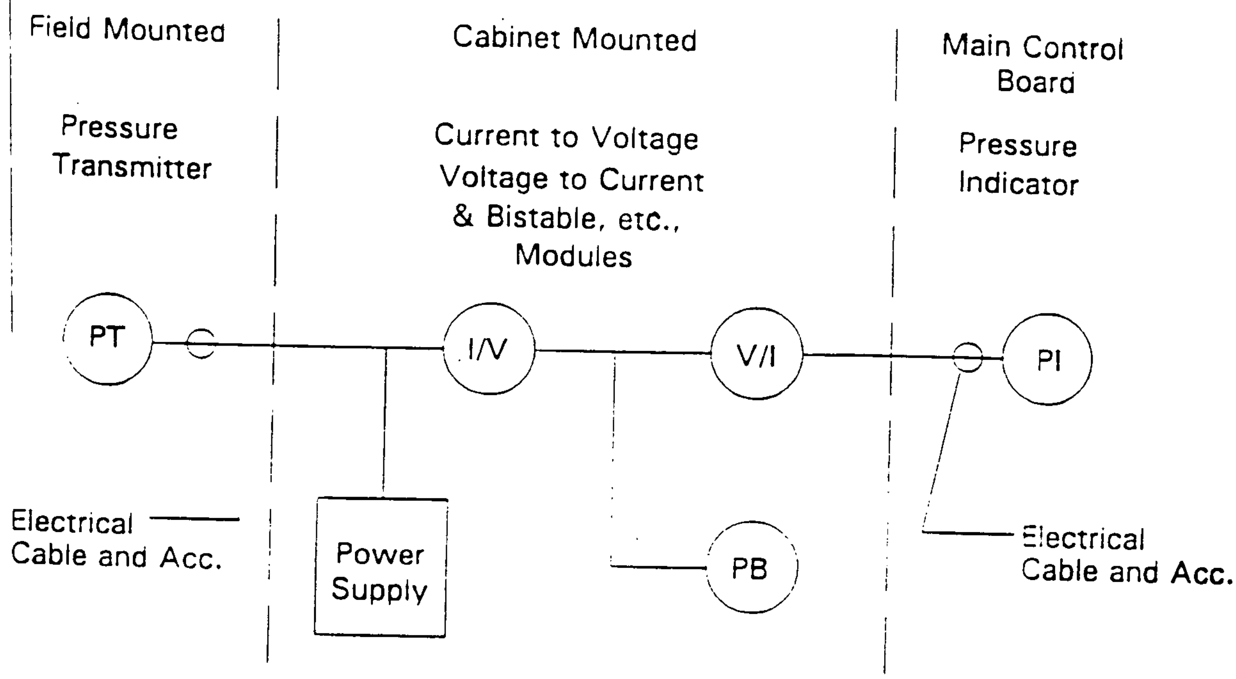


FIGURE III.A-1
TYPICAL INSTRUMENT LOOP

For sensors and electronic modules such as transmitters, current converters, function generators, etc., even small variations in ambient conditions can affect their performance. On the other hand, the loop signal transmission components (cable, splices, etc.) are generally immune to small ambient variations and only affect loop performance under extreme conditions.

Instrument loops can generally be divided into four major parts for loop error analysis:

- Process measurement - This includes a loop's transmitter, a flow element or other primary element, and/or other sensors/transducers used to measure a process variable. It also includes the basic

measurement process and any effects it may have on the performance of a loop, as well as, the interface with the process (tubing, etc.).

- Signal transmission - All of the loop components required to carry the measurement signal from the process measurement device to the signal processing section including the signal cable, cable connectors, splices, penetration assemblies, etc.

- Signal processing - All loop devices downstream of the process measurement section, used to condition or modify the signal from the measurement device. This would include such items as an isolator, square root extractor, function generator, etc.

- Final output - This is the final destination of a loop signal. Typically the final output is an actuating device such as a bistable module, and/or an indicating device such as an analog indicator, recorder or digital indicating device.

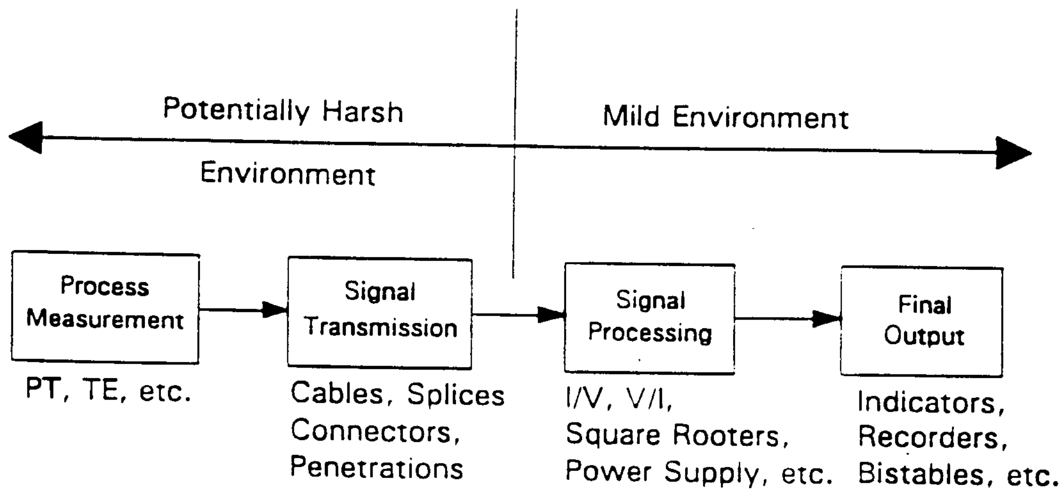


FIGURE III.A-2
TYPICAL LOOP BREAKDOWN

The environmental conditions to which the various parts of a loop are exposed can be different, depending on the location of actual loop components. Typically, two major classifications of environmental conditions are defined - harsh and mild. Harsh environments cover all ambient conditions resulting from High Energy Line Breaks (HELBs), such as a loss of coolant accident (LOCA) or main steam line break (MSLB). Mild environments cover all normal operating conditions besides the harsh areas.

Different ambient conditions exist under each classification, depending on the specific location of a device. The separation between harsh and mild conditions typically occurs somewhere between the field mounted sensors and the signal processing modules. Usually only the field mounted sensors and a portion of the signal transmission components will be exposed to harsh environment conditions. However, each loop must be individually evaluated to identify which components, if any, will be exposed to a harsh environment. Only those components which are potentially exposed to a harsh environment need to be considered for other than normal environmental effects in an uncertainty analysis.

3. Error Sources

Variations in instrument or loop accuracy are the result of a number of different error components. These error components can be divided into three major classifications or classes of error based on their source:

- Process Measurement Errors
- Instrument Uncertainties
- Other Errors

Process measurement errors are, as the name implies, basic errors in the actual process signal being detected by the process measurement device (sensor). These errors are wholly a function of the characteristics of the measurement process and not a function of the performance of the instruments. Process measurement errors include such things as variations in a measurement due to sensing line fluid density changes, errors in a head type flow meter measurement due to improper flow profile development or density effects, or temperature variations due to fluid stratification. Process measurement errors are discussed in detail in Section III.B.

Instrument uncertainties, or errors, are the performance limitations (inaccuracies) associated with the actual equipment used to measure and process the measurement signal. This class of errors includes the basic accuracy of an instrument, its performance versus ambient variations, and its performance over time. Instrument uncertainties are discussed in detail in Section III.C.

The class of "other errors" is used to account for a number of error sources that are essentially independent of the actual loop and its devices, but that can introduce significant error. This class includes such items as the uncertainty associated with the instrument calibration process and with the calibration test equipment. Additional errors are introduced into a measurement signal due to performance variations in signal transmission components exposed to a harsh environment. Section III.D discusses the error sources for the "other errors" class.

4. Loop Analysis

By expanding the loop block diagram shown in Figure III.A-2, a basic instrument loop error analysis diagram can be established. The diagram, presented in Figure III.A-3, shows the relationship of loop instruments, sources of errors, and environmental effects for a typical loop.

The basic error analysis block diagram starts with the process errors which may exist in a measurement. This is a subset of the process measurement errors discussed above. The next block, the primary element block, is included to account for loops which may have a true primary element such as a flow nozzle or orifice. Any errors associated with the primary element are considered part of the process measurement errors since they are integral in the variable being measured by the loop sensor. The remaining four blocks represent the four major sections of an instrument loop as defined above.

Actual loop error analysis uses the basic loop error analysis diagram as a model for identifying and calculating error values. The loop error analysis is done in a step by step calculation which builds the total loop error, or uncertainty, using a combination of the individual error effects. The process starts from the process error effects and progresses through the loop to the final output device of concern.

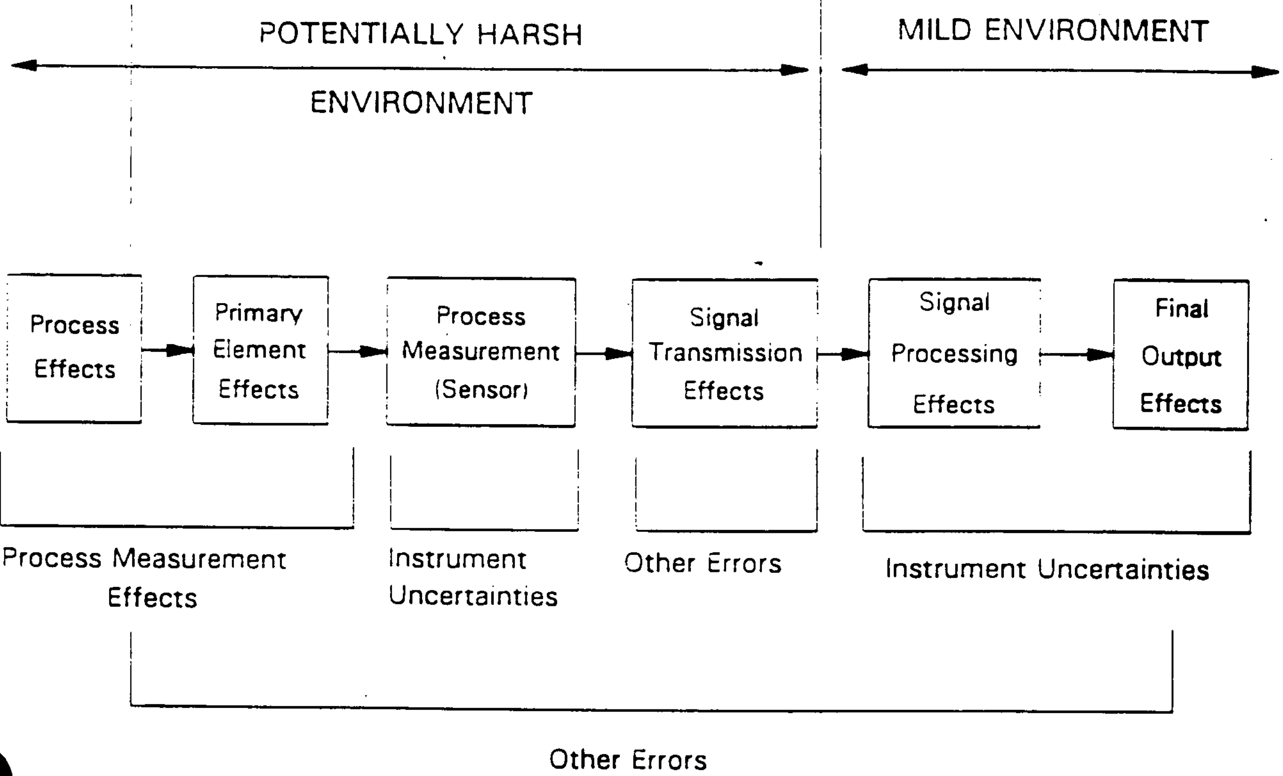


FIGURE III.A-3
INSTRUMENT LOOP ERROR ANALYSIS DIAGRAM

In reference to Figure III.A-3, the loop analysis will always progress from left to right. This also represents the functional flow of the measurement signal through the loop. Use of this method allows the uncertainty in a measurement signal to be determined at any point within a loop. This format also allows the calculation of uncertainty values for a loop that contains multiple signal paths or multiple signal processing. For example, both a pressure measurement signal and a temperature measurement signal, used in a temperature compensated level measurement, may be combined to establish a single level error value. By calculating the individual signal errors up to the point of combination, the total uncertainty for the loop can be calculated. The errors for the individual signal paths are determined using the same basic calculation process, and are then combined with any remaining error terms in the loop to obtain a final output error. This method is discussed in detail in Section III.E.

5. Error Component Types

All measurements, whether as simple as a length measurement by ruler, or as complicated as a three element water level control loop, have errors associated with them. No measurement is without an associated uncertainty. In some measurements, the error is minor and need not be quantified. When measurement error becomes potentially large, or where even small amounts of error can create problems, a quantitative determination of the error must be made. The determination of the measurement error can be accomplished in several ways (algebraic, statistical, or the combination of the two). These different methods are discussed in more detail in Section III.E.2. For now, suffice it to say that the most common method involves a combination of the algebraic and statistical derivation of the error, and this is what will be used for the CP&L plants.

The statistical derivation is possible due to the inherent nature of the errors which exist for instruments and measurements. The statistical derivation provides realistic estimates of the errors which exist. A given measurement is composed of two types of error components, the random/precision error, and the bias/fixed error. These two error terms form the bases of instrument error analysis. Proper application of these terms is essential to proper error analysis.

A general discussion of random and bias errors is provided below, and defines how these error types are treated in instrument error analysis. Sections III.B through III.D of this document define the individual errors which may be present in an instrument or loop. Each of these error terms is classified as typically being either random or bias in order to aid the user of this document in appropriately applying each type of error. However, the applicability of these classifications must be validated for each individual device/loop.

a. Random Error

A random error is, in itself, a statistical measurement of accuracy. It is the basic variation seen in the seemingly identical, repeated measurements of a parameter. A random error is caused by the culmination of the numerous small error effects which exist in any action. The exact magnitude and sign of a random error at a specific point in time cannot be predicted. However, the error is normally distributed about the true values, and a bounding set of limits to its upper and lower value can be established.

Random errors are independent variations (not dependent on one another or on the same parameters) in a measurement and cannot be eliminated. Bounds on the magnitude of a random error are established through statistical analysis of these variations.

By obtaining repeated measurements of a parameter, a measure of the random error magnitude can be calculated. The standard deviation, sigma (σ), is used as a measurement of the random error. The standard deviation is defined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - M)^2}{N}} \qquad (Eq.\ III.A-1)$$

Where,

X = Individual measurement values
M = Mean of all measurement values
N = Number of measurements

A group of random error measurements will exhibit a bell shaped (normal) distribution about the mean, when plotted as a function of measurement frequency (see Figure III.A-4). The figure illustrates the typical distribution of measurement deviations associated with random errors. As recorded deviation from the mean increases, the occurrence of measurements with that particular deviation decreases significantly.

By using the standard deviation term, a statistically acceptable measure of random error can be established.

Using normal probability analysis, it can be shown that the number of measurements that will vary within one standard deviation of the mean will represent 68.27% of all the measurements. In other words, approximately 68% of the time, the recorded measurement will be within one standard deviation of the true value. Expressing this in terms of probability, there is a 68% probability that the error will be equal to or less than one standard deviation.

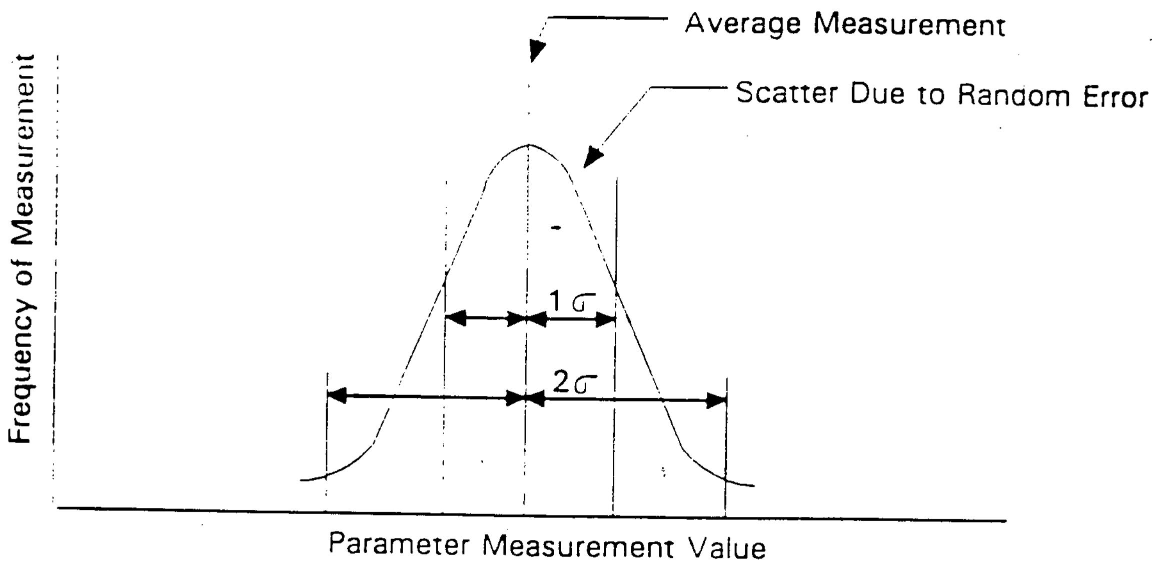


FIGURE III.A-4
MEASUREMENT UNCERTAINTY

Industry and the NRC have accepted a minimum level of random error probability of 95% for instrument error analysis. This 95% probability means that the error exhibited by a component or loop must be less than or equal to its established error at least 95% of the time. The 95% probability represents the deviation value from the mean which encompasses 95% of all measurement variations. Statistically, the 95% value can be shown to be $\pm$ 1.96 times the standard deviation. For simplicity, a value equal to two times the standard deviation is normally used. A two times standard deviation will actually yield an error probability of 95.45%.

When combining random uncertainties, it is important to identify whether each uncertainty is 1, 2, or 3 sigma. The resulting overall uncertainty will only be statistically equivalent to the least probable uncertainty. Thus, if one uncertainty is three sigma and the other uncertainties are two sigma, the combined uncertainty can only be two sigma. For CP&L, it will be assumed that published vendor uncertainties are two sigma unless the vendor can provide a more conclusive determination. This is based on common industry practice.

As stated above, random errors are independent variations with a normal distribution about the mean. What happens though, when two or more errors are dependent? If they are not random they are treated as biases as discussed below. If, however, their combined effect is random they may be summed together and treated as a single random error the same as other random errors. This is discussed in more detail in Section III.E.

b. Bias Error

Bias errors, also known as correlated or fixed errors, are systematic deviations in a measurement or output. A bias error does not exhibit normally distributed random behavior. The bias error exhibits a generally known behavior with respect to other parameters. A measure of total error for an instrument, or loop, can be determined by combining its bias error terms with its random error terms.

There are generally three types of bias error terms encountered in instrumentation. The first is defined as a bias with known sign and known magnitude. This type of bias is generally well defined and predictable. An example of such a bias is the reference leg heat-up effect on a filled reference leg level installation, as discussed in Section III.B. For a known temperature change, the level signal exhibits a known (direction and magnitude) shift in output. Many biases of this nature can be calibrated out of an instrument, and thus eliminated.

A second type of bias is defined as a bias with known sign but unknown magnitude. This type of bias is less predictable due to its variable magnitude, but may be quantified by establishing a maximum (worst case) value. An example of such a bias can again be seen in a filled reference leg level installation. After an event, the reference leg may be exposed to accident temperature conditions which cause errors in the level signal. The accident temperature, though, is not a known constant change. The temperature is a variable with a calculated maximum. As a result, the actual effect on the reference leg due to the variation in temperature is not known precisely. The difference between reference leg heat-up rate and the temperature change causes the exact bias magnitude to be unknown. A maximum bias effect can be determined, though, based on the maximum temperature to bound the actual bias.

The third type of bias is defined as a bias with unknown sign and unknown magnitude. This type of bias is similar to a random error due to its unknown sign. However, it cannot be classified as random since it will not exhibit a normal distribution. An example of this type of bias is the accident environment effect on some transmitters. When subjected to accident conditions, the transmitters begin to exhibit a shift in output. The shift may be either negative or positive for a specific transmitter, but once it's initiated, the shift will remain in the same direction (negative or positive). The magnitude of the shift will generally increase with the duration and severity of the accident conditions, but its value at a specific time cannot be determined. Only its maximum error for the stated conditions can be established. Because of the unknown sign, this type of bias error must be assumed to contribute to both the negative and positive uncertainty values.

It should be noted, that for the purpose of this document, the type of error described above will be treated as a bias. Other industry documents may call this an abnormally distributed uncertainty, or some other similar term. However, the name applied to such an error is not as important as how the error is combined with the other uncertainties. Both this document and other industry documents combine the error in the same manner. That manner is to algebraically combine the error with the positive random error and positive biases, and separately to combine the error with the negative random error and negative biases, as described below.

Bias errors are normally generated by specific effects internal to, or external to, an instrument. The magnitudes and signs of the errors are decided using known correlations between variations of a parameter and its effect on the output of a device (e.g., reference leg heat-up, IR effect). Thus, while a number of bias errors may have equal and opposite effects on instrument accuracy, each must be treated separately, and not used to offset another. Unless specific links exist between bias error, each must be assumed to occur separately.

The errors which bias a measurement in the same direction can be combined to establish the worst case error in a given direction. As discussed above, a specific bias can generally be a value anywhere from zero to its maximum value. By combining the maximum bias values in a given direction, the maximum error band over which a measurement can vary in that given direction is established. This approach usually provides extremely conservative error values which may not be desirable for all applications.

Figure III.A-5 illustrates the total uncertainty of a measurement or instrument output. The positive bias error (+B) is combined with the positive random error to define the largest positive error, while the negative bias error (-B) is combined with the negative random error to define the largest negative error. Based on the probability of the random error term, the uncertainty interval established will define the total error to the same degree of probability.

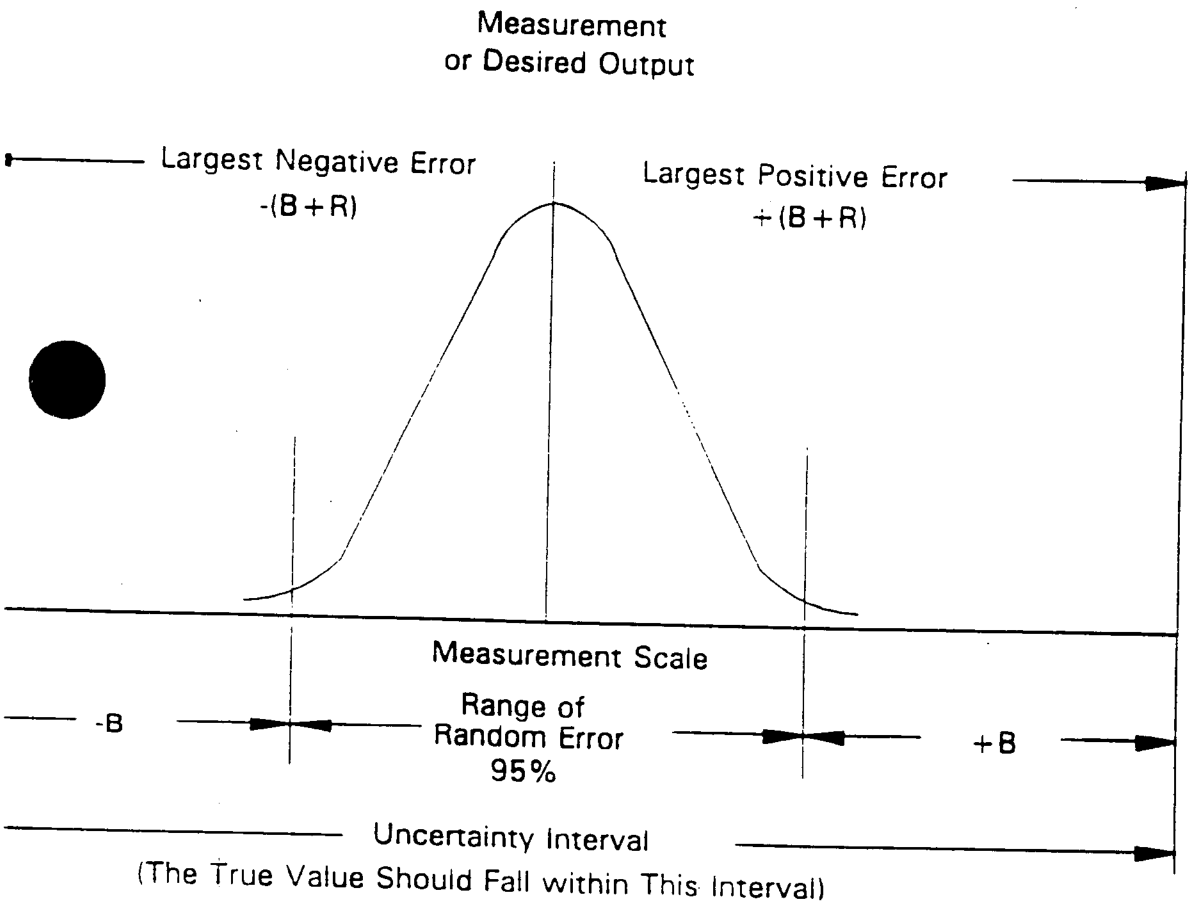


FIGURE III.A-5
TOTAL UNCERTAINTY

B. Process Measurement Errors

Process measurement requires the establishment of relationships between variables which enable the detection of changes in these relationships. The measurement of temperature by a mercury thermometer can be used to demonstrate this point. The thermometer measures room temperature by using the known relationship between the volumetric expansion of mercury and changes in temperature. As temperature increases, the volume of a fixed mass of mercury increases by a proportional amount. By placing the mercury in a tube with known graduations, the change in volume can be identified and correlated to a change in temperature.

The establishment of usable relationships between variables for measurement purposes is generally dependent upon other known influences not affecting the relationship of concern. In other words, only one variable is assumed to change at a time, so that the measured change is due solely to the variation of the parameter of concern.

Using the mercury thermometer illustration again: To isolate the mercury from other influences which could be misinterpreted as a temperature influence, the mercury is enclosed in a vacuum sealed glass tube. By doing this, other parameters which can cause the mercury to vary in volume, such as pressure or humidity, are isolated. Now, the only parameter which can cause the mercury volume to change is temperature. By calibrating the change in volume for a known temperature change, an accurate temperature measurement device is obtained.

In actual process measurement however, the effects of other parameters on a given measurement relationship may not be fully isolated. This can cause errors in the measured parameter. The effects of these other influences must be either accounted for or isolated in order to obtain an accurate measurement.

The effects of these influences are known as Process Measurement Effect (PME) since they are due primarily to variations in ambient and process conditions. The process measurement errors encompass all errors within a process measurement signal prior to the loop sensing device.

In design and calibration o: plant instrumentation, uniformity of all pertinent characteristics of the process fluid are assumed. However, there are many applications where uniformity is not a valid assumption. For example, varying fluid density or viscosity for a head-type mass flow meter, or thermal gradients in stagnant fluids with a point temperature measurement, can cause significant measurement errors. Many of these problems can be accounted for by providing compensating measurements, proper correction factors, or special calibrations. Others though, may not be correctable and will induce additional error or uncertainty into a measurement.

1. Liquid Level Measurement

One of the most common methods for liquid level measurement uses the hydrostatic head (pressure) created by a column of liquid. The measurement of the hydrostatic head usually provides a direct link to liquid level, and it is easily measured by a pressure transmitter/switch, or a differential pressure transmitter/switch. Depending on the specific method of measurement, changes in the density of the measured process liquid, or in the pressure sensing lines can cause errors in the level measurement. This variation in density can be caused by changes in temperature, pressure, and/or chemical composition.

a. Open Vessel Measurement

The measurement of level in an open vessel is one of the simplest forms of utilization of the hydrostatic head principle. The actual measurement can be accomplished by use of either a gauge pressure or differential pressure type device. Since the vessel is open, both devices use the local atmosphere as the common reference.

Figure III.B-1 shows a typical open tank application. The pressure (P) sensed at the point of connection to the tank can be calculated by:

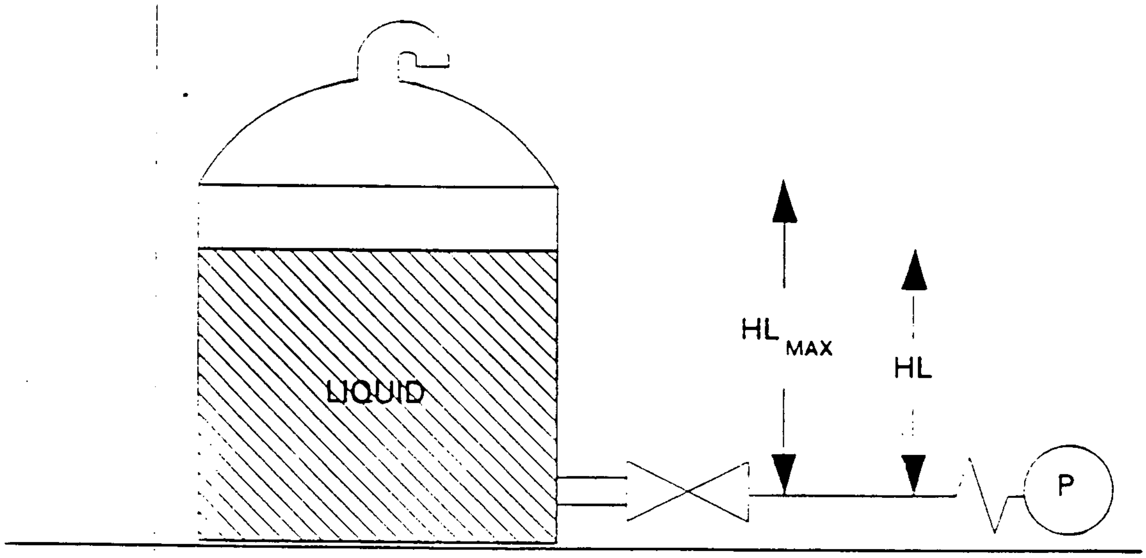
$$P = HL * SG \qquad \text{(Eq. III.B-1)}$$

Where,

HL = Height of liquid above the connection point, in inches of water

SG = Specific gravity of the liquid

P = Pressure, in inches of water



$$P \text{ (in. WC)} = HL * SG$$

$$\Delta P = HL(SG_2 - SG_1)$$

$$\text{Error (\% span)} = \frac{HL(SG_2 - SG_1)}{HL_{MAX} * SG_1} * 100\%$$

HL = Height of liquid measured in inches

HL_{MAX} = Maximum height of liquid

SG = Specific gravity of liquid

SG_1, SG_2 = Specific gravity of liquid at temperature 1 and temperature 2 respectively

P = Pressure sensed at the bottom of HL in inches of water column.

FIGURE III.B-1
HYDROSTATIC LEVEL MEASUREMENT

By using the specific gravity to calculate the pressure, the resulting pressure will be in units of inches of water column (in WC). The primary variable in the pressure equation, specific gravity, is by definition, the ratio of a fluid's density to the density of water at the standard temperature and pressure of 68°F and 1 atmosphere.

NOTE: Not all sources of SG use water at 68°F as a reference. Those must be converted to SG referenced to water at 68°F.

$$SG = \frac{\text{density of fluid}}{\text{density of water @ 68°F}} \qquad \text{(Eq. III.B-2)}$$

In nuclear power plant applications, water constitutes the majority of the fluid applications for which measurements are made. For water, the ASME Steam Tables provide a convenient source of data for the determination of specific gravity. The Steam Tables provide the specific volume for water in its liquid (f) and vapor (g) states at various temperatures and pressures. Since specific volume is the inverse of density, the specific gravity of a fluid can be calculated from the specific volume values by:

$$SG = \frac{\text{specific vol. of water @ 68°F}}{\text{specific vol. of fluid}} \qquad \text{(Eq. III.B-3)}$$

$$= \frac{0.01604537}{Vf \text{ or } Vg}$$

Two important facts must be noted about the measurement of level using hydrostatic head:

- The relationship of hydrostatic head (P) to fluid height (HL) is directly proportional. (see Equation III.B-1)

- The hydrostatic head produced by the fluid is dependent upon the temperature of the fluid since the temperature affects the fluid's density.

In the initial design and establishment of calibration parameters for a level loop, a base calibration temperature of the fluid must be assumed. In this example, the base temperature is typically the temperature of the fluid at normal operating conditions. When the actual fluid temperature varies from this assumed value, errors in level measurement occur. This is because the device sensing the hydrostatic head cannot distinguish a

pressure chang~ caused by temperature variation from a change in actual level. The error can be calculated, though, by calculating the change in specific gravity.

Assume for a temperature of T1, a fluid has a specific gravity of SG1. We will call this the base calibration temperature. The error calculated will be at a different temperature, T2. For temperature T2, the fluid has a specific gravity of SG2. P1 and P2 are the resulting hydrostatic heads at T1 and T2 (assuming level remains constant). Thus,

$$\text{Error (in WC)} = P2 - P1$$

$$DP = (HL * SG2) - (HL * SG1)$$

$$= HL\,(SG2 - SG1) \qquad \text{(Eq. III.B-4)}$$

To express this error in terms of level measurement loop span, the error term in Equation III.B-4 must be divided by the calibrated span of the loop. The calibrated span is typically equal to the difference between the maximum calibrated value and the minimum calibrated value. In this case, the calibrated span is equal to HLmax because minimum level is measured from the elevation of the level sensing nozzle (HL=0). To express the calibrated span in consistent units (in WC), it must be multiplied by the calibration specific gravity SG1.

Therefore,

$$\underset{\text{(\% span)}}{\text{Error}} = \frac{HL\,(SG2 - SG1)}{HLmax\,(SG1)} * 100\% \qquad \text{(Eq. III.B-5)}$$

Notice that the actual error incurred due to temperature change will vary as follows:

1. For T2<T1, SG2>SG1. The error is positive and becomes larger as T2 decreases.

2. For T2>T1, SG2<SG1. The error is negative and becomes larger as T2 increases.

3. The larger the actual level term HL, the larger the level error with the maximum error occurring when HL is equal to HLmax.

The positive and negative error annotations refer to the error with respect to actual level. A positive error will cause a measurement to be higher than actual value, while a negative error will cause a measurement to be lower than actual value.

Temperature may not be the only parameter which varies the density of a fluid. The chemical composition of the fluid can also cause the density to vary. In PWRs, the most common chemically induced variation of water density is caused by the presence of boric acid or Sodium Hydroxide. The effects of boric acid concentration, for example, can be determined using the same formulae developed above (Equations III.B-4 and III.B-5). The concentration of boric acid in water has a similar affect on the density of the water to that of temperature. If the density change is known, the measurement error can be calculated.

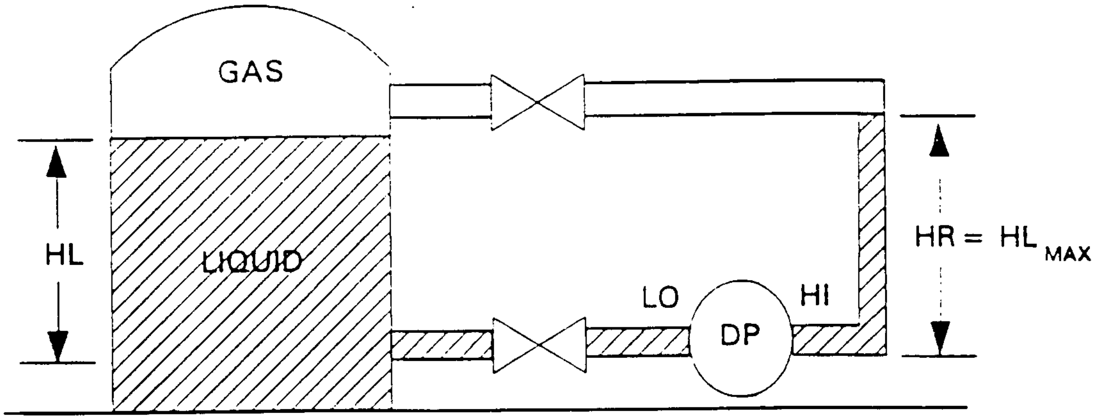
A simplified process for determining the densities of different boric acid solutions is described in Attachment C.

b. Closed Vessel Measurement

Another common level measurement application involves the detection of level in a closed vessel using the hydrostatic head measurement process. While the basic principles are the same as discussed in Section III.B.1.a, other factors can affect the measurement process.

Figure III.B-2 illustrates a typical closed vessel level measurement installation. In a closed vessel, the static pressure of the gaseous volume above the liquid must be taken into account. This requires the use of a differential pressure device which measures the pressure at both the bottom and top of the liquid. The lower sensing line, called the measurement or variable leg, measures the hydrostatic pressure of the liquid plus the static pressure of the gas. The upper sensing line, called the reference leg, measures the static pressure of the gas above the liquid. The differential pressure device measures the difference in pressure between the measurement and reference legs, such that the resultant output is a measurement of only the liquid's hydrostatic head.

As depicted in Figure III.B-2, a common practice of level measurement involves the filling of the reference leg with a liquid, typically the same liquid as found within the vessel or simple ordinary water. This provides both a seal between the contents of the upper portion of a vessel and the transmitter as well as providing a more stable reference leg measurement for certain applications.



$$DP \text{ (in. WC)} = (HR * SGR) - (HL * SGL)$$

$$\Delta DP \text{ (in. WC)} = HR(SGR_4 - SGR_3) - HL(SGL_2 - SGL_1)$$

$$\text{error \% span change} = \frac{\Delta DP}{-HL_{MAX} * SGL_1} * 100\%$$

HL = Height of vessel liquid measured in inches

HR = Height of reference leg liquid column in inches

SGL = Specific gravity of vessel liquid

SGR = Specific gravity of reference leg liquid

DP = Differential pressure representing vessel liquid level in inches of water

SP = Static pressure in gas at top of vessel

SGL_1, SGL_2 = Specific gravity of liquid at temperature 1 and 2 respectively

SGR_3, SGR_4 = Specific gravity of reference leg liquid at temperature 3 and 4 respectively

NOTE: It is assumed that the gas is at negligible specific gravity conditions in this example

FIGURE III.B-2
WET LEG LEVEL SYSTEM

The calculations of hydrostatic head, and associated errors for a level loop, using a differential pressure device, are the same as those for an open vessel, provided that the fluid in the reference leg does not contribute to the hydrostatic head. For reference legs containing a gaseous fluid (dry reference leg), the hydrostatic head in the reference leg will generally be zero. Only when the gas is under very high pressure would the density of the gas cause a significant head effect. In this discussion it is assumed that all gases are at low pressure and do not contribute any significant hydrostatic pressure. For a wet, or filled, reference leg installation, though, the level determination and potential errors in measurement are determined differently.

The basic formula for calculating the hydrostatic head for a wet reference leg system is:

DP (in WC) = (HR*SGR + SPE) - (HL*SGL + SPE)

= (HR*SGR) - (HL*SGL)

(Eq. III.B-6)

Where,

DP	=	Differential pressure created by the vessel liquid level, expressed in inches of water
HR	=	Height of the reference leg liquid column above the lower connection, in inches
HL	=	Height of liquid in the vessel above the lower connection, in inches
HLmax	=	Maximum height of liquid which can be measured, in inches
SGL	=	Specific gravity of the liquid in the vessel
SGR	=	Specific gravity of the liquid in the reference leg
SPE	=	Static pressure effect of the gas above the liquid, in inches of water

The resulting equation contains two components of potential error, SGR and SGL. As discussed in Section III.B.1.a, the specific gravity is affected by changes in temperature. In order to account for differences in temperatures, assumed calibration temperatures for both the vessel fluid and the reference leg fluid must be established. Variations in actual temperature induce errors into the measured level signal. The error can be calculated by comparing the changes in specific gravity in a manner similar to that shown in Section II.B.1.a:

- o Assumed base (calibration) temperature T3, with a reference leg fluid specific gravity of SGR3.
- o Actual temperature T4, with a reference leg fluid specific gravity SGR4.

If only the reference leg temperature varies, the error is determined by calculating the change (or error) in DP due to the change in reference leg specific gravity, assuming HL and SGL remain constant.

Error (in WC) = DP(Actual Conditions) - DP(Base Conditions)

$$DP = HR\ (SGR4 - SGR3) \qquad \text{(Eq. III.B-7)}$$

If both the vessel liquid and the reference leg liquid temperatures vary, the error is:

$$\text{Error (in WC)} = HR(SGR4-SGR3) - HL(SGL2-SGL1) \qquad \text{(Eq. III.B-8)}$$

If only the reference leg is affected by changes in temperature, the maximum error will occur at the maximum temperature variation. Since HR does not vary, it will not affect the maximum error. Equation III.B-7 reveals that the DP error is negative if $T4 > T3$ (since specific gravity decreases as temperature increases).

To express these errors in terms of level measurement loop span, the error terms in Equations III.B-7 and III.B-8 must be divided by the calibrated span of the loop. As was done for Equation III.B-5, the calibrated span is equal to the maximum level HLmax, multiplied by the calibration specific gravity of the liquid level, SGL1. Thus Equation III.B-7 becomes,

$$\text{Error (\% span)} = \frac{HR\,(SGR4 - SGR3)}{HLmax * SGL1} * 100\% \qquad \text{(Eq. III.B-9)}$$

And Equation III.B-8 becomes,

$$\text{Error (\% span)} = \frac{HR\,(SGR4 - SGR3) - HL\,(SGL2 - SGL1)}{HLmax * SGL1} * 100\%$$

(Eq. III.B-10)

If both the reference leg fluid temperature and the vessel fluid temperature vary, the maximum error will occur when one temperature is at a maximum with the other at a minimum.

The above example is for an installation with the "low" side of the transmitter connected to the lower tap, and the "high" side connected to the upper tap. A similar process could be used for a transmitter whose "low" side is connected to the upper tap and whose "high" side is connected to the lower tap.

Note in the example above, that though the DP error is negative for $T4 > T3$, the corresponding % span level error would be positive. This is due to the inverse relationship that exists between differential pressure and the liquid level in the tank. That is, a reduction in DP is equivalent to an increase in liquid level in the tank.

The effects of temperature variation on level measurement can cause significant amounts of error to be introduced into a loop. Thus, it is essential that the effects of process and reference leg temperature changes be considered in an overall setpoint or loop error analysis.

c. High Temperature/Pressure Vessel Level Measurement

The measurement of level by use of a differential pressure device can become very complex when measuring the level in a vessel containing process liquids at high temperature or pressure, or both. The high temperature causes a portion of the process to become vapor and fill the upper portion of the vessel. The resultant changes in the density of the vapor, as well as, of the liquid, can have a significant effect on the accuracy of a level measurement. In a similar manner, high pressure can compress the gas in the upper portion of a vessel causing significant changes in gas density, thus affecting the resulting accuracy.

Figure III.B-3 shows a typical closed vessel level measurement setup where the area above the liquid contains a fluid whose density can vary. For nuclear power applications the process liquid is generally water, such as in a pressurizer, a steam generator, or the reactor vessel, with the area above the liquid containing saturated steam. For this discussion we will assume the liquid in Figure III.B-3 is water and the area above the liquid is steam.

The basic formula for calculating the differential pressure or level, where the effects of both fluid densities must be included, is:

DP (in WC) = (HR*SGR + SPE) - (HL*SGL + HV*SGV + SPE)

= HR*SGR - HL*SGL - HV*SGV (Eq. III.B-11)

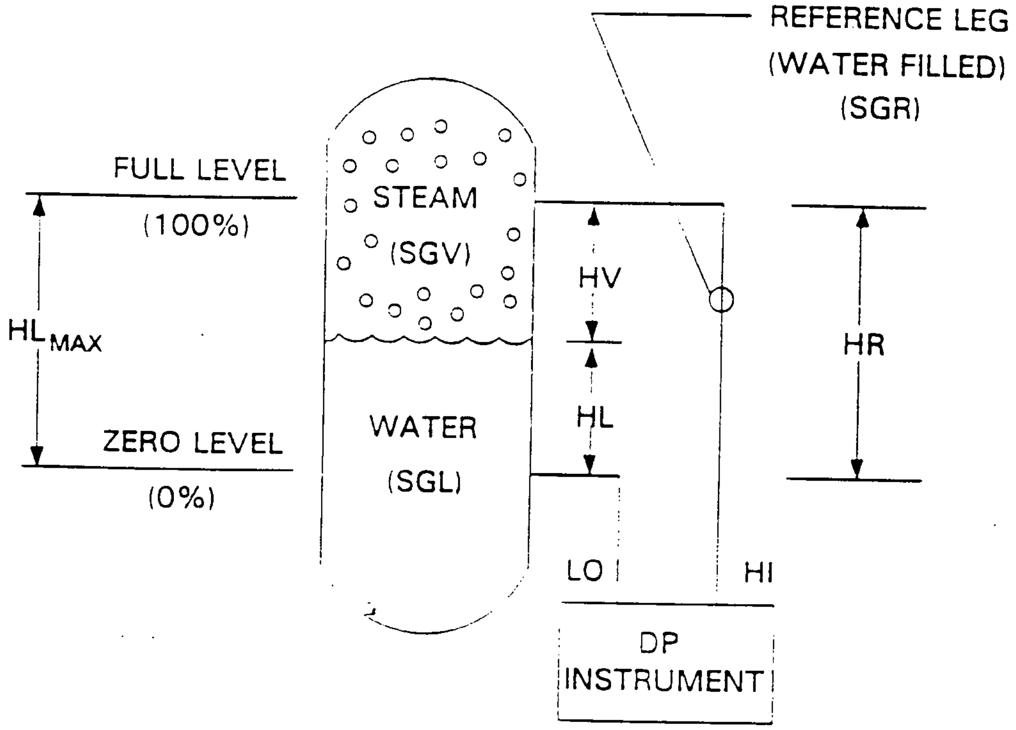
Where,

HR, HV & HL	=	Heights of the reference leg, vapor region, and liquid, respectively, in inches
SGR, SGV & SGL	=	Specific gravity of the reference leg liquid, vapor, and vessel water, respectively
SPE	=	Static pressure effect within the vessel, in inches of water
HLmax	=	Measurable level within the vessel, in inches

For this example, the measurable level (HLmax) within the vessel is equal to the height between the upper and lower sensing connections. This is also the height of the wet leg of concern. Those portions of the sensing lines (high and low) below the lower connection points are not of concern since, they will impart equal and opposite influences which cancel each other, assuming both lines are filled with the same fluid at approximately equal temperatures. Generally, HLmax will not be equal to the reference leg height, but will be at some level below the upper tap of the reference leg. However, for this example,

HLmax = HR = HL + HV (Eq. III.B-12)

Substituting Equation III.B-12 into Equation III.B-11 yields DP in terms of HR and HL only.



EXPLANATION OF SYMBOLS:

HL - Height of liquid (See note 1)

HV - Height of gas or vapor

HR - Height of reference leg (See note 1)

SGL - Specific gravity of liquid at saturation temperature

SGV - Specific gravity of vapor at saturation temperature

SGR - Specific gravity of reference leg

DP - Differential pressure in inches of water where

$$DP = HR(SGR-SGV) + HL(SGV-SGL)$$

NOTES:

1. All heights (except HV) are referenced above centerline of lower level sensing nozzle

FIGURE III.B-3
SATURATED LIQUID/VAPOR LEVEL MEASUREMENT

$$DP \text{ (in WC)} = HR*SGR - HL*SGL - (HR - HL)SGV$$

$$= HR(SGR - SGV) + HL(SGV - SGL)$$

(Eq. III.B-13)

For the more general case where HLmax does not equal the reference leg height, HLmax may be substituted for HL. Provided that the vessel and reference leg conditions (temperature/ pressure) remain the same as the base calibration conditions, the indicated level is a linear function of the measured differential pressure, and no vessel/reference leg density effect errors are created.

To assess the effects of density variations (typically caused by temperature variation) on the level measurement, Equation III.B-13 is rewritten in the form:

$$DP \text{ (in WC)} = (HR*SGR) - (HR*SGV) - (HL*SGL) + (HL*SGV)$$

(Eq. III.B-14)

As in the previous sections, let

T1 = Assumed base temperature of the liquid and vapor
T2 = Actual temperature of the liquid and vapor
T3 = Assumed base temperature of the reference leg
T4 = Actual temperature of the reference leg

Each temperature has a corresponding specific gravity value:

SGL1 & SGV1	=	Specific gravity of liquid and vapor at T1
SGL2 & SGV2	=	Specific gravity of liquid and vapor at T2
SGR3	=	Specific gravity of ref. leg liquid at T3
SGR4	=	Specific gravity of ref. leg liquid at T4

The change in differential pressure signal (ΔDP) at the instrument due to a change in density caused by variations in temperature from the assumed calibrated condition, can be determined by:

ΔDP (in WC) = DP (Actual Conditions) - DP (Base Conditions)

= HR(SGR4 - SGR3) - HR(SGV2 - SGV1) - HL(SGL2 - SGL1) + HL(SGV2 - SGV1)

= HR(SGR4 - SGR3 - SGV2 + SGV1) - HL(SGL2 - SGL1 - SGV2 + SGV1)

(Eq. III.B-15)

To convert the change in differential pressure, or error value, to error in percent of span, the ΔDP must be divided by the base span of the loop.

$$\text{Error (\% span)} = \frac{\text{Error (in WC)} * 100\%}{\text{DP Span}}$$ (Eq. III.B-16)

The span is the difference between the full scale (100%) value for level and the zero (0%) value for level. In terms of DP,

$$\text{DP span} = (DP_{100\%}) - (DP_{0\%})$$ (Eq. III.B-17)

Where,

$DP_{0\%}$ = the differential pressure when level is 0%
$DP_{100\%}$ = the differential pressure when level is 100%

Substituting Equation III.B-13 into Equation III.B-17,

DP span = [HR(SGR3 - SGV1) - $HL_{100\%}$(SGL1 - SGV1)] -[HR(SGR3 - SGV1) - $HL_{0\%}$(SGL1 - SGV1)]

= $HL_{100\%}$(SGV1 - SGL1) - $HL_{0\%}$(SGV1 - SGL1)

(Eq. III.B-18)

From Figure III.B-3, HL_0 is equal to 0; therefore,

$$\text{DP span} = HL_{100\%}(SGV1 - SGL1) \qquad \text{(Eq. III.B-19)}$$

Therefore, substituting Equation III.B-15 into Equation III.B-16 yields the error equation, expressed in percent of span, of:

$$\Delta DP = \frac{HR(SGR4-SGR3-SGV2+SGV1)-HL(SGL2-SGL1-SGV2+SGV1)}{HL_{100\%}(SGV1-SGL1)}$$

(Eq. III.B-20)

The above formulae for calculating the variation in level can be applied to a number of different types of level loops.

These equations represent the general formulae for calculating differential pressure level measurement error due to variations in density. The equations apply for density variations in any of the fluids which can affect the measurement. By equating the effects of certain specific gravity terms to zero (e.g., SGV1 = SGV2 = 0 in a simple closed vessel), the equations can be shown to be equivalent to those for the open vessel and simple closed vessel.

While many loops only measure level, and are calibrated for specific conditions, other more complicated loops may have automatic temperature compensation circuitry. Such circuitry can adjust a level instrument's calibration parameters to account for the changes in fluid density. Temperature compensation can be used for either process temperature variations, reference leg temperature variations, or both. Utilization of temperature compensation in a level loop will eliminate the errors in measurement caused by density variations.

The effects of both process and reference leg temperature variations must be considered in the analysis of a level loop's accuracy. Since the magnitude of the error is governed by both the level and the magnitude of temperature change, care must be taken when defining the conditions under which the accuracy must be determined. While the maximum, or worst case, error can easily be calculated for a level equal to 100%, the actual levels of concern may be considerably less than 100% and thereby have much less potential error. In a similar manner, the actual process and reference leg temperatures expected at the time a level measurement is needed may greatly decrease the potential error in comparison to worst case temperature conditions.

Consider the following example:

EXAMPLE

Calculate the worst case and specific error due to temperature variations in the process and reference leg of the vessel in Figure III.B-3.

Assume:
- Process and reference leg fluid is water
- Normal and calibrated process temperature = 532°F
- Normal and calibrated reference leg temperature = 120°F
- Distance between level connections (HLmax & HR) = 169 in
- Specific error conditions:
  40% level
  500°F process temperature
  250°F reference leg temperature
- Process temperature minimum 400°F
- Reference leg temperature maximum 280°F
- All conditions are saturated steam/water

Using the basic level formula (Eq. III.B-13), the level signals in inches of water at Standard Temperature and Pressure (STP) at 68°F are determined for normal operation using (ASME) Steam Tables (See specific gravity conversion from specific volume in Section III.B.1.a):

$$DP = HR(SGR - SGV) + HL(SGV - SGL)$$

DP for 100% of level (DP_{100}):

$$HL = HLmax = 169 \text{ in}$$

$$DP_{100\%} = (169 \text{ in})(0.990249 - 0.032047) + (169 \text{ in})(0.032047 - 0.755817)$$

$$= (169 \text{ in})(0.958202) - (169 \text{ in})(0.723770)$$

$$= (161.936 - 122.317) \text{ in}$$

$$= 39.619 \text{ in}$$

DP for 40% of level ($DP_{40\%}$):

HL = 40% HLmax

40% level = (40%)(169 in) = 67.6 in

$DP_{40\%}$ = (169 in)(0.958202) - (67.6 in)(0.723770)

= 113.009 in

These represent the calibrated DP values for the loop. No process error would exist in the loop as long as the process temperature remained at 532°F and the reference leg temperature remained at 120°F.

The worst case error within the loop will always occur when level is at a maximum and both the process and reference leg temperatures are at their opposite extremes. The worst case error for this loop is calculated using the general formula for differential pressure change (Eq. III.B-15).

ΔDP = HR(SGR4 - SGR3 - SGV2 + SGV1) - HL(SGL2 - SGL1 - SGV2 + SGV1)

HL = 100% = 169 in
HR = 169 in
SGR3 = Specific gravity of ref. leg water at 120°F
SGR4 = Specific gravity of ref. leg water at 280°F
SGL1 = Specific gravity of process water at 532°F
SGL2 = Specific gravity of process water at 400°F
SGV1 = Specific gravity of steam at 532°F
SGV2 = Specific gravity of steam at 400°F

ΔDP = (169 in)(0.929449 - 0.990249 - 0.008613 + 0.032047) - (169 in)(0.860837 - 0.755817 - 0.008613 + 0.032047)

= (169 in)(-0.037366) - (169 in)(0.128454)

= -6.32 in - 21.71 in

= -28.02 in WC

Therefore, the worst case error causes the measurement by the level loop to be off by 28.02 in WC in the negative direction. Differential pressure

level installation that have a wet reference leg have an inverse relationship between DP and actual vessel level. As the vessel level increases, DP decreases, and as the vessel level decreases, DP increases.

Expressed in percent span,

$$\text{DP Span} = HL_{100\%}\,(SGV1 - SGL1)$$

$$= (169\text{ in})(0.032047 - 0.755817)$$

$$= -122.32\text{ in.}$$

$$\text{Error} = \frac{(-28.02\text{ in})}{(-122.32\text{ in})} * 100\% = +22.9\%\text{ of span}$$

Therefore, the negative (or decrease) error of - 28.02 in WC differential pressure represents a level error of +22.9% span. In other words, an indicator would read 123% even though the actual level is only 100%.

The error within the loop measurement at the specific level of concern and conditions would be:

$$\Delta DP = HR(SGR4 - SGR3 - SGV2 + SGV1) - HL(SGL2 - SGL1 - SGV2 + SGV1)$$

HL	=	40% = 67.6 in
HR	=	169 in
SGR3	=	Specific gravity of ref. leg water at 120°F
SGR4	=	Specific gravity of ref. leg water at 250°F
SGL1	=	Specific gravity of process water at 532°F
SGL2	=	Specific gravity of process water at 400°F
SGV1	=	Specific gravity of steam at 532°F
SGV2	=	Specific gravity of steam at 400°F

$$\Delta DP = (169\text{ in})(0.943549 - 0.990249 - 0.023775 + 0.032047) - (67.6\text{ in})(0.785414 - 0.755817 - 0.023775 + 0.032047)$$

$$= (169\text{ in})(0.038428) - (67.6\text{ in})(0.037869)$$

$$= -6.49\text{ in} - 2.56\text{ in}$$

$$= -9.05\text{ in WC}$$

$$\text{Error} = \frac{(-9.05\text{ in})}{(-122.32\text{ in})} * 100\% = +7.4\%\text{ of span}$$

Therefore, the actual error at 40% is -9.05 in WC differential pressure or +7.4% actual level. Thus, the level loop would indicate 47.4% while actual level would be 40%.

2. Pressure Measurement

The point at which the measurement for a process variable is made must be considered when establishing a setpoint. The point of measurement for a process variable can require an actual setpoint value to be increased or decreased to satisfy the specific setpoint function. Many times, a specific process variable cannot be measured precisely at the point of concern within the process. This is a particular problem for pressure measurements. When a setpoint limit exists for this situation, the pressure effects of process flow and hydrostatic head must be evaluated.

Fluids flowing through a piping system experience a drop in pressure due to fluid friction. Many factors affect the actual pressure loss including length of piping, number of bends, diameter of piping, fluid viscosity, fluid velocity, etc. This pressure drop is generally referred to as "line loss".

The line loss at a specific point in a piping system configuration can be determined by analysis of the specific piping system, and the application of standard industry formulae. Line loss effects for a specific application should be calculated, with help obtained, as necessary, from the Mechanical Engineering Group.

Hydrostatic pressure effects can exist when the measurement point for an installation is at an elevation different than that of the point of concern. This elevation difference induces a hydrostatic head difference proportional to the height and the specific gravity of the process fluid.

The true measurement point elevation is the elevation of the loop sensing device, and not the elevation of the connection to the process. However, many times this elevation difference is accounted for in the calibration process. Hydrostatic pressure effects, therefore, can be the result of process piping elevation differences or instrument sensing line elevation differences (from process connection to sensing device), or both.

Therefore,

$$HP = EL * SG \qquad \text{(Eq. III.B-21)}$$

Where,

HP = Hydrostatic head pressure
EL = Elevation difference
SG = Specific gravity of fluid

Consider the following example:

EXAMPLE

Referring to Figure III.B-4, a low pressure trip is to be initiated on the pump when the pump suction pressure (Point B) falls below 50 psig. The instrument used to monitor suction pressure senses the pressure at a point 35 feet upstream and 15 feet below the actual suction. The instrument itself is 5 feet above the sensing line connection on the pipe.

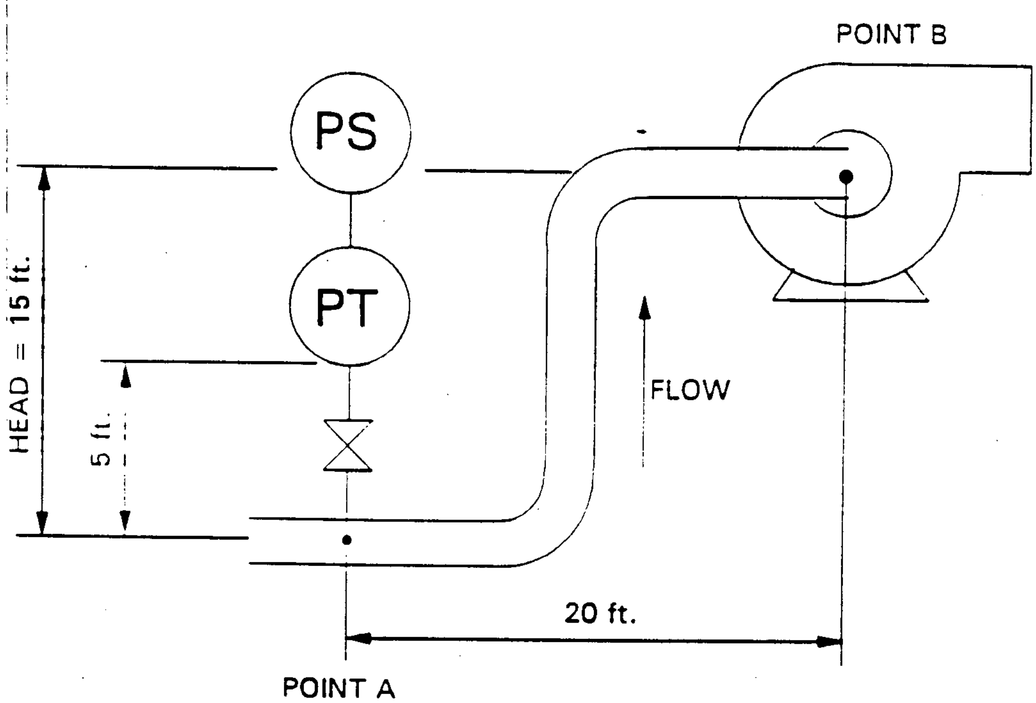
Process fluid = Water
Process temperature = 150°F (Saturated Conditions)

The line loss effect between point A and point B could be calculated from the actual piping and fluid conditions. In this example we will assume a line loss effect of 4.0 psi.

With elevation (EL) for the example being equal to the 15 feet difference between point A and point B, the hydrostatic pressure effect (HP), or head effect, is:

$$HP = EL * SG$$

$$= (15 \text{ ft})(0.98183)$$



NOTES:

(1) - Pump trip must occur if pressure falls below 50 psig (at point B)

(2) - PT is pressure transmitter

(3) - PS is pressure switch (bistable)

FIGURE III.B-4
LINE PRESSURE LOSS HEAD EFFECT EXAMPLE

$$= (14.73 \text{ ft})(0.43[illegible] \text{ psi/ft})$$

$$= 6.38 \text{ psi}$$

The setpoint for the pressure loop at point A must be corrected for both effects:

Actual setpoint = Desired setpoint at B + Line loss effect + Hydrostatic pressure effect

$$= (50 + 4.0 + 6.38) \text{ psi}$$

$$= 60.38 \text{ psi}$$

This would be the required setpoint at point A to ensure that the pump tripped when actual suction pressure, at point B, was 50 psi. An additional increase of the setpoint may also be included to account for other uncertainty effects in the actual instrument loop.

In the example presented above, the line loss must be added to the 50 psi limit in order to obtain a conservative setpoint. For example, if the line loss and head effect were neglected, using a value of 50 psi at point A would not be conservative since the pump trip would occur when pressure at point B was 46 psi, i.e below the 50 psi limit. The head effect also has to be added, as shown above, to effectively take credit for making the desired setpoint less restrictive, since the head pressure above the point of measurement reduces the available pump suction pressure.

Note that the head effect/line loss errors are known fixed error terms. The error must be added, or subtracted, from the desired setpoint depending on the particular circumstances. This is discussed in more detail in Section III.G.

As noted above, hydrostatic pressure (head) effects may be accounted for in the calibration process, or in the determination of the overall loop uncertainty. It is important to specify for each application, where such effects are incorporated, either via the calibration process or the loop uncertainty. Otherwise, the effects may not be addressed, or may be addressed twice.

3. Flow Measurement

The most common form of flow measurement is the head type flowmeter. These flowmeters operate on the principle that placing a restriction in a flowing fluid causes a pressure drop in the fluid across the restriction. By measuring the pressure drop across the restriction with a differential pressure device, flow can be derived. Flow orifices, nozzles, and venturies are all forms of head type flowmeters.

The accurate measurement of flow is affected by a number of design factors. These factors include the assumed sizing and calibration attributes of the flow meter and piping loop, adherence to installation requirements, and potential process influence. Each of these factors must be reviewed and accounted for in the analysis of a flow loop.

a. Basic Flow Accuracy Influences

In the initial selection and sizing of a flow meter, design assumptions are made as to the pressure, temperature, flow range and chemical composition of the fluid to be metered. These design assumptions become the bases of a meter's sizing, and the differential pressure profile versus flow characteristics for the meter.

The basic formula for determining the volumetric flow from a head type flowmeter is:

$$Q = (K)(C)(Y)(Fa)(d)^2 (h/D)^{0.5} \qquad \text{(Eq. III.B-22)}$$

Where,

Q	=	Flow rate
K	=	Correction constant for a specific installation
C	=	Coefficient of discharge ratio
Y	=	Expansion factor
Fa	=	Thermal expansion factor
d	=	Flow meter orifice diameter
h	=	Differential pressure produced across the meter
D	=	Density of the flowing fluid

The correction constant (K) is generally a true constant for a particular flow meter. This factor includes the effects of Beta ratio (orifice size vs. pipe size) and unit conversion values which are fixed values for an installation.

The coefficient of discharge ratio (C) is a correction factor for the pressure sensing taps on a meter. The coefficient of discharge is a function of the Reynolds number calculated for an installation and the specific pressure tap arrangement employed. For most flows at the CP&L plants, the Reynolds number is between 10,000 and 1,000,000 and the ratio is a fixed value. It would only require analysis consideration if major changes in the assumed flow conditions take place (e.g., a ten-fold increase or decrease in base flow rate).

The expansion factor (Y) accounts for changes in a meter's performance when metering compressible fluids such as air, steam, and nitrogen. The value is a fixed constant of one (1.0) for non-compressible fluids. In its liquid state, water is considered to be a non-compressible fluid.

The thermal expansion factor (Fa), or area expansion factor, as it is sometimes referred to, is a correction factor which accounts for the thermal expansion of a flow meter orifice due to a change in temperature. The thermal expansion factor is generally a very small value, varying from 1.000 to 1.0187 over a 900°F temperature change. Temperature variations of 200°F have less than a 0.5% effect on the actual flow measurement. In some applications, it may be considered negligible.

The flow meter orifice size (d) is the diameter of the actual orifice within a flow meter. It is generally considered a constant except for the effects of thermal expansion as discussed above. In some applications though, wear within the orifice may occur, causing the orifice size to change. Meters in severe service conditions should be evaluated for potential wear or erosion, and suitable allowances made.

The differential pressure (h) is the difference in static pressure between the fluid upstream and downstream of the meter. This difference is a function of the square of the flow; therefore, the square root of the signal must be taken to obtain actual flow. A differential pressure device measures this parameter in a flow loop installation.

The density (D) of the flowing fluid directly affects the differential pressure produced by a meter. As discussed in Section III.B.1.a, density may vary due to changes in temperature or chemical composition. The primary cause of a variation in density is the change in temperature of the fluid. However, an evaluation should be made for any possible density changes due to all potential sources.

An important fact to remember when utilizing head flow elements such as an orifice is, that because the flow rate is proportional to the square root of the differential pressure, the rangeability of the device is rather limited. The effective operating range is about 25-100% full flow. This is a limit imposed by the differential pressure meter, not the accuracy of the orifice discharge coefficients. For example, consider the case where 10% of rated maximum flow produced 1% of rated differential pressure. If the differential pressure transmitter accuracy was ± 0.5% of full scale differential pressure, the transmitter itself could introduce an error of ± 50% at the 10% rated flow value.

The measurement of flow with head type flow meters is a well documented, but complicated subject. The specific factors discussed above are the factors which affect a meter's accuracy once it is sized for a particular application. This methodology document will limit its discussion to those factors which affect the accuracy of a meter after installation.

Specific values for the uncertainty of the head flow device should be obtained from the vendor, design specifications, etc. Where no specific values can be located, a typical value for the basic uncertainty of such a device is ± 1% of differential pressure. Any other process or installation effects, such as those discussed below, would be in addition to the basic accuracy of the device.

b. Density Variation Effects

Variations in the density of a process fluid to be metered can be the biggest source of potential process measurement error in a flow loop. The density variation is normally caused by variations in the process fluid's temperature. A simplified version of the flow formula will be used to determine the effects of density variation on flow measurement accuracy:

$$Q = k\,(h/D)^{0.5} \qquad \text{(Eq. III.B-23)}$$

Where,

k = Combined value of all other factors and constants

If the volumetric flowrate, Q, is held constant, it is seen that a decrease in density (D), due to an increase in temperature, will cause a decrease in differential pressure, (h), thus resulting in an error in the transmitter reading. This error occurs because the differential pressure transmitter was calibrated for a particular differential pressure corresponding to that flowrate at a lower temperature. The lower "h" value causes the transmitter to indicate a lower flowrate.

Assuming Q remains constant between a base density condition, D1, for which the instrument is calibrated, and an actual process condition, D2, an equality can be written between the base flowrate, Q1, and actual process flowrate, Q2, as shown below:

$$Q2 = Q1 \qquad \text{(Eq. III.B-24)}$$

Substituting Equation III.B-23 into Equation III.B-24 yields

$$k(h2/D2)^{0.5} = k(h1/D1)^{0.5} \qquad \text{(Eq. III.B-25)}$$

or,

$$h2/D2 = h1/D1$$

$$h2/h1 = D2/D1$$

A fluid's density and temperature have an inverse relationship. That is, the density of a fluid decreases as temperature increases and vice versa. As can be seen in Equations III.B-24 and III.B-25, as the density decreases, the corresponding differential pressure must decrease to maintain the relationship. Since the density is the reciprocal of specific volume of fluid (SVF), the equation may be rewritten as,

$$h2/h1 = SVF1/SVF2 \qquad \text{(Eq. III.B-26)}$$

Therefore, as temperature increases, the differential pressure produced by a meter will decrease for the same flow rate. The opposite is true for a decrease in temperature. The differential pressure error (eh) produced by the change in density can be written as:

$$eh = h2 - h1 \qquad \text{(Eq. III.B-27)}$$

Rewriting Equation III.B-26 as,

$$h2 = h1(SVF1/SVF2)$$

and substituting this into Equation III.B-27 yields,

$$eh = h1(SVF1/SVF2 - 1) \quad \text{(Eq. III.B-28)}$$

It can be observed in Equation III.B-28 (which is the process error equation for density effect on volumetric flow), that the absolute error is maximized when "h1" is maximized. This occurs at the upper end of the calibrated differential pressure span for which the transmitter is calibrated. This is also the maximum calibrated flow. The error varies from negative values for temperatures above the base value (SVF2 > SVF1), to zero for temperatures equal to the base value (SVF2 = SVF1), and finally to positive values for temperatures below the base value (SVF2 < SVF1).

Once the differential pressure error has been determined, the actual flow rate error can be determined. The actual flow rate error will vary for a given differential pressure error due to the square root relationship between "h" and "Q". The error of a flow loop is dependent on the specific flow of concern. While the maximum error of a loop can be calculated at 100% flow conditions, application of this error to lower flows may be overly conservative. The density error should be calculated for the specific flows of concern. The calculated "eh" can then be factored into the differential pressure error for the given flow condition and the true impact on flow evaluated.

Consider the following example:

EXAMPLE

The error in a flow loop due to density effects is to be determined for the following:

Assume an orifice plate is used to measure flow in a water system that is normally at 80°F. The orifice is sized to produce a differential pressure of 100 inches of water for a flow rate of 5000 GPM. Assume further that under accident conditions the temperature rises to 200°F at an actual flow of 2000 GPM.

The first step is to determine the relationship between "Q" and "h". Given that,

$$Q = k(h/D)^{0.5}$$

the constant k can be determined from the design parameters as follows:

$$5000\ \text{GPM} = k\,(100\ \text{in WC}/1)^{0.5}$$

$$k = 5000/10 = 500$$

Thus,

$$Q = 500(h)^{0.5}$$

Now, using the established constant, and the accident flowrate of 2000 GPM, we can solve for h1, or the differential pressure that would be present for the normal 80°F condition for which the orifice is sized.

$$Q1 = k(h1/D)^{0.5}$$

$$Q1 = 500(h1/D)^{0.5}$$

$$2000 = 500(h1/1)^{0.5}$$

or,

$$h1 = (2000)^2/(500)^2 = 16\ \text{inches of water}$$

Using the thermodynamic steam tables and assuming saturation conditions,

$$\text{SVF1 (at 80°F)} = 0.016072\ \text{ft}^3/\text{lbm}$$

$$\text{SVF2 (at 200°F)} = 0.016637\ \text{ft}^3/\text{lbm}$$

Substituting these into the error formulae,

$$eh = h1(SVF1/SVF2-1)$$

$$eh = 16\,(0.016072/0.016637-1)$$

$$= -0.54\ \text{in WC}$$

Therefore, the rise in temperature reduces the actual differential pressure (h2) created by the orifice to,

$$eh = h2 - h1$$

$$h2 = eh + h1$$

$$= (-0.54\ in) + (16\ in)$$

$$= 15.46\ in\ WC$$

This yields an indicated flow of,

$$Q = 500\ (15.46)^{0.5} = 1966\ GPM$$

The error induced by the density change is the difference between the indicated flow at the higher temperature condition (Q2) and the indicated flow at the normal temperature condition (Q1),

$$Q2 - Q1 = 1966\ GPM - 2000\ GPM = -\ 34\ GPM$$

This represents an error, expressed in percent of reading, of,

$$\frac{-34\ GPM}{2000\ GPM} * 100\% = -1.7\%\ \text{of reading}$$

or, as expressed in percent of span,

$$\frac{-34\ GPM}{5000\ GPM} * 100\% = -0.68\%\ \text{of span}$$

The density variation effect from a base, or calibration, condition to an actual condition of interest is a known predictable effect. As such, the effect is treated as a bias type error.

c. Effects of Piping Configuration

The actual installation of a head type flow device can affect the measurement accuracy of a flow loop. Bends, fittings, and valves in piping systems cause turbulence in the flowing fluid. This turbulence can cause errors to be induced into the differential pressure measurement.

ASME has published results of extensive testing of piping systems and guidance for various types of installations. The ASME recommendations provide the minimum acceptable upstream and downstream lengths of straight pipe needed for a specific flow meter installation to keep the effects of this turbulence from significantly decreasing a flow meter's accuracy. The piping arrangement showing locations of valves, bends, fittings, piping planes, etc. must be reviewed to verify that an installation meets the minimum requirements. Typically locations can be obtained from piping isometric drawings.

As established by Reference II.B.17, if the minimum pipe lengths are met, the resultant flow measurement error due to piping configuration will be less than ±0.5% of reading. If the minimum criteria cannot be met, an additional tolerance of ±0.5% of reading must be applied to the flow measurement error allowance.

The effects of the piping configuration on accuracy is considered to be a bias error term, since their sign is calculable.

Typically, the minimum pipe lengths for orifices are as follows:

1) On the downstream side of the device, five pipe diameters of straight run pipe is sufficient.

2) On the upstream side of the device, ten pipe diameters of straight run pipe is sufficient if the disturbance is due to flanges, collars, wide open gate valves, reducers, or bends, elbows, or tees in the same plane. Fifty pipe diameters is sufficient if the disturbance is due to piping angle turns in two planes. Seventy-five pipe diameters is sufficient if the disturbance is due to pressure regulators, valves, or similar apparatus.

To determine the minimum pipe lengths for venturis, flow nozzles, etc., consult either vendor specific recommendations, reference books, or ASME guidelines. The Mechanical Engineering Group should also be contacted, as necessary.

d. The mal Expansion Factor Effect

The basic flow equation discussed in Section III.B.3.c above includes a correction factor for expansion of the flow meter orifice or primary element due to temperature change. The correction factor is known as the Area Factor, or Thermal Expansion Factor (Fa). The factor, Fa, is dependent on the material composition of the primary element. This factor provides for changes in the flow meter orifice size due to the thermal expansion or contraction of the primary element material.

While the thermal expansion of the flow element generally has little effect on the flow measurement, the effects of large temperature gradients must be evaluated.

The values of Fa for various materials is shown in Reference II.B.17, Figure II-I-3. For a 300 Series stainless steel flow meter, a 200°F temperature change results in less than a 0.5% change in Fa. Therefore, for most applications, the effects of Fa variation need not be considered for temperature variations less than 200°F. For greater temperature variations, the effects of Fa should be evaluated. Errors induced by Fa are considered to be bias errors since their direction can be determined.

Generally, the orifice plate and the pipe are made of similar materials. Thus, the thermal expansion factor for the pipe will be very similar to that of the orifice plate, and no changes in the d/D, or Beta ratio, will occur. Significant errors may occur if this material conformity does not exist.

The following example is provided to illustrate how errors associated with Fa variation can be established.

EXAMPLE

Determine the percentage error in reading, caused by the Fa factor alone, for the following:

Initial flow rate	1000 GPM
Process calibration temperature	100°F
Process accident temperature	300°F
Orifice plate material	316 SS

From Reference II.B.17, Figure II-I-3,

Fa initial = 1.0005
Fa accident = 1.0042

If all other parameters remain constant, the basic flow formula can be written as,

$$Q = (Fa)(Constant)$$

Solving for a constant for the conditions defined above,

$$\text{Constant} = Q1/Fa = 1000/1.0005 = 999.5$$

Assuming no other effects on flow are present, the change in flow due to the change in Fa is,

$$Q2 = (1.0042)(999.5) = 1{,}003.7 \text{ GPM}$$

or an increase of 3.7 GPM. This corresponds to an error of,

$$\% \text{ Error} = \frac{3.7 \text{ GPM}}{1000 \text{ GPM}} * 100\% = 0.37\% \text{ of reading}$$

4. Temperature Measurement

When measuring temperature, we assume that the temperature at the sensor is the same temperature as the gas, liquid, or solid whose temperature we want to know. In most situations, we do not think about whether that assumption is true. But for some applications it is necessary to ensure that the sensed temperature is really the product temperature. Heat flows from a hot region to a cooler one by conduction, convection, and radiation. An accurate temperature measurement ensures that the amount of heat flowing between the point being measured and the point of concern is not sufficient to cause a significant temperature difference.

Where the differences in temperature within a medium are significant, it is referred to as temperature stratification and can affect the accuracy of the temperature measurement.

Consider the measurement of temperature, via a thermocouple, of a stirred liquid in a tank. For practical purposes, we can consider the entire volume of liquid to be at the same temperature. If we insert a thermocouple assembly with a half-inch diameter stainless steel protecting tube into the tank, heat flows along the protecting tube towards the colder thermocouple head. If the tube is immersed only one-half inch, we can sense that the thermocouple junction is probably colder than the liquid because of the temperature stratifying along the protecting tube.

As the depth of immersion is increased, the hot junction temperature more nearly equals the liquid temperature. This is because more of the protecting tube is at the same temperature as the liquid and there is little or no heat flowing in the region of the hot junction. If no heat flows, there is no temperature difference. For this reason, it is generally considered that the depth of immersion of a well or protecting tube in a tank should be at least 10 times its diameter.

The above example shows temperature stratification due to the actual measurement. In other applications, the stratification is a result of the process being monitored. The pressurizer for example, employs two different temperature detectors - one for the pressurizer liquid and one for the pressurizer steam. Both are needed to provide a representative measurement of the actual temperatures within the pressurizer.

Other examples of where temperature may be stratified are: rooms or large areas of a building, large diameter piping, tanks, piping or vessels that are heat traced or only partially insulated.

Regardless of the reason for the stratification, the potential for it to exist must be recognized and addressed in order to ensure an accurate temperature measurement. Corrections are treated as a bias, similar to head effects, to account for any temperature difference between the point of measurement and the point of concern.

C. Instrument Uncertainties

All instruments have limits on their ability to accurately perform their function. These limits of accuracy, generally expressed as inaccuracies or errors, vary, based on the specific design capabilities of the instrument, and the service within which it is used. By evaluating the various effects on instrument accuracy, a total uncertainty limit can be established for the instrument.

Each instrument has a basic accuracy established by its manufacturer. In addition, various types of instruments have different parameters which affect their basic accuracy. While one type of instrument may be greatly affected by a change in humidity, another may show no effect. The instrument's basic accuracy, and all of the applicable parameters which can affect its accuracy, must be taken into account in performing loop uncertainty analyses.

The information described below must typically be obtained from the vendor, either through product data sheets, test reports, technical manuals, etc. In order to maintain consistency between calculations that utilize the same types of devices, it is recommended that the vendor data be obtained from the same common sources. Ideally, the information should come from the plant's vendor technical manuals since these are controlled. However, some information may not be within these reports and other sources may need to be utilized. If possible, the vendor technical manuals should be updated to include any information obtained from supplemental sources. Whenever the vendor is contacted, the information obtained via letter, telecon, telecopy, etc. should be maintained in a manner that will allow subsequent calculations to utilize the same information.

The major parameters which govern an instrument's accuracy are discussed below. Additional parameters may be identified, by a manufacturer, as having an influence on the specific instrumentation. These parameters, and their effects, would be handled in the same manner as those described below.

Each of the major parameters which affect an instrument's accuracy has been assigned an abbreviation to aid in the identification of error terms within a specific error analysis. The abbreviations are indicated in the individual sections discussing the error, and a complete listing can be found in Section II.D.

1. Reference Accuracy (RA)

The Reference Accuracy (RA) of a device is the base performance accuracy of a device, typically established by the manufacturer. The RA should include the effects of hysteresis, repeatability and linearity for an instrument. Where these effects are not included, the individual effects of the omitted components should be included separately, or resolved with the vendor to be not applicable. For example, one instrument's manufacturer may provide separate values for accuracy and repeatability. If the accuracy value does not include the repeatability value, they must be combined to determine the overall reference accuracy. The vendor may provide guidance on how they should be combined, either algebraically or SRSS. If no guidance is given, they should be combined via SRSS. Figure II.C-2 provides a graphic representation of RA.

For some devices such as bistables, no reference accuracy is provided by the vendor. Instead, the vendor may only provide a value for repeatability. If the vendor states that this is the only applicable term for the device, then it can be used as the reference accuracy.

Reference accuracy is considered to be a random error component unless specifically indicated otherwise by a manufacturer, and is normally stated in terms of percent of span for the instrument.

The RA is the accuracy that an instrument can meet, and it defines the limits of acceptable performance in normal operation. The RA typically can only be met over a small band of operating conditions specified by the manufacturer.

The RA value is generally established by a manufacturer based on equipment testing. The results of the testing allow a manufacturer to statistically define the performance of an instrument, and develop an RA value with a high degree of confidence. While some disagreement exists on the degree of statistical confidence a manufacturer's RA value should have, for the purposes of this document a 95% confidence factor (or 2 σ) will be assumed. Thus, a vendor should be contacted to determine whether his published reference accuracy values represent 1, 2, 3, or some other σ value. If such information cannot be provided by the vendor, the values will be assumed to be 2σ. This is based on common industry practice. Refer to Section III.A.5. for additional discussions on statistics.

Reference accuracies should be established based on vendor information applicable to the specific equipment. In some cases, the vintage of the equipment at the plants may preclude the identification of equipment specific reference accuracies. Where no specific information can be obtained, the value for the calibration tolerance may be used as the reference accuracy. Another option may be to use the following values as reasonable representations of reference accuracy. However, the calibration tolerance or the default values should be used for the reference accuracy only after a valid effort has been made to obtain specific vendor values.

Equipment	Representative Ref. Accuracies
Thermocouples	±1.0% full scale
RTDs	±0.5% full scale
Pressure transmitters (incl. d/p)	±1.0% full scale
Recorders	±2.0% full scale
Indicators (Analog - PWRs)	±1.5% full scale
(Analog - BWRs)	±3.0% full scale
(Digital)	±0.5% full scale

Values are based on References II.B.22, II.B.23, and common industry values.

2. Drift (DR)

Drift (DR) is a natural phenomenon exhibited by instrumentation, and is caused by the changing properties of instrument components due to aging or other naturally occurring phenomena. The individual elements of an instrument all have characteristics which may vary with time. The culmination of these changes imparts a specific drift characteristic to an instrument. Drift is a measure of an instrument's stability over time, and is often referred to as stability by a vendor.

For most instruments, drift is typically considered proportional to a given period of time. As more time is allowed, the potential error due to drift increases. Some instrument manufacturers though, are able to put a bounding value on drift. This bounding allows increased time periods without incurring additional inaccuracies beyond a maximum drift value.

In a nuclear power facility, drift for a loop is generally broken into two parts, sensor drift, and signal processing drift. The two are separated to allow periodic verification of loop calibration parameters. Many times, a loop's sensor is inaccessible for calibration/verification during operation while the remaining components are accessible. By maintaining separate drift components, additional flexibility is provided for maintaining accurate instrumentation systems.

Drift is usually specified in terms of a limiting value per unit of time, and is considered a random error component unless otherwise indicated by a manufacturer. The actual drift value for a loop must be determined using the anticipated time interval between calibrations for a loop. The calibration intervals for each loop are specified as follows for each of the CP&L plants:

Brunswick - The calibration frequency of instruments is noted on the "Periodic Maintenance" screen of the Equipment Data Base System (EDBS).

Robinson - The calibration frequency of instruments is identified in MMM-006, Appendix A, "Calibration Instrument List".

Harris - The calibration frequency of instruments is identified in the Calibration Procedures (MST's, LP's) or in the Surveillance Test Scheduling System (STSS).

The calibration frequencies specified by these documents are the nominal frequencies. With regard to surveillances, the Technical Specifications allow a grace period of the nominal frequency, by an amount of 25% of the specified interval. For example, if a surveillance's frequency is specified as each refueling (i.e. 18 months), the actual frequency could be up to 18 $\pm$ 25% months, or 22.5 months. Therefore, the interval taken as the calibration interval must be the maximum interval allowed by a plant's program, and not just the nominal interval.

In many cases, the drift value specified by a manufacturer may be less than the actual calibration interval. If possible, the manufacturer should be contacted to determine if more recent drift data is available, or if he can provide guidance on how it should be applied to longer intervals than what is published. Otherwise, the drift value should be extrapolated out to encompass the calibration interval.

Consider the following example.

EXAMPLE

A manufacturer specifies a drift value of ±0.25% span for 6 months for his device. The range of the device is 0-500 psig and is calibrated from 0-440 psig. The nominal surveillance interval is 18 months.

The simplest and most conservative approach is to assume that the drift is linear with respect to time. This would provide a drift value of,

18 months ± 25% = 22.5 months

$$\frac{(22.5 \text{ months})}{(6 \text{ months})} * \frac{(500 \text{ psig})}{(440 \text{ psig})} * 0.25\% = \pm 1.07\% \text{ cal. span}$$

Note that the manufacturer specified a drift value of ±0.25% span. Frequently, vendors specify a value in terms of span which correlates to range, not calibrated span. That was the case here. Thus the range of the instrument, 500 psig, is divided by the calibrated span the instrument is used for this application, 440 psig. This factor is frequently referred to as the Turndown Factor (TDF) or turndown ratio. Anytime a value is being converted from units of range or actual span of an instrument to its calibrated span, the turndown factor must be applied.

As stated above, treating the drift linearly is a rather simple and conservative approach. A more realistic assumption is that the drift is random and independent with respect to each time interval. Based on this assumption, the drift may be calculated using the SRSS method. Using the SRSS method, the drift would be calculated as follows,

18 months ± 25% = 22.5 months or, ~ 4 separate 6 month intervals

$$DR = [\ (0.25)^2 + (0.25)^2 + (0.25)^2 + (0.25)^2\ ]^{0.5} * \frac{(500)}{(440)}$$

$$DR = (4)^{0.5} * (0.25) * \frac{(500)}{(440)}$$

$$DR = \pm 0.57\% \text{ cal. span}$$

Although either method may be used, the SRSS method is .he preferred method for the CP&L plants.

The drift value for a device should primarily be obtained from vendor information. However, there may be some instances where either vendor data does not exist, or the vendor data is rather conservative and it is desirable to try to use another method. A drift value for a particular device can be inferred from an analysis of the device's calibration history. The methodology for calculating drift in this manner is described in both Section 6.2.6.3 and Appendix E of Reference II.B.3.

There are several important points which must be understood however, prior to determining drift from as-left/as-found data. First, it should be recognized that the use of as-left/as-found data may actually provide a higher drift value than provided by the manufacturer. Another potential issue is that the analysis may identify that the actual drift for a device is not random, and normally distributed. Thus, instead of being able to SRSS the drift value, it may have to be treated as a bias.

Another factor to consider when assessing whether to determine device specific drift values from as-left/as-found data, is that such an analysis may be rather time consuming. To establish a proper population size often requires collecting numerous surveillance/calibration test results. Each application must also be evaluated for any factors which may cause its data to be different from other applications. As noted in Reference II.B.3, the as-left/as-found data typically includes uncertainties other than drift, such as temperature effects, humidity, power supply variations, etc. Thus, if possible, such effects should be separated from the as-left/as-found data to provide a value that is more representative of just the drift uncertainty.

When drift values cannot be obtained from a vendor, and analysis of as-left/as-found data is not feasible, default values for drift can be used. However, these should only be used after a reasonable effort has been made to obtain a drift value via another method. Per Reference II.B.23, typical values which may be assumed for drift are ±1.0% full scale for 18 months for a sensor and ±1.0% full scale for 18 months for the total rack, or signal processing equipment.

If default values are used for safety-related applications, then once enough as-left/as-found data is available to calculate a drift value, such data should be used to replace the default values.

3. Temperature Effect (TE)

Temperature effect (TE) is the term given to the change in an instrument's accuracy due to changes in ambient temperature. Generally, all instruments exhibit some form of TE. The temperature effect is normally stated by a manufacturer in terms of accuracy change per unit change in temperature within the normal operating limits of the device. The TE is caused by changes in temperature between the ambient temperature at time of calibration, and the ambient temperature in normal operation.

The temperature effect is normally stated as an additional percent of span error per unit of temperature. For an instrument transmitter, though, the TE may be stated in terms of the transmitter range. For example, a typical Rosemount Model 1153D transmitter has a TE of,

$$TE = \pm(0.75\% \text{ Upper Range Limit} + 0.5\% \text{ of span}) \text{ per } 100°F \text{ change}$$

In this case, the resulting error from the Upper Range Limit (URL), must be calculated and corrected to a percent of span limit before the true TE can be determined. The 1153D transmitter can have any of eight different URLs varying from 30 inches of water to 4000 psi. The proper URL value must be multiplied by 0.75% and divided by the actual span for the transmitter to convert the value to percent of span.

For example, if the URL was 1000 psi and the actual span was 800 psi, the resulting TE would be:

$$TE = \pm \left[(0.75) * \frac{(1000)}{(800)} + (0.5)\right]$$

$$TE = \pm 1.44\% \text{ calibrated span per } 100°F$$

In addition to the TE for normal operating limits, many field mounted devices have an accident temperature effect. The accident temperature effect provides the limits of uncertainty for an instrument when operated outside its normal operating limits. This is discussed further in Section III.C.7.

The temperat· re effect is considered a random error term unless otherwise specified by a manufacturer. For Harris and Robinson, the TE is calculated from the maximum range of temperatures for a given location, unless otherwise justified. For Brunswick, the TE is calculated for an assumed calibration temperature range of 65-90°F. Thus, if the maximum range of temperatures for a location is 40-115°F, then the TE would be determined for a temperature difference of 50°F (i.e., 115 - 65 = 50 and 90 - 40 = 50).

The normal temperature bands for plant areas at each of the CP&L plants is presented in the following documents:

Brunswick - Drawing D-3056

Robinson - Drawing HBR2-11260

Harris - FSAR Table 9.4.0-1, FSAR Section 3.11B and FSAR Section 6.2.2.

The temperature band an instrument is normally expected to be exposed to can be determined from the entire design range of temperatures in its location (which is very conservative), or determined from the difference between its assumed calibration temperature and the ranges of temperatures identified in the above documents. One qualification should be added to this guidance, however. For panel mounted equipment, the normal temperature band for an instrument's location should be increased by 10°F. This is to account for the elevated temperatures above the ambient room temperatures inside the racks/panels.

It should be noted that the temperatures identified in the above documents are intended to bound all locations within the stated area. Thus, after further evaluation, these temperatures could potentially be reduced for a specific location.

As an example of how to use the temperature bands and the assumed calibration temperature, consider the Rosemount 1153D transmitter discussed above, located in the Brunswick Reactor Building. Per Brunswick Drawing D-3056, the normal ambient temperature inside the Reactor Building is between 40 and 104°F. The assumed calibration temperature for a sensor, as described above, is 65-90°F. Therefore, the expected temperature change for such a transmitter is,

$$\Delta T = 90 - 40 = 50°F$$

and,

$$\Delta T = 104 - 65 = 39°F$$

The largest expected temperature difference is 50°F and is combined with the vendor specified temperature effect per 100°F determined above to provide the specific temperature effect for this application.

$$TE = \pm 1.44\% \text{ cal. span} * \frac{(50°F)}{(100°F)}$$

$$TE = \pm 0.72\% \text{ cal. span}$$

As with the other instrument uncertainties, the TE should be obtained from vendor specific information, combined with the ambient temperature change for a given location. However, in some instances such data may not be available. If, after a reasonable effort has been made to obtain vendor specific data, no such data can be identified, default values can be utilized.

Based on the temperature bands for each of the plants, a typical value of TE for components located within the Reactor Building at Brunswick, or within Containment at either Robinson or Harris, would be ± 1.00% full scale. For instruments in other plant locations, a typical value for TE is ± 0.50% full scale.

4. Static Pressure Effect (SPE)

Most differential pressure transmitters exhibit an error effect related to the static pressure (SPE) imposed by the process. The static pressure effect can cause changes in a transmitter's calibration parameters (at both full and zero span) which affect its basic accuracy. Some manufacturers quote the SPE in terms of basic accuracy changes, while others indicate changes in both a transmitter's zero, and full span calibration parameters. Care must be taken in determining the actual SPE for a transmitter, as it often requires the review of both the manufacturer specifications, and the plant calibration procedures.

Consider the following example,

EXAMPLE

Rosemount, for its model 1153D transmitters, states that the static pressure span effect is systematic and can be compensated for through calibration measures. If "calibrated out", a correction uncertainty of ±0.5% reading/1000 psi would remain. A separate static zero effect is specified as ± 0.2% URL per 1000 psi and ± 0.5% URL per 1000 psi, depending on the range code of the transmitter.

Although not specifically stated, the zero effect can also be "calibrated out". Before including either a zero or span SPE error term in the uncertainty calculation, a check should be made to determine whether the plant calibration procedure does or does not "calibrate out" these terms. As noted, however, even if both terms are "calibrated out", a correction uncertainty still remains.

Using the above Rosemount transmitter example, assume it is a Range Code 4, with a range of 0-150 in WC, and is calibrated for 0-100 in WC, at a maximum static pressure of 1700 psi. Also, assume that the zero and span effects are "calibrated out". The resulting static pressure effect would be,

$$SPE = \pm 0.5\% \text{ of reading} * \frac{(1700 \text{ psi})}{(1000 \text{ psi})}$$

$$SPE = \pm 0.85\% \text{ of reading}$$

The static pressure effect is considered a random error unless otherwise indicated by a manufacturer. The SPE is only applicable to differential pressure transmitters in high static pressure process service. For process static pressures less than 200 psi, the SPE generally need not be considered, since the resultant error is negligible. If, for a particular manufacturer, the SPE can be determined to be greater than 0.05% of span at less than 200 psi, the effect should be included.

It is important to note that normally the maximum static pressure which the sensor may realize should be used in calculating the static pressure effect. This may be from any expected normal, test or accident process conditions. The range of such process conditions may be obtained from the UFSAR, System Descriptions, DBDs, Calculations, etc.

5. Overpressure Effect (OP)

The overpressure effect accounts for errors in a transmitter's performance after exposure to process pressures in excess of its normal design range. In general, the overpressure effect is not required to be included in loop error analysis. Most loops are designed to operate within their worst case process conditions, which include the worst case process pressure.

6. Power Supply Effect (PSE)

All electronic instrument loops are powered by low voltage power supplies designed to maintain the loop voltage and current for the loop devices. Power supplies vary from loop to loop with some supplied from unregulated sources while others have precision regulated supplies. Variations in the loop voltage can cause variations in an instrument's accuracy. This variation is called the power supply effect (PSE).

The instrument loops which contain transmitters are generally 4-20 mA current loops, which require a driving potential of 12 to 40 VDC. Selection of the power supply for a specific loop is based on the configuration of the loop, and the required voltages of the individual devices in the loop. Once set, the voltage is generally not changed unless loop performance is unsatisfactory.

The (PSE) effect is determined based on the variation in the power supply voltage. Consider the following example,

A Rosemount 1153D transmitter has a (PSE) value of less than 0.005% of output span per volt of change. For an unregulated power supply with a voltage variation of ± 4 VDC, the PS becomes,

$$(PSE) = \pm (0.005\%) * (4)$$

$$(PSE) = \pm 0.02\% \text{ output span}$$

For instruments with regulated power supplies, the PSE effect may be negligible because the regulation keeps the voltage variations small. This, coupled with the generally minor effects of the pwer supply per volt, may allow the PSE effect to be eliminated.

Since some loops may have unregulated power supplies, the PSE effect cannot be totally eliminated for all loops. The variations in individual loop power supplies should be determined from the following sources:

BSEP - Vendor information for the applicable loop power supply.

HBR - Calculation RNP-E-1.005 can be used to determine the voltage variations for instrument busses. Other individual electrical calculations can be used for determining the variations of all other power supplies.

SHNPP - Vendor information for the appliable loop power supply.

The PSE effect is considered a random error due to the generally random variation in actual supply voltage. Where the PSE effect is found to be less than ±0.05% of span, the effect can be ignored. Since this is typically the case, if no device specific data for the PSE can be found, it can be ignored. If however, device specific information is found, it should be compared to the ±0.05% of span to determine whether or not it should be included in the uncertainty calculation.

Similar consideration of the PSE effect must also be applied to pneumatic instrument loops (i.e. "bubbler" type loops). For these cases, the PSE effect may be contingent upon the maximum variation allowed by the pneumatic regulator as well as the voltage variation. The sensor should have an associated uncertainty given in terms of this variation. If not, the manufacturer should be contacted to obtain this uncertainty.

7. Accident Temperature Effects (ATE)

Instruments which can be exposed to severe ambient conditions as a result of an accident, and which are required to remain functional during or after an accident, may have additional accident related error terms which must be considered in a loop accuracy analysis. These additional terms account for the effects of extreme temperature, radiation, pressure, and seismic/vibration conditions.

Environmentally qualified (EQ) instruments make up the largest portion of the instruments exposed to severe ambient conditions. However, additional instruments may also exist, besides just the EQ instrumentation. The effects are generally applied only to the field mounted devices, but some accident related errors may also be experienced by other instruments in the loop. For example, a loop device mounted in a controlled environment which experiences a temperature rise after an accident due to changes in HVAC performance should be included in an accident error analysis.

The accident error effects are a separate set of accuracy values generally derived from the environmental qualification testing of an instrument. Based on this testing, manufacturers establish worst case performance specifications for the instruments. These specifications are based on generic accident temperature, pressure, and radiation profiles which envelope values at multiple nuclear facilities. As a result, the profiles are worst case conditions which should meet or exceed the specific conditions at each of the three CP&L plants.

The applicability of accident error effects in a specific loop analysis is based on the loop's functional requirements. Accident error effects are time dependent, occurring from the initiation of an accident/event through long term recovery. The effects are normally not instantaneous. Many instrument loops, primarily those in the Reactor Protection System (RPS) and Engineered Safety Features Actuation System (ESFAS), meet their intended function before being significantly affected by accident environmental conditions. For such loops, the accident error effects may not have to be included in the analysis. Care must be taken, though, to ensure that all functional requirements are evaluated against potential accident conditions. Many loops perform accident mitigation functions (not requiring accident effect consideration) initially, and then perform additional post accident functions which require accident effect considerations.

For most instrument loops, the manufacturer's accident performance specification is utilized for the accident effects. When more specific Accident Effect (AE)data is available, more realistic terms can be developed. Accident error terms can be developed based on the actual qualification test results, and plant specific accident parameters. The extrapolation of accident terms should, where possible, be based on actual test data rather than being based on manufacturer's performance specifications.

However, care must be taken when reviewing, and establishing, specific accident effects based on actual test data. In general, the accuracy of test data is limited by both the number of tests performed, and the sample size (number of instruments tested). These limitations can lead to many unexplained variations in test results, and raise questions as to the validity of the test data. The use of actual EQ test data should be limited to cases where sufficient test data exists to clearly substantiate an interpolation/extrapolation.

The format in which the accident error is supplied can vary from manufacturer to manufacturer. One manufacturer may provide an uncertainty based on the consolidation of multiple accident effects (temperature, pressure, humidity, etc.). Another manufacturer may provide an uncertainty for each accident effect. If the accident effects are consolidated into one uncertainty value, it may be necessary to segregate the accident radiation effects from the other effects. This may be necessary if the device is in a radiation harsh environment only (i.e. it is not exposed to the other effects). It may also be necessary because the total of all accident effects results in an extremely high value, and are not all applicable to a specific application.

Following an accident inside containment , all of the accident effects except radiation will be present rather quickly. The radiation effect is typically contingent upon the total integrated dose (TID) rather than the dose rate, but on occasion can be contingent upon the dose rate. For those instances where the radiation effect is contingent on the TID, it may not become a significant factor until quite sometime following the accident. Once the radiation effect does become significant, the other accident effects typically have been reduced to near normal conditions. Therefore, it may only be necessary to incorporate one of these effects, either the accident radiation effect or the combination of the other accident effects.

Evaluating the "timing" of the different accident effects, as discussed above, is normally not done for each instrument loop. This method is only employed whenever the total device or loop uncertainty is unacceptably high due to using all accident effects simultaneously.

If a manufacturer only lists one accident uncertainty and it is not necessary to segregate the individual effects, the effect will be referred to as the accident temperature effect.

Frequently, the ATE is the largest contributor to an instrument's inaccuracy during an accident. While a field mounted device, such as a transmitter, may be able to perform well under design temperatures of up to 200°F, an accident temperature of near 300°F can cause severe changes in performance. Typical inaccuracies of 5% to 10% are not uncommon.

The accident temperature effect (ATE) is generally obtained from the manufacturer's performance specifications. For a Rosemount Model 1153D transmitter, for example, the accident temperature effect (given as Steam Pressure/Temperature) is:

$$ATE = \pm(4.5\% \text{ Upper Range Limit} + 3.5\% \text{ span})$$

The specification sheet details the temperature, pressure, and duration of the test accident profile on which the performance is based. The actual worst case error can be calculated by substituting the upper range limit value for a specific transmitter, converting to percent span, then adding the 3.5% span. The temperature profile used by the vendor should be compared with the plant specific accident temperature profiles. The plant's specific profiles must be fully enveloped by the actual test profiles for the specification to be valid.

The accident temperature profiles for each plant can be found in the documents identified below:

BSEP -	Drawing D-3056
HBR -	Drawing HBR2-11260
SHNPP -	Section 3.11B of the FSAR

As another example, consider a Foxboro Model N-E11 transmitter, whose specification sheet shows three different error terms related to temperature. Each term is valid at a different temperature, causing the error term to change with time after an event. Based on the functional requirements of the specific loop, the accident temperature effect can be minimized since the error varies from ±8% to ±3% over the duration of the test.

The acceptability of a particular device's environmental qualification should be documented in a QDP (Qualification Data Package) for BSEP, or a EQDP (Environmental Qualification Data Package) for HBR and SHNPP. The applicable QDP/EQDP should be reviewed to ensure that all assumptions, constraints, etc. documented for the device's qualification are consistent with the device's useage and design basis. The NED I&C Supervisor should be notified if a device is required to operate in an accident environment but does not have a qualification package.

The components which have a qualification package are listed in the following documents:

BSEP - The EQ Master List maintained by the NED EQ Group

HBR - TMM-019, "List of Environmentally Qualified Electrical Equipment"

SHNPP - 2166-S-2500, "Equipment Qualification Master List"

The accident temperature effects are considered to be random error terms unless otherwise indicated by a manufacturer. When an accident temperature effect is included in an error analysis, the normal temperature effect (TE) would not be included in the portion of the calculation addressing accident effects. Note that an increase in the temperature may yield a Bias condition in a Reference Leg, for example, that needs to be accounted for.

8. Accident Pressure Effects (APE)

Accident pressure effects can occur for some instrumentation because of the large increase in ambient/atmospheric pressure associated with an accident. While most instrumentation is not affected by changes in atmospheric pressure, devices which use local pressure as a reference of measurement can be greatly affected. Of primary concern are gauge pressure transmitters which may use the containment pressure as the reference atmospheric pressure. Loop error analysis must take into account the containment pressure over time following an accident for the gauge transmitter. If the transmitter uses a sealed reference to establish the gauge pressure, no additional error will be encountered.

Accident pressure effects will generally not be included in an error analysis except for the reason cited above. The accident pressure effect is only to be included if specifically required by an instrument manufacturer. The effect can be treated as either a random error, or bias error, depending on the manufacturer's specifications, and the level of predictability of the error. In other words, for the example cited above, the error would be treated as a bias if it is known that the pressure increase causes the transmitter to read less than actual pressure.

The QDP/EQDP should also be reviewed and evaluated when identifying the APE, as discussed above for the ATE. The accident pressure profiles for each plant are identified in the same documents that list the accident temperature profiles, as noted above.

9. Accident Radiation Effect (ARE)

High radiation levels caused by an accident are yet another effect which can greatly influence an instrument's accuracy. Electronic instrumentation may be affected by both the rate of radiation, and the total radiation dose to which it is exposed. In normal operation, radiation effects are small and can be calibrated out during periodic calibrations. Accident radiation levels can exceed an instrument's normal life time radiation dose by a factor of 10 to 100. This high radiation exposure can increase instrument error by as much as 10%.

Accident radiation effects are also determined as part of a manufacturer's environmental qualification testing. Generally, the effect is stated as a maximum error effect for a given integrated radiation dose, typically 10^7 or 10^8 Rads. The accident radiation levels used for testing are chosen so as to envelope maximum dose levels expected at a large sampling of plants.

Because of the irradiation process used in EQ testing, very little interpolation of error effect versus radiation is possible. When an instrument must function during or following exposure to high radiation levels, the manufacturer's performance specification values should typically be used. Comparison of manufacturer tested radiation levels to the plant specific radiation levels should be made, to ensure the dose rates and TIDs used for the tests envelope the plant profiles. These profiles are identified in the same documents as noted above that contain the accident temperature and pressure profiles.

The accident radiation effect is considered to be a random error component unless otherwise determined by a manufacturer.

10. Seismic Effects (SE)

Some instrumentation experiences a change in accuracy performance when exposed to equipment or seismic vibration. The vibration can cause minor changes in instrument calibration settings, component connections and/or sensor response. The seismic effect may have different values for seismic and post-seismic events. Care must be taken when establishing loop functional requirements so as to establish loop accuracy under the anticipated conditions.

The licensing design bases for the CP&L plants does not require both seismic and accident conditions to be analyzed concurrently. That is, it is not considered probable that both a seismic event, and a design basis accident would occur at the same time.

Based on this assumption, either the SE or accident effects (ATE, APE, and ARE) may be eliminated from the uncertainty calculation whenever an instrument must operate both under seismic conditions and accident conditions. Therefore, whenever an instrument is required to operate for a seismic event and for accident conditions, the greater of either the SE or the accident effects should be used in the uncertainty calculation.

The components that have been designed to withstand a seismic event are identified within each plant as Seismic Class 1. However, some of these devices are intended to operate during or post-seismic and some are only intended not to fail. That is, some devices are intended not to change state or cause accident conditions because of the seismic event. Such devices are not required to operate for the seismic event, they are designed not to fail.

The SE uncertainty should be determined for all components that are designated Seismic Class 1. If the inclusion of this effect becomes too restrictive, the instrument can be evaluated further to determine if the instrument is only intended not to fail during a seismic event. In this case, the SE term could be deleted.

The seismic profile which the component was tested and qualified to must be compared to the plant specific profile to ensure that the test conditions envelope the plant conditions. The NED Civil Group can provide the seismic profiles which must be considered for specific Seismic Class 1 instrumentation.

The seismic effect should be considered a random error term unless otherwise indicated by a manufacturer.

11. Readability (RE)

In instrument loops in which the final output device is an indicator or recorder, the readability of the output device must be taken into account in the loop uncertainty analysis. The readability of an analog indicator/recorder is based on the interval between scale demarcations. The indicator's/recorder's scale demarcations, and calibrated span, are used to define the readability of the device.

It is important here to differentiate the difference between the readability of the indicator/recorder for calibration purposes and its readability during operation. When calibrating an indicator/recorder, an input test signal will be provided by M&TE and the "output" will be directly read from the indicator/recorder. The output is typically aligned on the scale demarcations during the calibration process. If so, no additional M&TE error must be considered for reading the value. Otherwise, an additional readability error, as discussed below, must be considered for the M&TE error.

For an indicator/recorder, however, there is a separate readability that must be included for its use by an operator. An actual signal will not always line up on the scale demarcations. The operator is forced to interpret the indication as a function of how close the indicated signal is to the demarcations. Operator A may interpret the signal as closer to the higher demarcation, Operator B may interpret the signal to the lower demarcation, and Operator C may take the mean between the demarcations. Thus, an error is introduced into the total loop uncertainty based upon an individual operator's ability to interpret the indication. This is the readability uncertainty of concern.

For linear analog indicators and recorders, readability (RE) is generally defined as one half of the smallest scale increment.

$$RE = \tfrac{1}{2}\ \text{smallest scale demarcation} \qquad \text{(Eq. III.C-1)}$$

This definition is based on limited interpolation of process values between specific scale markings. This interpolation is limited by scale pointers, potential parallax, and operator judgment.

While some indicators and recorders may allow more detailed interpolation of readings between scale markings, it cannot be ascertained that an operator will accurately perform this interpolation on a consistent basis. The plasma type indicators are a good example. While the indicators are actually comprised of approximately 200 discrete scaled segments, an operator does not count the segments to determine a reading. Most readings are obtained from a distance which makes the segments indiscernible. Therefore, unless an instrument has a specific evaluation and justification identifying why its readability can be some other value, readability will be considered to be one-half the smallest increment scale.

Consider the following example,

A control board indicator displays a pressure signal. The indicator is scaled from 0 to 1000 psi and has minor scale marking every 20 psi. The indicator uses a pointer to show pressure, and it is located somewhere between 520 psi and 540 psi. Whenever the pointer is between scale markings, an operator reading the indicator generally only has the ability to determine one of three possible values for the parameter, 520 psi, 530 psi or 540 psi. The ability to interpolate more precisely than 10 psi is limited. The operator can judge whether the pointer is closer to the 520 psi mark or the 540 psi mark, or is approximately halfway between the two marks. The readability of the indicator is therefore ½ of 20 psi, or, 10 psi.

The readability defines the highest degree of accuracy that a loop can have through an indicator or recorder. That is, the accuracy of an instrument, or loop, cannot be greater than the final output device's readability.

Indicators or recorders with digital displays do not follow the same definition of readability as analog displays. Since no scale is used for the digital display, no interpolation is necessary by an operator. The readability of digital displays is equal to the value of the least significant digit in the display.

Readability is typically considered a random error term, since it is an objective variable.

D. Other Errors

In addition to the basic performance uncertainties of process measurement, external influences on the loop can affect accuracy. These influences are totally independent of loop process and instrument errors, but impart an additional level of uncertainty to a loop's measurement, and as such, must be considered in any error analysis calculation.

1. Calibration Errors

The cornerstone of all instrumentation performance, and accuracy, is the calibration process. The instrument and loop calibration(s) establish the baseline parameters necessary for accurate measurement and presentation of information. The calibration process consists of two important facets; 1) the calibration procedure itself, and the tolerances that are allowed in calibrating the device (or loop segment); 2) the measurement and test equipment used during calibration. Both of these directly affect the performance of an instrument and/or loop and are discussed in detail below.

a. Calibration Tolerances

The calibration process is used to adjust an instrument, or loop, to ensure that it functions within an acceptable set of limits. Calibration tolerances are the defined limits, above and below a desired value, within which an instrument or loop signal may vary and still be considered acceptable. Calibration tolerances are established to aid technicians in the calibration of instrument loops and devices. The calibration tolerances prevent unnecessary adjustment/calibration of devices when they are within their acceptable bounds.

For example, if a device has a reference accuracy of ±0.25%, calibration of the device to a tolerance less than its reference accuracy (say ±0.1%) cannot increase its accuracy. Since the output of the device may vary continuously by ±0.25%, calibration adjustment of the device to tolerances set less than the RA would be futile in that the device cannot maintain calibration to these tight tolerances. Even if possible during the calibration process, the device cannot be expected to maintain performance to these tight tolerances between successive calibrations.

Calibration tolerances define for the instr ment technician the acceptable band of operation for a device or loop. The calibration tolerance is defined for each calibration point of a loop. Usually, the calibration tolerance included within the loop uncertainty/setpoint calculation is obtained directly from the device's/loop's calibration procedure.

For the three CP&L nuclear plants, the calibration tolerances for a device are generally established within the calibration procedures as follows,

BSEP - MMM-002 describes how calibration tolerances should generally be established equal to a device's reference accuracy.

HBR - MMM-006 describes how calibration tolerances should be established in accordance with the type of device, and provides tolerances for specific device types.

SHNPP - Ultimately the setpoint document specifies tolerances to scaling document which specifies all tolerances for cal procedures. Where there is no scaling documents, the setpoint document MMM-005 specifies tolerance. Therefore, the list of priority is (1) Setpoint Document, (2) Scaling Document, (3) MMM-005, (4) MMM-04. MMM-005 also specifies device tolerances for generic device types for any devices which do not have a calculation or worksheet.

Calibration tolerances must be established for all instruments, devices, and loops, including setpoint bistable devices, and output indicators. The upper and lower setpoint limits, discussed later in Section III.G.2.c, are tolerances.

The calibration tolerance does not necessarily have to be limited to a component's reference accuracy. Additional margin or tolerance is acceptable in selected instrument or loop calibrations, as long as the functional requirements can still be satisfied.

Thus, the Calibration Tolerance (CAL) can be defined as that uncertainty allowance that is applied to a loop error analysis to compensate for the reference accuracy (RA) of the instrument (or loop segment) which is being calibrated, as well as, for any additional potential calibration setting

uncertainties allowed.

As described above, each plant has its own guidelines for establishing a calibration tolerance. However, each plant also has a policy that states that the measuring and test equipment error should be less than or equal to the error of the device/loop being calibrated. While this policy is discussed further in Section III.D.1.b below, it directly affects the establishment of the calibration tolerance.

For each calibration, the calibration tolerance is used to account for the reference accuracy of a device. Thus, the error attributable to the test equipment should be less than or equal to the calibration tolerance of the device/loop being calibrated. If the test equipment error is higher than the device/loop being calibrated, two options are generally available - either utilize more accurate test equipment, or if this is impractical, increase the calibration tolerance.

Therefore, the guidelines for calibration tolerance should be as follows,

1. The measuring and test equipment accuracy should be better than or equal to the calibration tolerance of the device/loop being measured.

2. If the calibration tolerance is greater than or equal to the reference accuracy it may be used in place of the reference accuracy.

One assumption that is inherent in replacing the reference accuracy with the calibration tolerance is that the calibration process verifies all of the attributes of reference accuracy. As previously discussed in Section III.C.1, the reference accuracy represents the combined effects of linearity, hysteresis, and repeatability. If the calibration checks multiple points along the span of the device, it verifies the linearity. If the calibration checks these points in both an increasing and decreasing direction, it verifies the hysteresis. If the calibration checks the points in both directions several (i.e., three or more) times, it verifies the repeatability.

All of the calibrations used for the CP&L plants verify linearity, and most verify hysteresis; however, few verify repeatability. The individual calibration procedure should be reviewed to identify for each calibrated device, which specific attributes are verified during calibration.

If all f the attributes are not verified during the calibration, then the attributes that are not verified must somehow be compensated for within the uncertainty calculation. Reference II.B.3 provides four separate ways of addressing this problem. Although any of the methods described in Reference II.B.3 may be used, the simplest method is to include both the calibration tolerance and the reference accuracy within the uncertainty calculation. However, this may be too conservative an approach for many devices. An alternate method would be to assume that each of the three attributes affects the reference accuracy equally such that the SRSS of the three attributes would equal the reference accuracy,

$$RA = (x^2 + x^2 + x^2)^{1/2} \qquad \text{(Eq. III.D-1)}$$

where x represents each attribute. If the calibration procedure did not verify one attribute, then the value for x could be substituted for the reference accuracy and used with the calibration tolerance. Similarly, if the calibration procedure did not verify two attributes, then the SRSS of x and x could be substituted for the reference accuracy and used with the calibration tolerance.

Consider the following example,

EXAMPLE

A transmitter has a reference accuracy of ±0.25% and a calibration tolerance of ±0.50%. The calibration procedure only checks 5 points of the transmitter's span in one direction.

If there is enough margin in the uncertainty calculation, both the reference accuracy and the calibration tolerance should be used. If not, the value that could be substituted for the reference accuracy could be determined as follows,

$$\pm 0.25\% = (x^2 + x^2 + x^2)^{1/2}$$

$$x = \pm 0.144\%$$

Since the calibration did not verify two attributes (i.e., hysteresis and repeatability), then the substitute reference accuracy term would need to account for both of these attributes.

Substitute RA = $\pm(0.144^2 + 0.144^2)^{1/2}$

Substitute RA = ±0.20%

Thus, the uncertainty of the device would be determined by SRSS of the ±0.20% value for the substitute reference accuracy, the ±0.50% for the calibration tolerance, and any other applicable device uncertainty terms. It should be noted that not all terms are random. Only random terms are included in the SRSS calculation.

b. Measurement and Test Equipment

Measurement and Test Equipment is the general name given to all of the equipment required to calibrate instrumentation. The test equipment includes voltmeters, ammeters, resistance decade boxes, test gauges, test point or test resistors, deadweight testers, etc. All test equipment must be controlled and calibrated to known standards. The calibration of test equipment must be done using highly accurate precision standards which are traceable to the National Institute of Standards and Testing (NIST), formerly the National Bureau of Standards (NBS). This standardization provides known bases for test equipment accuracy, and allows for the determination of the test equipment effects on plant instrumentation.

All test equipment used for the CP&L nuclear plants is controlled by site specific programs to ensure that traceability is maintained. Test equipment is periodically re-calibrated and verified to be within known limits. Each of the CP&L nuclear plants has established a policy that requires all test equipment used in the calibration of instrumentation to be at least as accurate as the instrument being calibrated. For example, if an instrument has a reference accuracy of ±0.25% of span and is calibrated to ±0.25% of span, the combined accuracies of the test equipment used in calibrating the instrument must be less than or equal to ±0.25% of span.

The basic accuracy of test equipment is generally not documented in relation to the accuracy of the instrument or loop being calibrated. Instead, test equipment accuracy must be converted to an equivalent instrument or loop accuracy value, by factoring in the test equipment range in terms of the instrument (or loop) span.

Consider the following example,

EXAMPLE

A multimeter (MM) with an accuracy of ±0.25% of its range is to be used to calibrate a pressure transmitter. Transmitter span is 4-20 mA. The MM has a 0-20 mA and a 0-50 mA range. The accuracy of the multimeter can vary depending on the MM range used.

MM accuracy = (0.25% of MM Range)/(Transmitter Span)

Therefore, MM accuracy on the 0-20 mA range is,

$$\frac{0.25\% * 20 \text{ mA}}{16 \text{ mA}} = 0.31\% \text{ of span}$$

The MM accuracy on the 0-50 mA range is,

$$\frac{0.25\% * 50 \text{ mA}}{16 \text{ mA}} = 0.78\% \text{ of span}$$

As can be seen, the basic accuracy of the test equipment and the proper selection of test equipment range is important. The final test equipment accuracy, expressed in equivalent instrument or loop accuracy units, must have an overall accuracy less than or equal to the accuracy (i.e., calibration tolerance) of the device/loop being calibrated. Thus, for this example the calibration tolerance would have to be greater than or equal to 0.31% to account for the multimeter or, a more accurate multimeter used.

The Measurement and Test Equipment Error (MTE) is that uncertainty allowance included in the loop uncertainty calculation, to account for the uncertainty imposed into a loop component, or loop, as a result of the calibration using imperfect measurement and test equipment. The MTE term is, in essence, the uncertainties associated with measurement and test equipment used to calibrate the loop, or component. When a component is calibrated, the reference accuracy errors associated with the test equipment are imposed on the component. That is, reference accuracy errors associated with the test equipment are transferred to the loop component being calibrated. These additional errors bias the future performance of the component, after calibration. As such, the MTE error and the CAL, are treated as random, but dependent, terms. In the uncertainty analysis, these two terms would be algebraically combined with each other before being statistically (SRSS) combined with the other random terms.

In order to determine the MTE for a device/loop, the applicable calibration procedure should be reviewed. The calibration procedure will identify the test equipment to be used for the calibration. The test equipment may be identified specifically via manufacturer and model (i.e., Fluke 8600) or only generically as to type of test equipment (i.e., Digital Voltmeter). Typically, the M&TE error is determined from the "worst case" accuracy for the types of M&TE specified, in order to provide the I&C technicians the most flexibility in performing the tests. If there is not sufficient margin in the total loop uncertainty to accomodate this flexibility, the M&TE can be calculated for specific M&TE. If this changes the calibration procedure, the plant I&C staff should be contacted and this matter discussed with them to ascertain if any other options are available.

For new or revised loops, the calibration procedure may not exist prior to performing the uncertainty/setpoint calculation. In this case, the calculation should be developed using assumed test equipment that is used in similar types of existing loops. The assumed equipment must be identified to the preparers of the calibration procedure, so that such equipment, or better, may be incorporated into the calibration.

The listing of measuring and test equipment available for a plant and its associated accuracy, is maintained in the following locations:

BSEP - Test Equipment Room Bar Code Computer, kept by the Site Test Equipment Room Attendants.

HBR - MMM-020 provides a listing of the test equipment available at HBR and its associated range and accuracy.

SHNPP - Required Test Equipment Accuracy in MST and LP as well as guidelines for determining, are in MMM-005, Instrument Loop Calibration Procedure.

When multiple measurement and test equipment devices are used in the calibration of a component, the MTE error imposed on the component is determined by combining, using SRSS, the individual MTE errors associated with each individual M&TE device.

Consider the following example,

EXAMPLE

Assume a transmitter, with a reference accuracy (and calibration tolerance) of ±0.50% of span, is calibrated using a deadweight tester and a multimeter, each with a reference accuracy error equal to ±0.25%. The MTE error is:

$$\text{MTE} = \pm (0.25^2 + 0.25^2)^{0.5} = \pm 0.354\%$$

When combining the errors for test equipment, one device that is frequently overlooked is a test resistor. This includes any such resistors that may be installed in the loop to facilitate testing/calibration, as well as any resistors provided by the technician for performing a specific calibration. Whenever any such resistor is used as part of a device's/loop's calibration, it should be evaluated for inclusion in the determination of the MTE term. (Typically, the effect due to resistors accurate to ±0.01%, will be negligible.)

As an illustration of MTE error, consider a device used to measure an absolute value such as a primary standard, or to measure barometric pressure, at sea level, on a perfect day (29.92 in Hg = 0.000 psig). If this device has an accuracy of ±0.5% of span, then its output can vary by as much as 0.5% from its ideal value, with the input held at this absolute value. Therefore, the output has a bandwidth of 1.0% span, centered about the absolute value, see Figure III.D-1.

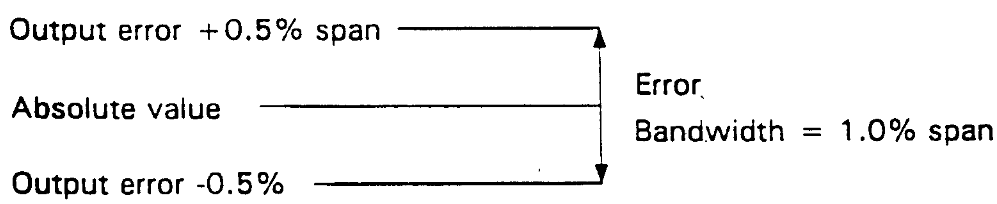


FIGURE III.D-1
DEVICE ERROR BAND

Now, instead of an absolute calibration device, the de ice is calibrated using test equipment that has a combined error of ±0.25% of the device's span. The MTE error can bias the device's accuracy above or below the absolute value to a new reference value. In other words, if at the instant of device calibration adjustment, the test equipment output was +0.25% span, the device's error band would be adjusted such that it was centered on a new reference value -0.25% span below the absolute value. The device's error bandwidth is still 1.0% of span but it is now centered about the new reference value rather than about the absolute value. By superimposing the additional error on Figure III.D-1, the result is shown in Figure III.D-2. The device output deviates from the ideal by the amount of test equipment error. Note that comparison of Figures III.D-1 and III.D-2(c) reveals an increase in the error bandwidth when the effects of MTE are considered.

Like RA, MTE error is a random error, but due to the interdependence between MTE and CAL, it must always be combined with CAL before being included in an overall error analysis.

MTE error must be considered for each instrument, or device, within a loop, which is calibrated independently. Generally, calibrations are performed device-by-device or by performing "string" calibrations of multiple devices at one time. The method of calibration selected determines how the MTE will be included in the overall loop uncertainty.

For example, if a loop contains 8 devices and each device is calibrated individually, the overall loop uncertainty must include provisions for 8 MTE errors. Each of these would be added to the calibration tolerance of the device and SRSSed with the other uncertainties. Alternatively, the calibration could be performed by a "string" calibration whereby all 8 devices would be treated as one device, with regard to the MTE. For this case, the overall MTE would only have to be applied once, thereby decreasing the total loop uncertainty.

The MTE, when applied to each component, can impose an excessively conservative penalty on plant operations. Implementing partial loop tuning of all components checked during a periodic calibration (i.e., after individual component calibration) or performing just a "string" calibration (i.e., not calibrating the devices individually) are two viable alternatives. These techniques minimize the number of times the overall MTE must be applied to the total loop uncertainty.

Effect of Positive MTE Error
(+0.25%)

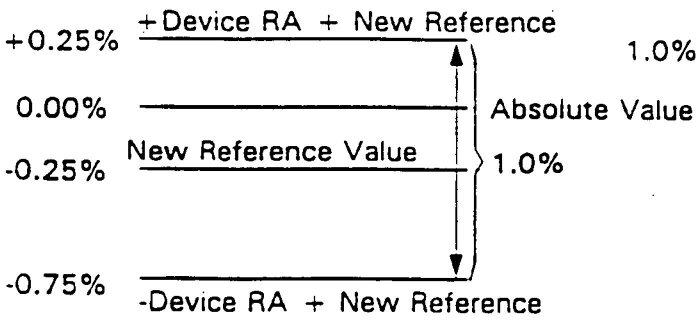


FIGURE III.D-2(a)

Effect of Negative MTE Error
(-0.25%)

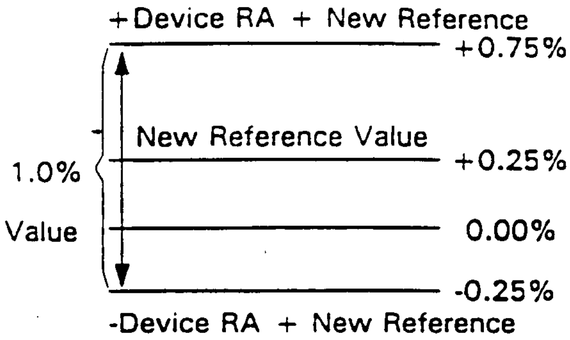


FIGURE III.D-2(b)

Combined Effect of Device Reference Accuracy and
M&TE on Overall Accuracy

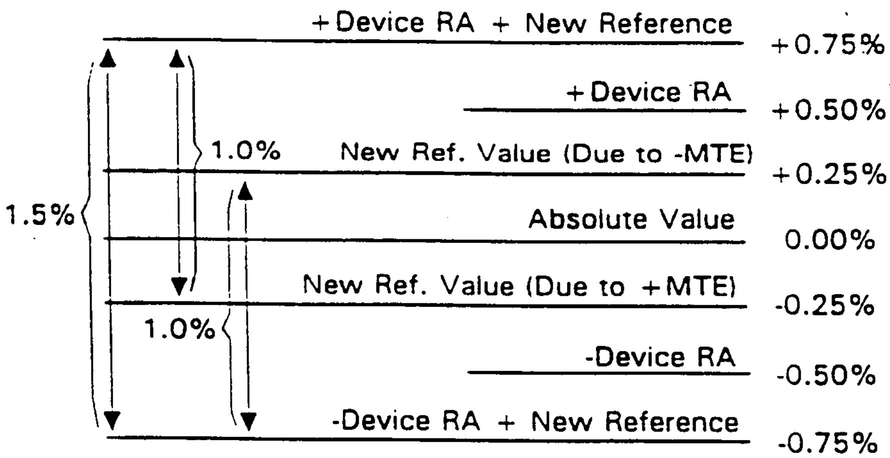


FIGURE III.D-2(c)
DEVICE ERROR BAND BIAS

In summary, the ger .ral rules for calibration error are:

- o Calibration error, CAL, is typically equal to the RA for a device/loop, plus any additional tolerance deemed necessary to aid in the calibration of the device/loop.

- o Component accuracies are directly dependent on the test equipment used to calibrate the component. Therefore, the applicable MTE error must be algebraically summed with the CAL error prior to being combined with other loop errors.

- o All MTE errors must be converted to units consistent with the loop error analysis.

- o The MTE error should include the MTE_{in} and MTE_{out} as SRSS terms.

- o The MTE error should be applied to each calibrated component, or group of components, in a loop depending upon whether the calibration is performed device-by-device or via a "string" calibration.

- o If all of the attributes of a component's reference accuracy are not verified during its calibration, then the reference accuracy or a portion of the reference accuracy must be included in the uncertainty calculation as a random, independent term. If all of the attributes of a component's reference accuracy are verified during calibration, and the calibration tolerance is greater than or equal to the reference accuracy, then the reference accuracy term can be ignored.

- o The MTE error should be less than or equal to the CAL error for a component, or group of components.

c. Calibration Temperature

The calibration temperature refers to the ambient temperature for an instrument at the time of calibration. The calibration temperature may be used as the initial temperature for determining errors based on temperature variation such as reference leg density effects, instrument temperature effects, etc.

As discussed in Section III.C.3, for error calculation purposes, an assumed calibration temperature of 65-90°F is to be used for Brunswick. For Robinson and Harris, a calibration temperature is not typically assumed. Instead, the temperature effects are determined from the spectrum of design temperatures for a given location. If calibration procedures record the ambient temperature, then the mean temperature for previous calibrations can be used as the calibration temperature for calculation purposes.

If as-left/as-found data may potentially be evaluated for a device/loop to determine device specific drift values, then it is recommended that calibration procedures include provisions for recording actual calibration temperature. This will allow the evaluation of the as-left/as-found data to readily segregate temperature effects from drift, and provide smaller, more representative values for drift.

2. Insulation Resistance Error (IR)

During accident conditions, when temperature, pressure, and humidity are well above their normal operating conditions for certain areas, electrical signal components can experience degradation in their electrical insulation. This phenomenon is known as Insulation Resistance (IR) Degradation, or IR loss. Such a reduction in IR can cause an increase in leakage currents between conductors, and terminals, of an instrument loop, resulting in potential degradation of loop performance.

In normal operation, changes in electrical insulation performance are so small that typically no effect on instrument loop performance can be seen. Even as the electrical signal component's (primarily cable, splices, and connectors) IR characteristics change with age, the periodic calibration process corrects the loop to eliminate any effects of leakage currents.

However, plant design basis accidents can impose extreme changes in ambient operating conditions on the components, primarily increases in ambient temperature and radiation. All electrical insulating materials experience some decrease in electrical insulation resistance properties with increasing temperature or radiation. The resulting decrease in electrical resistance, while not generally a concern for power applications, can cause significant changes in low level signal wiring or control loops.

The effects of IR can be determined by analyzing the changes in resistance, through the use of equivalent instrument loop circuit models. The following section provides a synopsis of the IR effects on various types of instrument loops.

a. Current Loop IR Effect

The insulation resistance degradation of electrical signal components in an instrument current loop causes an increase in the apparent signal for the loop. The loop signal current will increase as a result of reduced insulation resistance between the signal conductors of the loop. A leakage current between the conductors causes an increase in the signal current to the downstream loop devices. The magnitude of this leakage current, and that of the subsequent signal error, are directly proportional to the change in insulation resistance.

The magnitude of the IR error for a current loop is directly affected by the following parameters:

- o Loop supply voltage - The error is directly related to the value of the loop supply voltage. The higher the voltage, the higher the error is and vice versa.

- o Loop load resistance - As the loop load resistance increases, the error is reduced.

- o Loop current range - The error current generated is inversely related to the loop current. The highest error occurs at the minimum value of loop current.

- o Cable length - The majority of the leakage current comes from the actual length of cable exposed to the accident environment. The shorter the cable length, the lower the IR error effect.

The IR error effect for a current loop always causes an increase in current.

Since the IR error has a known effect on instrument performance, the IR error is considered a bias error, and as such, it must always be algebraically added to a loop's uncertainty. However, the IR error is a bias with known sign but unknown magnitude.

Many variables (environmental temperature, cable length, cable type, etc.) determine the magnitude of IR error, and it cannot be predicted to occur for every type of event. As such, IR error should be calculated as a "worst case" value for "worst case" conditions. Generic IR calculations exist for HBR and SHNPP, and may be used for determining the IR for the applicable instrument loops. For any other applications, specific IR calculations may need to be developed.

b. RTD Loop IR

The degradation of electrical signal components in an RTD sensing loop causes a different type of error than in the current loop. In the RTD loop, the total resistance of the RTD for a given temperature is known. Changes in the total resistance are assumed to be changes due only to changes in the RTD sensor as a result of temperature change. When the signal wiring also experiences a change in resistance characteristics between conductors, the loop mistakes this change for a change in sensor resistance. Changes in signal wiring IR will have the same effect as changes in sensor resistance. The signal wiring insulation provides a parallel resistance path to the RTD thus causing an apparent decrease in RTD sensor resistance as signal wiring IR decreases. Therefore as IR decreases, the loop will exhibit a negative error in measured temperature, since RTD resistance increases with temperature.

The magnitude of the IR error for an RTD loop is directly affected by the following parameters:

- Cable length - The majority of the leakage current comes from the actual length of cable exposed to the accident environment. The shorter the cable length, the lower the IR effect error.
- RTD values - The higher the RTD ice point resistance (R_0, or resistance at 32°F), the higher the error.
- 3-wire RTDs vs 4-wire RTDs - A 4-wire RTD will demonstrate more IR effect error than a comparable 3-wire RTD, due to the increased leakage paths.
- IR effect error for an RTD loop is always a negative error.

Since the IR error has a known effect on instrument performance, the IR error is considered a bias error, and must always be algebraically combined with a loop's uncertainty. As discussed above for the current loop, the IR error is a bias with a known sign and an unknown magnitude. Thus, its value should be determined for "worst case" conditions.

3. Conduit Seal Effects (CSE)

In certain applications of high ambient temperatures, conduit seals may provide a current leakage path similar to that discussed above for insulation resistance. Depending on how the IR error is determined, the conduit seal error may be combined with the IR error or determined separately. Like the IR error, it will act as a bias and have the same effect on the loops as the IR error - acting as a positive bias for current loops and a negative bias for RTD loops. Loops susceptible to IR error should also be evaluated for conduit seal effect error.

4. RTD Lead Wire Effects (LW)

Resistance temperature detectors (RTD) can experience an additional error effect due to changes in the resistance of the signal wiring conductors. The effect, generally known as the lead wire effect (LW), is usually only significant on RTDs which use two (2) wires to sense RTD variation. To a lesser extent, the lead wire effect is apparent on three (3) wire RTDs, but the third lead eliminates most of the error.

In a two (2) wire RTD installation, the resistance temperature coefficient in the signal wiring can cause significant changes in total circuit resistance. This change in resistance appears as a change in sensed temperature. As the temperature of the signal wiring goes up, the wire resistance rises in the same manner as the RTD itself. The wire resistance is directly proportional to the length of the cable as well. Therefore, two (2) wire RTDs should only be used where required accuracy is not critical, or cable lengths are limited to a few feet.

As a general rule, three or four wire RTD's are used in applications requiring accurate temperature measurement. The four wire RTD does not experience any significant lead wire effect since it measures the voltage variation caused by the RTD.

The relevant points to remember regarding lead wire effects are:

- o The lead wire error is a positive bias for the 2 wire RTD and a negative bias for a 3 wire RTD.
- o The magnitude of lead wire error increases with increasing cable length. For example, for a three wire RTD whose wires are all routed and terminated the same, the effect would be determined from the RTD cable length multiplied by three.
- o The higher the RTD ice point resistance, the lower the lead wire error.

5. RTD Self Heating Effect (SH)

The measurement of the resistance of an RTD demands that a current be passed through the resistance element. This current produces heat that raises the temperature of the element and, therefore, its resistance. The self-heating error is the amount of resistance change, converted to degrees, and is typically stated by the manufacturer.

The magnitude of the self-heating error depends on the efficiency of heat transfer from the sensing element to the protective sheath and from the sheath to the medium being measured. The self-heating error is, therefore, much larger when the detector is measuring moving air than when it is measuring moving liquid.

The standard method of determining the self-heating error is to immerse the thermometer in a stirred constant temperature bath, usually an ice bath. The resistance of the bulb is measured at two levels of current and the wattage dissipated at each level of current is calculated. The self-heating error, SH, is then:

$$SH = \frac{1}{S} * \frac{(R_2 - R_1)}{(W_2 - W_1)} \quad \text{(Eq. III.D-2)}$$

Where,

S = Average slope of the calibration curve, in ohms/°C at the temperature at which the test is carried out.

R_1 = Resistance at the first level of current, in ohms

R_2 = Resistance at the second level of current, in ohms

W_1 = Wattage dissipated at the first level of current

W_2 = Wattage dissipated at the second level of current

The error is calculated in terms of °C/watt and must be converted to units of percent span.

The above discussion characterizes what the self-heating effect is and how it is determined. However, it should be noted that the effect is typically insignificant, relative to the other uncertainties.

E. Error Analysis

The analysis of instrument, and loop, uncertainty requires the application of probabilities and statistics to known instrument and loop errors. By defining each of the errors as either random or bias, as discussed in Section III.A.5, one is able to apply the science of statistics to establish the cumulative effects of the errors. By using statistical analysis, truer relationships between probable errors and their resultant effects can be established. The statistical analysis of errors allows the determination of a total error effect based on both the magnitude of individual errors and the probability of their occurrence over time.

There are numerous methodologies within the science of statistics for analyzing data (errors). These methods include, in depth analysis techniques (regression, partial derivatives, etc.) which are designed to predict the most probable value for a given set of numerical data. While the subject of probabilities is not the primary focus of this document, an understanding of the subject is necessary for instrument error analysis. The following sections discuss the primary methodology used in instrument error analysis. This methodology is based on accepted data analysis techniques, and has been endorsed by both the Nuclear Regulatory Commission, and the Instrument Society of America (References II.A.1 and II.A.2, respectively).

1. Summary of Errors

Before discussing the methodology for combining the individual error terms, it would probably be helpful to reiterate the individual error terms, and how they are applied. Described below is a summary of the types of errors that should typically be considered for the determination of instrument loop uncertainty. Other errors may also be applicable to individual loops, however, the errors described below represent the most common error types. This summary is derived from the discussions previously presented in Sections III.B, III.C, and III.D.

Process Measurement Effects -	Consider for each loop, including any primary elements such as flow orifices, venturies, etc.
Reference Accuracy -	Consider for each device within a loop.
Drift -	Consider for each device within a loop.
Temperature Effect -	Consider for each device within a loop. Does not have to be included whenever an ATE value is used.
Static Pressure Effect -	Consider for Differential Pressure transmitters that operate at high (i.e. > 200 psig) pressures.
Overpressure Effect -	Consider only for pressure transmitters (including d/p).
Power Supply Effect -	Consider for each device within a loop.
Accident Temperature Effect -	Consider for each device within a harsh environment.

Accident Pressure Effect -	Consider for each device within a harsh environment.
Accident Radiation Effect -	Consider for each device within a harsh or radiation harsh environment.
Seismic Effect -	Consider for each device within a loop that is designated Seismic Class 1.
Readability -	Consider for each indication or recording device, including local gauges and digital displays.
Calibration Tolerance -	Consider for each device within a loop that is calibrated.
M&TE Uncertainty -	Consider for each device within a loop that is calibrated. Include all M&TE used within the calibration.
Insulation Resistance Error -	Consider for the portion of a loop within a harsh environment.
Conduit Seal Effect -	Consider for the portion of a loop within a harsh environment.
RTD Lead Wire Effect -	Consider for two or three wire RTDs.
RTD Self Heating Effect -	Consider for RTDs.

2. Error Combination Methodologies

There are two primary methods of combining instrument and/or loop uncertainties: linear addition, and a simple statistical analysis called the Square-Root-Sum-of-the-Squares method. By combining these two methods, a third method can be defined such that random error terms are combined in the statistical manner and then algebraically summed with the bias error terms. This third method, or "combined" method, is the primary method used in industry for instrument loop error analysis. A fourth, but rarely used, method is one where individual device errors are determined from SRSS, and then the error allowance for each device is added together to yield the loop error. The three predominant methods are described below.

a. Linear Addition

Combination of all component errors by linear addition is by far the most conservative approach to loop uncertainty analysis. By algebraically summing all of the error effects of each component for the most severe abnormal situations anticipated, a bounding total loop uncertainty can be generated. This large uncertainty, though, when combined with plant limits can reduce operating bands to such an extent that it will impact process limits and restrict the operational flexibility of a plant.

It is true that an instrument loop will always function within the boundaries established using the linear addition method. However, it is generally not cost effective to take the operational penalties associated with such a conservative analysis. The linear addition method essentially treats all errors as correlated (bias) terms, and does not take advantage of the statistical nature of random error components.

b. Square Root Sum of the Squares

Square-Root-Sum-of-the-Squares (SRSS) is a statistical method of combining multiple random errors for a device, or loop, in order to establish the total error attributable to all of the individual errors. The SRSS method accounts for the individual probabilities of random errors. The method is based on the knowledge that the probability of a group of random errors, each being at their maximum value, and in the same direction (i.e., + or -), simultaneously, as is assumed in the linear addition method, is extremely small.

The SRSS method of con›ining random error terms is a methodology accepted by the NRC as discussed in Reference II.A.1. The methodology produces a resultant error value which has the same level of probability as the individual terms being combined. A pure SRSS equation considers that all uncertainty effects are independent and random.

Since all component errors are generally considered independent, personnel doing this type of analysis need only square each uncertainty term and take the square root of the sum.

The basic SRSS combination of error terms takes the form:

$$Z = \pm[A^2 + B^2 + C^2 + . . + n^2]^{0.5} \qquad \text{(Eq. III.E-1)}$$

Where,

A, B, C, n - are random and independent error terms
Z - is the resultant uncertainty

c. Combined Analysis Method

The combined method uses portions of both the linear addition, and SRSS methods for combining uncertainties. For the combined method, the individual random error terms are combined by SRSS to establish a single, resultant random error component. Linear addition is then used to combine all non-random (bias) terms to establish single positive, and negative, bias error components. The total error or uncertainty, is obtained by combining the random and bias components of error, as discussed in Section III.A.5.

The basic formula for an uncertainty calculation takes the form of:

$$Z = \pm [A^2 + B^2 + C^2 + . . .n^2]^{0.5} + L + M \qquad \text{(Eq. III.E-2)}$$

Where,

A,B,C, & n - are random and independent uncertainty terms.

L & M - are, respectively, the positive and negative bias error terms (terms which are not random and independent, but which are dependent uncertainties, non-random, correlated, etc).

Z - is resultant uncertainty. The resultant uncertainty combines the random uncertainty with the positive and negative components of the correlated terms separately to give a final total uncertainty.

The random and bias components for each device in an error calculation must remain separate and distinct throughout each intermediate calculation step, except when determining a final total error. In addition, the bias errors of opposite signs (+ or -) must remain separate, since biases can contain uncertainties which vary in magnitude over time. In other words, a bias may not exist at all moments in time, or always be at its maximum value with respect to other bias terms. Therefore, the positive and negative bias terms must be kept separate in order to establish a worst case possible error. Bias terms of opposite sign cannot be assumed to offset each other, and thereby reduce total error. However, certain bias terms such as head effects, will always be present and are of known sign and magnitude. For these cases, the bias term could be used in the determination of both the positive and negative uncertainty terms.

In calculating the total error, the total bias error for a given direction is combined with the random error in that direction. This establishes a final set of upper and lower bounds of error for a group of individual error terms. The bounds represent the limits within which the total error for a group of individual errors will remain 95% of the time. (Assuming all random error terms were of 95% probability as discussed in Section III.A.5.a).

Consider the following example,

EXAMPLE

If we have a loop which contains the following error terms,

Process measurement error	=	+0.5 (bias)
Transmitter accuracy	=	±0.25 (random)
IR error	=	-1.2 (bias)
Indicator accuracy	=	±0.5 (random)

The total loop uncertainty, TLU, is calculated as:

$$TLU = \pm [0.25^2 + 0.5^2]^{0.5} + 0.5 - 1.2$$

$$= \pm 0.56 + 0.5 - 1.2$$

$= + 1.06 / - 1.76$

The total error is between +1.06 and -1.76 of the true value.

In determining the random portion of an uncertainty, situations may arise where two or more random terms are not totally independent of each other, but they are independent of the other random terms. This dependent relationship can be accommodated within the SRSS method by algebraically summing the dependent random terms prior to performing the SRSS determination. An example is the dependent relationship between MTE error and CAL error, as discussed in Section III.D.1.b. The formula would take the following form:

$$Z = \pm [A^2 + B^2 + C^2 + (D+E)^2]^{0.5} + L+M \qquad \text{(Eq. III.E-3)}$$

Where,

D, E - are random, dependent uncertainty terms that are independent of terms A, B & C.

The combined analysis method can be used in the calculation of either a device uncertainty or a total loop uncertainty. The results are independent of the order of combination as long as the dependent terms, and non-random terms are accounted for properly. For example, the uncertainty of a device can be determined from its individual terms, and then combined with other device uncertainties to provide a loop uncertainty. Or, all of the specific device terms for each device in the loop can be combined in one loop uncertainty formula. Either way, the result will be the same. The specific groupings of an uncertainty formula can be varied for convenience of understanding.

3. Instrument/Device Uncertainty Equations

Using the basic analysis methods discussed above, the uncertainties introduced into a loop measurement signal, by the individual instruments/devices within a loop, can be determined. The effect that a device has on a measurement signal is dependent on both the mathematical relationship between the input and output signals, and the amount of additional error the device imparts on the signal due to its own inherent error effects.

Loop devices such as amplifiers, multipliers, and square root extractors each impart a predictable level of error into a measurement. Non-linear devices, such as a square root extractor, not only increase potential error but can cause extreme variations in total error, due to mathematical manipulation of input error as part of the signal.

To aid in the development of actual loop error analysis, instrument/device uncertainty equations have been developed for the common devices. The equations define the output error, or uncertainty of a device based on its function, input error, input signal, and accuracy. These equations are intended to be used in the development of specific loop error analyses for the CP&L nuclear plants, as needed.

In the uncertainty equations contained in this section, the following codes are used:

A, B	=	Input signal(s) to the device
a, b	=	Uncertainty in the input signal(s)
C	=	Output signal from the device
c	=	Uncertainty in the output signal
e	=	Inherent uncertainty of the device
k1, k2	=	Gain of the device inputs

a. Signal Converter

The term, "signal converter" alludes to any loop transducer having an overall gain equal to unity (1.000), and an error free transfer function of:

Output = (k)[Input]

$$C = k * A$$

The output uncertainty (c) for signal converters is expressed as:

$$c = \pm (a^2 + e^2)^{0.5} \qquad \text{(Eq. III.E-4)}$$

The output uncertainty equation is applicable to any component having a gain (k) equal to 1.0. All errors are expressed in terms of percent span.

Typical applications are transmitter, indicatc ·, and isolation/buffer amplifier output uncertainties.

b. Linear Signal Devices

These are single input, fixed gain devices such as a common amplifier or ratio station. Linear signal devices have an error free transfer function of:

Output = (k)(Input)

C = k * A (From Section III.E.3.a above)

The output uncertainty (c) for linear devices is expressed as:

$$c = \pm [(ka)^2 + e^2]^{0.5} \quad \text{(Eq. III.E-5)}$$

This statistical uncertainty equation is applicable to any component having a fixed gain, where gain, k, is expressed as a multiple or fraction of 1.0, or unity gain. All errors are expressed as percent span. Any errors associated with the function of the device are included as part of the inherent device uncertainty (e).

c. Multiplier

This type of device not only changes the amplitude of the input by a factor of the gain, but also by a factor proportional to the amplitude of a second input. The module has individual gains for each input. The module has an error free transfer function of:

Output = (k1)(Input 1)(k2)(Input 2)

$$C = (k1A)(k2B) \quad \text{(Eq. III.E-6)}$$

The output uncertainty (c) for multipliers is expressed as:

$$c = \pm [(k1k2Ab)^2 + (k1k2aB)^2 + (kak2ab)^2 + e^2]^{0.5}$$

(Eq. III.E-7)

d. Divider

A divider is used for applications such as a differential pressure signal which needs to be corrected for density changes in the flowing fluid, or liquid level. The error free transfer function of a divider is:

Output = (k1)(Input 1)/(k2) (Input 2)

$C = (k1A)/(k2B)$

The output uncertainty (c) for dividers is expressed as:

$$c = \pm\ k1/k2B(B^2 - b^2)\ [(aB^2)^2 + (abB)^2 + (ABb)^2 + (Ab)^2 + e^2]^{0.5}$$

(Eq. III.E-8)

e. Square Root Extractor

A square root extractor module has a fixed gain of unity, and its output is the square root of its input. The error free transfer function of this module is:

$\text{Output} = (\text{Input})^{0.5}$

$C = (A)^{0.5}$

The output uncertainty (c) for square root extractors is expressed as:

$$c = \pm\ [(a/2C)^2 + e^2]^{0.5}$$ (Eq. III.E-9)

The user of this equation should be aware that better error models are available and may be applicable for use.

f. Summing Amplifier

A summing amplifier is a very high gain operational amplifier with a summing junction (resistor network) connected in front of its input. The gain factor (k1, k2, etc.) for an individual input is controlled by selecting an input resistor such that the feedback resistor value divided by the input resistor value provides the desired gain. The error free transfer function of a two input summing amplifier is:

Output = (k1)(Input 1) + (k2)(Input 2)

C = k1A + k2B

The output uncertainty (c) for summing amplifiers is expressed as:

$$c = \pm [(k1a)^2 + (k2b)^2 + e^2]^{0.5} \qquad \text{(Eq. III.E-10)}$$

The output uncertainty equation is applicable to any device required to add, subtract or compare two or more input signals. As a summer, the output signal will be equal to the algebraic sum of the input. In the case of a comparator (bistable), one signal (A) is a constant or variable (setpoint) with polarity opposite that of the process variable signal (B). The switching device is energized or de-energized when the two opposing signals approach the same amplitude.

g. Characterizer (Function Generator)

A characterizer module approximates a nonlinear mathematical function using multiple straight line segments. To operate on each segment of the nonlinear input, an adjustable gain (k1, k2, . . . kn) control is provided for each segment, and a separate gain (k0) is provided for the output amplifier. Therefore, the error free transfer function is:

Output = k0[k1(Input to segment 1) + k2(Input to segment 2) +. . . + kn(Input to segment n)]

C = k0[k1A1 + k2A2 + . . . + knAn]

where, segment input (A1, A2, . . . An) is defined as the total input value minus the low breakpoint value of that segment.

It is important to note that when a specific function segment is in operation, only the gain for that segment of the function curve is to be used for error quantification. All other segments are not in operation, and thus the gains are zero.

The output uncertainty (c) for characterizers is expressed as:

$$c = \pm [(k0\ k1\ a1)^2 + (k0\ k2\ a2)^2 + \ldots + (k0\ Kn\ an)^2 + e^2]^{0.5}$$

(Eq. III.E-11)

For a characterizer, the errors associated with the segmented curve fit are included as part of the device error term (e).

h. Controllers

Controllers by nature of their function, continuously correct a process to eliminate what they see as errors between a measurement and a setpoint. The basic purpose of a controller is to force the measured variable to match the setpoint value, such that the setpoint minus measured value is equal to zero. Controllers will normally not impart additional significant error uncertainty into a loop unless improperly calibrated or tuned. The controller uses both internal and process measurement feedback to continually adjust its output signal, and related control elements to force the detected error to zero.

Error in the measured variable used by the controller can cause significant errors in a controller's final control point. However, the error present in the measured variable signal cannot be detected by the controller. Therefore, it becomes a proportional error in the final control point. If a measured variable contains a +1% error, the controller will decrease the variable by an amount equal to the error (-1%), and vice versa, due to negative feedback. Once corrected, the final control point will be -1% below the actual desired point of control. The error could not be reduced unless a separate measurement loop, with no error, were available to check the actual control point.

F. Establishment of Uncertainty Allowances

All of the potential error effects for a loop must be evaluated, and applicable ones incorporated into a loop error analysis. The analysis may cover the total loop from process to final output device, or only that portion of a loop needed to perform a specific function. The loop error analysis will establish the total uncertainty in a loop's measurement under the conditions of concern. From the total uncertainty, allowances can be established and used to delineate the required control limits. These allowances define the boundaries of uncertainty a loop can possess under various operating conditions. Allowances are used to define the acceptable levels of performance an instrument/loop must meet to satisfy its functional criteria.

1. Conditions for Which Uncertainty is Determined

For the CP&L plants, three design bases conditions of operation have been established for which instrument accuracy should be determined. The three conditions, calibration (reference), normal, and accident, define the bases and limits of the plant process, and environmental conditions, under which instrumentation must function. The three conditions are shown pictorially in Figure III.F-1.

a. Calibration Conditions

The calibration conditions are, essentially, the conditions under which an instrument/loop provides its highest degree of accuracy. Typically, no operational influences are imposed on the loop under these reference conditions. For calibrations, all ambient environmental parameters are considered to be within an instrument's/loop's relatively narrow range of reference operating limits. This accuracy is that of a loop immediately after calibration.

b. Normal Conditions

The normal conditions define the environmental conditions under which an instrument/loop must function during normal plant operation. This condition includes anticipated operational occurrences, but does not include design bases accident conditions. The normal conditions are defined as the normal condition maximum values.

c. Accident Conditions

The accident conditions define the maximum or worst case process and environmental conditions under which an instrument/loop must function. This condition includes all applicable combinations of design bases accidents. The accident conditions are defined in each plant's FSAR.

2. Loop Error Determination

The calculation of instrument loop error must utilize a clear, and straightforward process. The calculation should coincide with a loop's layout from process measurement to the final output device(s) of concern. The terms for each device in a loop must be clearly identified and classified for proper inclusion in the error formula.

For the CP&L error calculations, a set of standard abbreviations has been developed to identify the various error components of a loop. This nomenclature is provided in Section II.D of this document. All calculations should use these abbreviations for consistency and ease of identification of terms contained within this design guide.

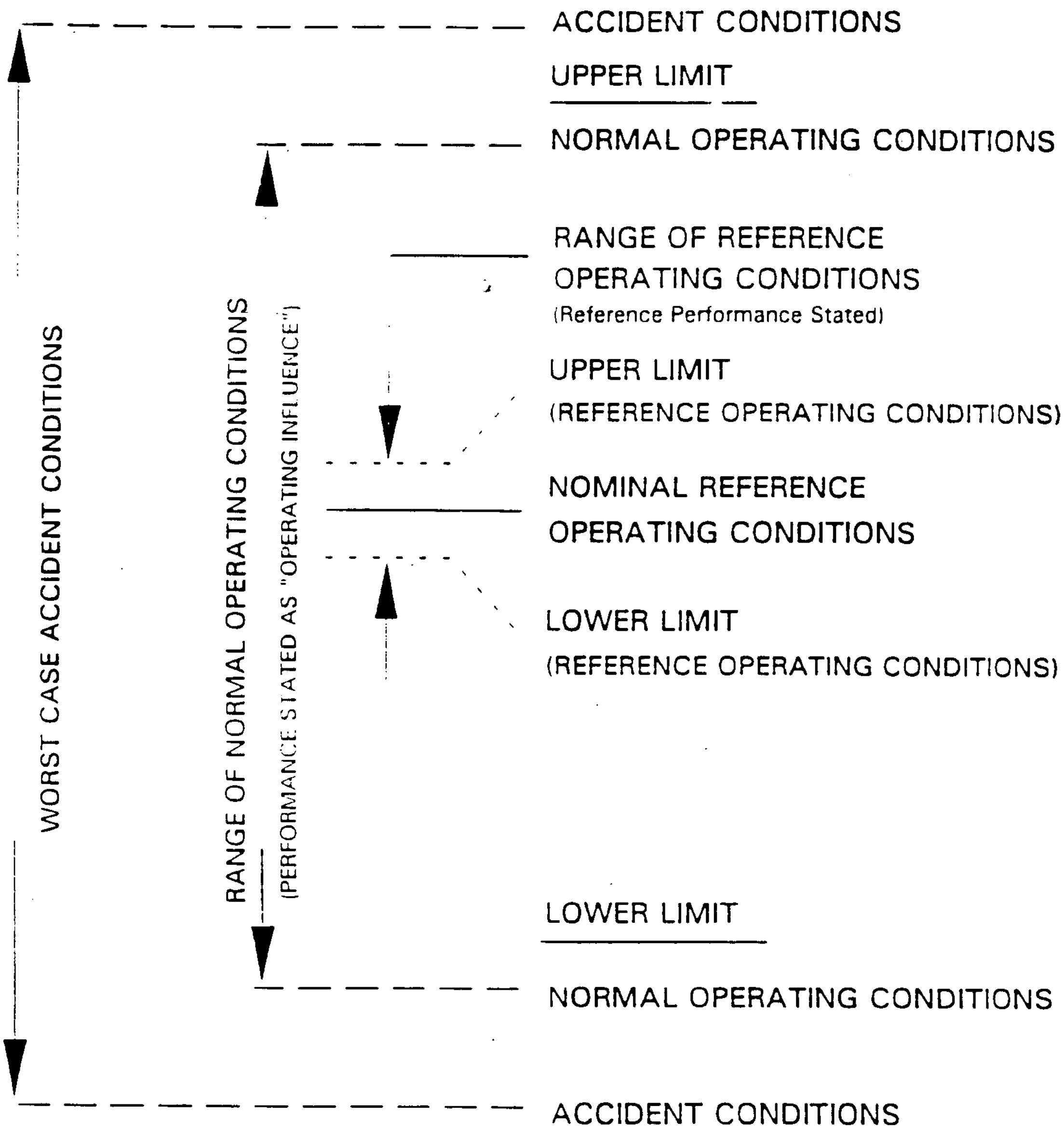
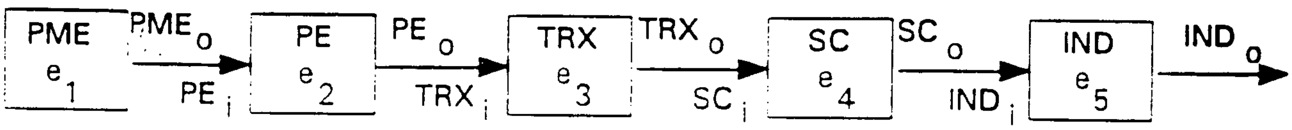


FIGURE III.F-1
DIAGRAM OF INSTRUMENTATION OPERATING CONDITIONS

The basic process for calculating loop errors will involve the separate calculation of individual device uncertainties, and the calculation of partial loop error values at the output of each loop device. This process is shown graphically in Figure III.F-2.



PME - Process Measurement Error with error e_1
PE - Primary Element with error e_2
TRX - Transmitter with error e_3
SC - Signal Converter with error e_4
IND - Indicator with error e_5

The lower case i and o suffix designate the input and output errors for the devices

FIGURE III.F-2
TYPICAL LOOP ERROR DIAGRAM

A loop error analysis should always start with an evaluation fo process measurement errors as discussed in Section III.B. Even if no process measurement error exists, a statement to that affect should be noted in the calculation. The process measurement error (PME), e_1, would take the form of,

$$e_1 = \pm \text{PME} + \text{PMEb}^+ - \text{PMEb}^- \qquad \text{(Eq. III.F-1)}$$

Where,

± PME - are the random components of PME, if any
PMEb - are the bias error portions of the process measurement, if any

Bias error term abbreviations will use a lower case "b" as a suffix to designate bias. Random error term abbreviations will not have a random suffix designator.

Since PME is the starting point of the loop analysis,

$$\text{PMEo} = e_1$$

In general, no additional error will exist between PME and the primary element (PE). Therefore,

$$\text{PEi} = \text{PMEo}$$

The PE error, e_2, would then be calculated,

$$e_2 = \pm[\text{RA}^2 + (\text{other error effects})^2]^{0.5} + \text{PEb}^+ - \text{PEb}^-$$

(Eq. III.F-2)

Where,

RA - is the primary element's reference accuracy
PEb - are the bias error portions of the primary element, if any.

The PE error, e_2, would then be combined with the PEi error to establish the primary element output error, PEo.

$$PEo = \pm [PEi^2 + e_2^2]^{0.5} + PMEb^+ + PEb^+ - PMEb^- - PEb^-$$

If no additional error is identified between the PE and the transmitter (TRX), then

$$TRXi = PEo$$

The TRX error, e_3, would then be calculated from an equation such as,

$$e_3 = \pm[(MTE + CAL)^2 + DR^2 + TE^2 + RA^2]^{0.5} + TRXb^+ - TRXb^-$$

(Eq. III.F-3)

The actual error components which make up the total transmitter error will vary based on functional requirements, and reference operating conditions. The individual error components are discussed in Section III.C. For this discussion, we will assume that no bias error exists for the transmitter, thus allowing the bias terms to be dropped from Equation III.F-3.

The TRX error, e_3, would then be combined with the TRXi error to establish transmitter output error, TRXo. The transmitter device equation from Section III.E.3.a is used to combine the errors.

$$TRXo = \pm[TRXi^2 + e_3^2]^{0.5} + PMEb^+ + PEb^+ - PMEb^- - PEb^-$$

(Eq. III.F-4)

The output error of one device will generally equal the input error of the next device in a string. The exception occurs when an additional error term such as IR comes into play between two devices. In this situation, the signal conditioning equipment input (SCi) is,

$$SCi = TRXo + IRb^+ \text{ (or } - IRb^-)$$

In an actual loop analysis, only one IRb component would exist (+ or -) since IR does not exhibit both a positive and negative component for the same loop.

The process of calculating individual device error terms and combining them with the partial loop error term would continue through to the device of concern.

Assuming no bias errors exis:ed for SC and IND,

$$INDo = \pm[INDi^2+e_5^2]^{0.5} + IRb^+ + PMEb^+ + PEb^+ - PMEb^- - PEb^-$$

(Eq. III.F-5)

All loop and device error terms shall be expressed in the same basis (i.e. units) prior to combining the error terms. Typically, the simplest basis to express the errors in is percent of calibrated span. Careful evaluation of the individual error terms is required to ensure that consistent units are maintained throughout the calculations. Examples of various expressions of error terms and conversion values for percent of span are shown in Sections III.B through III.D. Attachment D shows techniques for converting from other bases to percent calibrated span.

If it is questionable whether a particular module or uncertainty is applicable because it may not have an appreciable amount of error associated with it, the calculation does not need to consider the term as long as acceptable justification is documented within the calculation for the term's exclusion. Due to the statistical nature of combining the errors, if a random independent uncertainty is one-fifth or less than the largest random independent uncertainty, it may be disregarded. However it is important to document within the calculation why it can be disregarded.

When a loop contains a non-linear device, the loop errors must be calculated for specific values of span downstream of the non-linear device. For a non-linear device, such as a square root extractor, the output error is proportional to the magnitude of the true signal. This non-linearity can be seen in the example below.

EXAMPLE

Assume we have a flow measurement loop containing a square root extraction module. The loop is calibrated such that an output signal of 0-4000 GPM is generated for an input of 0-100 in WC.

The basic flow to differential pressure relationship is:

$$F = k(DP)^{0.5}$$

where, k is a constant for a particular loop.

For this example k is:

$$k = F/(DP)^{0.5} = 4000/(100)^{0.5} = 400$$

Now if we have an error in the measurement upstream of the square root extractor, this error is seen as a change in the DP input.

Using the basic flow/DP relationship, a table can be made showing the effect of a +2% DP span error on the flow measurement.

F actual (GPM)	F (% flow)	D (inWC)	DP (% DP span)	DP+2% error (inWC)	F reading (GPM)	F error (% flow span)	F error (% reading)
0	0	0	0	2	565.7	14.1	∞
800	20	4	4	6	979.8	4.5	22.5
2000	50	25	25	27	2078.5	2.0	3.9
3200	80	64	64	66	3249.6	1.2	1.6
4000	100	100	100	102	4039.8	1.0	1.0

Note that as the true flow signal increases, the effect of the constant +2% DP span error decreases due to the basic non-linear function of square root extraction. Therefore, the error in the output of a non-linear device must be calculated for specific values of output span.

3. Uncertainty Allowances

The uncertainties determined to exist in a loop are used to establish allowances for that loop. The allowances define the bounds within which a loop and/or its components can operate and still satisfy their design functions. Multiple allowances exist for each instrument loop. These allowances, also known as tolerances, or performance limits, are provided to aid in the calibration, and maintenance of the instrument loop.

a. Tolerances

Tolerances, as discussed in Section III.D.1.a, are allowances established on specific loop components, groups of components, or the total loop, and which are used to aid in the maintenance and calibration of the loop. Tolerances define the limits to which an instrument loop must be calibrated to assure proper loop function. Tolerances allow for the basic inaccuracy of a device, or group of devices, and establish the acceptable level of performance of the components being calibrated. Tolerances are defined under the reference conditions only, since calibration is performed under these conditions. For an instrument loop, the various tolerances are,

- o Device Tolerance - the calibration tolerance of a specific component or device within a loop. The device tolerance is equal to the reference accuracy of the device, plus any device setting tolerance.

- o Loop Tolerance - the total loop calibration tolerance which defines the basic accuracy of a loop. The loop tolerance is established based on the calibration tolerances of the devices which make up the loop.

- o As-Found Tolerance - the generic term given to the bounding tolerance allowed between calibrations of a defined device, loop segment, or loop. The As-Found tolerance establishes the limit of error the defined device(s) can be found to have during surveillance testing, and still be considered to be in calibration. The As-Found tolerance accounts for the calibration tolerances, drifts, and M&TE uncertainties of the device(s) under test. Note that if only the rack instruments through the final device is being tested, the sensor uncertainties should not be included.

o As-Left Tolerance — the generic term given to the calibration tolerance allowed for a defined device, group of devices or loop. For a single device, the As-Left tolerance is the same as the device tolerance discussed above. For a total loop, the As-Left tolerance is the same as the loop tolerance discussed above. The term is also commonly used to define the calibration tolerance allowed in a loop segment which is periodically tested. The As-Left tolerance accounts for the calibration tolerance of the loop segment. The As-Left tolerance establishes the required accuracy band within which the loop segment must be calibrated.

b. Loop Allowances

An understanding of the concepts of allowances, and tolerances, in instrument loops is essential to understanding loop performance, and capabilities. The allowances, and their associated limits, establish the performance characteristics of an instrument/loop, which in turn establishes the design relationships between the loops and plant control.

(1) Basic Relationships

Figure III.F-3 shows the basic relationship of allowances for a typical instrument or loop. In Figure III.F-3, the horizontal center line marked "desired value" represents a measurement value without error. This desired value could be the output of any device, group of devices, or loop. The true output will vary about the desired value based on the accuracy of the device(s). This variance is encompassed by the As-Left tolerance for the device(s). For a general measurement process, the As-Left tolerance is typically applied both above, and below, the desired value, since the true output varies randomly about the actual value.

The As-Left tolerance is normally equal to the reference accuracy, or the combination of reference accuracies for the device(s). A device setting tolerance, which is a value used to increase a device tolerance above the reference accuracy, may also be applied as desired. However, for the remaining discussions, no device setting tolerances will be assumed to exist.

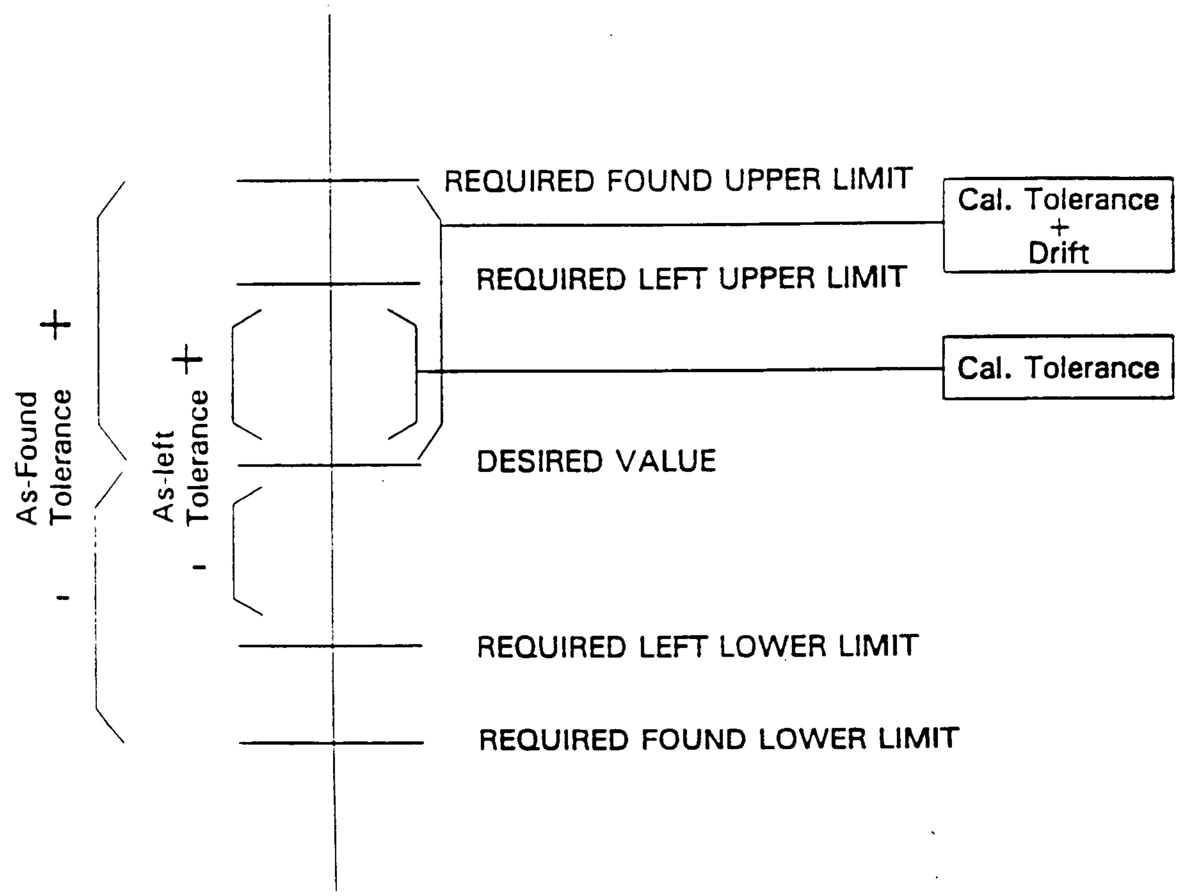


FIGURE III.F-3
TOLERANCE RELATIONSHIPS

The As-Left tolerance provides calibration personnel with a measurable calibration band, within which the device(s) must be adjusted. In addition, the As-Left tolerance allows a set of acceptable performance limits to be set, against which actual performance can be monitored. The acceptable performance limits are actually beyond the As-Left tolerance by an amount equal to the MTE error effect.

As discussed in Section III.D.1.b, the MTE error effect is an error due to calibration equipment inaccuracies, which is not discernable to a calibration technician. As such, it cannot be eliminated. Therefore, actual performance limits for the device(s) being calibrated are equal to the As-Left tolerance plus MTE effect. The acceptable performance limits define the true uncertainty in an output for plant reference conditions (i.e. the highest accuracy obtainable). However, the device(s) must be left within the As-Left tolerance band, as indicated by the technician's MTE. If the performance of the device(s) remains within these limits, no further calibration adjustment would be required. Device(s) found outside of the As-Left tolerance would require recalibration to bring the errors back within the tolerance.

Because all devices experience drift, as discussed in Section III.C.2, the additional tolerance value of As-Found has been created. The amount of drift applies only to that which can occur between successive periodic calibrations. The As-Found tolerance establishes what can be called "required limits of performance" on the device(s). These required limits define the maximum amount of error allowed during normal plant operation. Any device whose error exceeds the As-Found tolerance would be considered inoperable. The As-Found tolerance provides a means to verify the operability of the device(s), at any time after calibration.

The As-Found tolerance, as indicated, includes the As-Left tolerances (usually equal to the Reference Accuracy), the MTE error, and the drift (DR) of the device(s), and are combined as discussed in Section III.D.1.a. If the equipment is tested on a frequency greater than the normally scheduled calibration intervals, the drift can only account for the time between successive surveillance tests. For many safety-related loops, the surveillance test for accessible components, such as those located in the rack, are required to be performed on a monthly basis.

It is important to note, that As-Left, and As-Found tolerances can be established for a single instrument, or device, a select group of devices, or a total loop. The tolerances only encompass inherent instrument inaccuracies, and do not account for inaccuracies caused by varying external influences (i.e.: ambient environment effects, PME, IR, etc.).

For Brunswick, only one tolerance is provided within the calibration procedures (MSTs, PICs, LPs), and it represents the As-Left tolerance. A separate As-Found tolerance for each device being calibrated, is not delineated within the procedures. Instead, the procedures specify that any device found to be outside the (As-Left) tolerance by more than twice the tolerance, shall have a Calibration Nonconformance Action Form (CNAF) prepared. The "twice the tolerance" criteria acts as an As-Found tolerance to account for drift of the devices, and if devices are found outside of this tolerance, they must be evaluated for operability via the CNAF.

The manner in which Brunswick utilizes the "twice the tolerance" criteria to act as an As-Found tolerance is a generic method of providing two tolerances. However, the method must also be used with caution. When establishing the setpoints and allowable values discussed in Section III.G, the As-Found tolerance may be larger than just the As-Left tolerance plus the drift. If so, this must be accounted for within the individual setpoint and allowable value determinations. Otherwise, a device could drift within the "twice the tolerance" band yet potentially be beyond its allowable value.

Consider the following example,

EXAMPLE

A pressure switch at Brunswick has a reference accuracy (and calibration tolerance) of ±0.50% calibrated span. The drift value for the pressure switch, as provided by the vendor is ±0.50% calibrated span per 6 months. The MTE error for calibrating the pressure switch is ±0.25% calibrated span. The existing allowable value is equivalent to 1.0% calibrated span, and the pressure switch is required to be calibrated every 18 months ± 25%.

In performing a calibration of the pressure switch, the As-Found condition would have to be greater than twice the tolerance, or greater than 1.0% calibrated span (i.e., 2 * 0.50%) before a CNAF would be initated. However, at greater than 1.0% calibrated span, the existing allowable value would be exceeded. Thus, using the "twice the tolerance" criteria for As-Found values provides the potential for exceeding the allowable value. If the allowable value had been established considering the reference accuracy, the drift, and the MTE, it would have been determined as follows,

$$AV = [(CAL)^2 + (DR)^2 + (MTE)^2]^{1/2}$$

First, the drift would be determined for the 18 months ± 25%. Using the SRSS method, the 18 months ± 25% is approximately equal to 4 six month periods. Thus, drift would be determined as,

$$DR = [(0.5)^2 + (0.5)^2 + (0.5)^2 + (0.5)^2]^{1/2}$$

$$DR = 1.0\%$$

The allowable value would then be calculated as,

$$AV = [(0.5)^2 + (1.0)^2 + (0.25)^2]^{1/2}$$

$$AV = 1.15\%$$

Even though the existing allowable value was 1.0% calibrated span, it should probably be increased, via the proper procedures, to at least 1.15% calibrated span. Otherwise, the switch may be found to exceed the allowable value more often than would normally be expected.

In order to prevent the As-Found value from being less than twice the tolerance but greater than the allowable value at Brunswick, the actual allowable values are shown on the calibration sheets and the technician is instructed to verify the As-Found are less than the allowable values. However, it is important that the preparer of any uncertainty calculation understand the way that Brunswick treats the "twice the tolerance" criteria and ensure that if a value is found up to twice its tolerance, it would still be considered operable in the field.

For Robinson, only one tolerance is specified within the calibr: ion procedures and it acts as the As-Left tolerance. If the As-Found value is found to be outside the tolerance, it is calibrated back to within tolerance. The calibration records are then reviewed by cognizant Maintenance personnel. It is the responsibility of these reviewers to evaluate any device which had exceeded its tolerance.

Using this method, evaluating out of tolerance conditions is rather subjective. If calculations quantify the expected drift for a device, then this value should be provided to the Maintenance group. This will afford the reviewers of calibration data with an "As-Found" value that will allow a quantifiable assessment of which out of calibration values present a problem, and which out of tolerance values are justified.

For Harris, generally only one tolerance is specified within the calibration procedures and it acts as the As-Left tolerance. The devices with allowable values have the allowable values denoted on the individual calibration sheets. All As-Found and As-Left values must be within the allowable values to meet the calibration requirements of the procedure. If the As-Found values are found to be within the allowable range, then no adjustment is necessary. For Q-Class A transmitters an Allowable Drift tolerance is given in addition to the allowable range. The transmitter allowable drift tolerance (which may be single sided) is defined by the (S) term in Technical Specification Equations 2.2-1 and 3.3-1. When the transmitter allowable drift tolerance is exceeded, then a Maintenance Feedback Report (MFR) must be initiated to evaluate Technical Specification drift. This report provides a documented mechanism for evaluating the out of tolerance condition. For all other devices found to be out of tolerance, the device is calibrated back to within tolerance and the Shift Supervisor notified.

For all other devices without any criteria for assessing out of tolerance values, the device may have drifted beyond what was expected but it does not create a plant operability concern. It may create a device operability concern, and this determination is left up to the Shift Supervisor to make an evaluation. As was noted above for Robinson, if calculations quantify the value a device is expected to drift, then this value should be provided to the plant. This will yield a quantifiable assessment of out of tolerance conditions to more easily identify potential problem devices and those

whose o ¿ of tolerance condition is within the expected range of drift.

(2) Loop Relationships

Normally, the calibration of instrument loops (or channels) is divided into three major parts due to the general inaccessibility of loop field sensors for calibration during plant operation. In order to be able to verify loop performance, the loop is divided into a section which is required to be tested and a non-testable section. The section which is required to be tested generally includes the portion of the loop downstream of the sensor, to a specific loop output. The non-testable section generally contains only the field sensor. Actual division of the loop is as defined in the applicable loop calibration procedures. The section of the loop required to be tested, the individual loop devices, and the loop as a whole make-up the three parts for calibration. Each part has an associated set of tolerances.

Individual device tolerances define the performance requirements for each of the devices within a loop. As discussed in Section III.F.3.b.(1), each device has an As-Left tolerance and may have an actual or implied As-Found tolerance. The As-Left tolerances are assigned for a device as discussed in Section III.D.1.a. If an As-Found tolerance was to be assigned to a device or simply used in assessing an out of tolerance condition, it would be determined as shown below:

Device Tolerance

$$\text{As-Found} = \pm[(\text{As-Left})^2 + (DR)^2 + (MTE)^2]^{0.5} \qquad \text{(Eq. III.F-6)}$$

The tolerances for the section of th loop required to be tested define the requirements for a group of devices. This group can consist of a number of loop devices and is usually defined by the group of devices tested periodically to verify acceptable loop operation. The tolerances for a group of devices is defined as:

Group Tolerance

$$\text{As-Left} = \pm [\text{As-Left}_1^2 + \text{As-Left}_2^2 + \ldots + \text{As-Left}_n^2]^{0.5}$$

(Eq. III.F-7)

Where, As-Left_1 through As-Left_n represents the As-Left tolerances of the individual devices which make-up the defined group 1 through n.

$$\text{As-Found} = \pm[\text{As-Left}_1^2 + DR_1^2 + MTE_1^2 + \text{As-Left}_2^2 + DR_2^2 + MTE_2^2 \ldots + \text{As-Left}_n^2 + DR_n^2 + MTE_n^2]^{0.5}$$

(Eq. III.F-8)

Where, As-Left_i, DR_i, and MTE_i are the As-Left, drift, and MTE error, respectively, for each device 1 through n.

Figure III.F-4 shows the relationship of the group tolerances to the final set of tolerances, the loop tolerances. The loop tolerances, as discussed in Section III.F.3.a, define the performance requirements for the loop as a whole. The loop tolerances are calculated in the same manner as defined above, for a group of devices, but include all devices from sensor to final loop output device.

The As-Found tolerance for a loop, establishes an important performance limit for safety-related instrument loops. This limit, which we will call the "Channel Operability Limit", is the limit for verifying operability of a safety-related loop. A safety-related loop found outside of its channel operability limit would be declared inoperable, and may cause the initiation of a Licensee Event Report (LER) to the NRC.

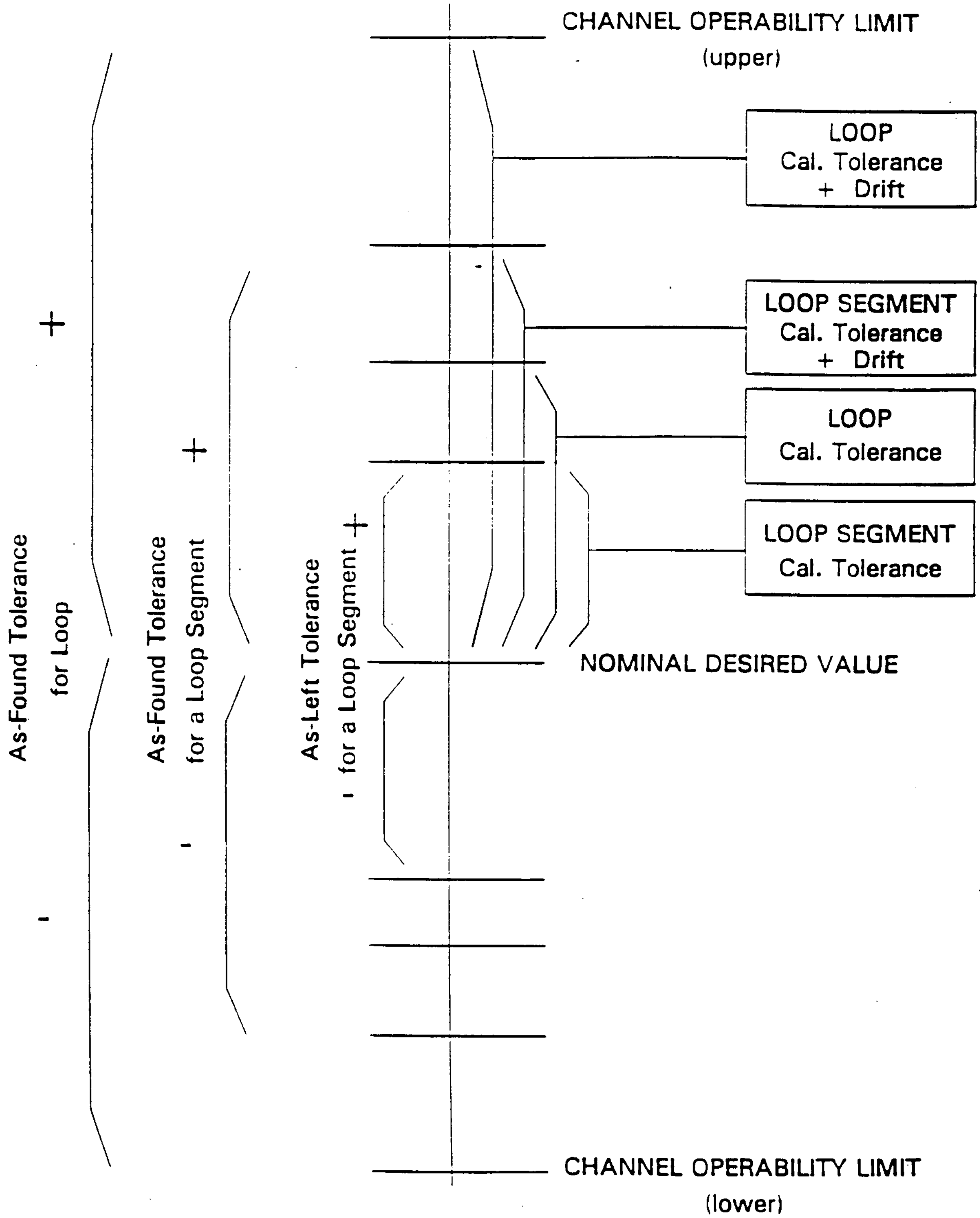


FIGURE III.F-4
LOOP TOLERANCE RELATIONSHIPS

(C) Setpoint Relationship

The application of tolerances, or allowances, in loops containing setpoints, is of particular importance for a nuclear power plant. This is particularly true of the numerous setpoint functions in quality-related applications. For loops containing setpoints, the output of the setpoint device defines the end of a complete loop or channel. This division allows each setpoint/setpoint device to be treated as a separate loop or channel.

The loop is normally divided in the same manner as discussed in Section III.F.3.b.(2), with the setpoint device included in the testable section of the loop. This division allows for the periodic testing of the loop's setpoint actuation value.

The primary function of setpoint loops is to actuate within an acceptable process variable range. This function leads to a slightly different treatment of tolerances for setpoint loops. Instead of being concerned with the accuracy of the loop measurement (i.e., the variance band around the true value), the concern focuses around when the loop will actuate with respect to a true process value limit of concern. Because of these differences, tolerances for setpoint loops will be discussed in detail in Section III.G.

G. Setpoint Determination

Development and maintenance of setpoints is an essential prerequisite to the safe and efficient operation of plant systems and equipment. Properly selected setpoints provide early warning of pending problems, correct abnormal situations, and protect the public, plant personnel, and equipment, without unduly compromising the operability, or efficiency, of the plant.

Keeping this in mind, the purpose of each setpoint must be satisfied by the final value established. Setpoints for alarms, for example, should have sufficient margin from a system trip point, or safety limit, to allow an operator time to take corrective action. An alarm, coincident with an equipment trip setpoint, may serve no useful function. However, when attempting to achieve this margin, alarm and plant trip points should not be set so close to normal plant operation limits that they cause nuisance alarms and spurious trips.

An instrument loop using many cor ponents and functional modules can possess large uncertainties, even though the accuracy rating of the individual components may be reasonable. Therefore, for all instrument loops, and particularly for multi-component instrument loops, setpoints should be located in that portion of the instrument range which has the required accuracy. It is accepted practice that setpoints should generally not be located in the extreme upper or lower portions of the instrument range.

Figure III.G-1 shows the relationships between the various parameters that make up, or define, safety-related setpoints and related allowances. Each of these parameters will be discussed in more detail in the following paragraphs.

1. Limits

The Technical Specifications for each of the three CP&L nuclear plants are governed by 10CFR50.36, which defines two terms, safety limit (SL) and limiting safety system setting (LSSS), and their relation to instrumentation and control design bases. These terms, as well as two other associated terms, are described below.

a. Safety Limit

Plant safety limits (SL) are design limits placed on important process variables to maintain the integrity of plant barriers designed to prevent the release of radioactivity. The limits are established by various regulatory requirements, industry design standards, such as ASME, and initial plant design assumptions bases. The actual plant systems and equipment must be designed such that the plant safety limits are not exceeded during the worst case accident conditions.

Safety limits are the absolute limits. To exceed them, risks incurring uncontrolled releases of radioactivity. In order to ensure they are never reached or exceeded, each plant has conducted in-depth analyses of the accidents and transients postulated to occur for that facility. Such analyses are described in Chapter 15 of each plant's FSAR, as well as in supplemental analyses such as reload reports.

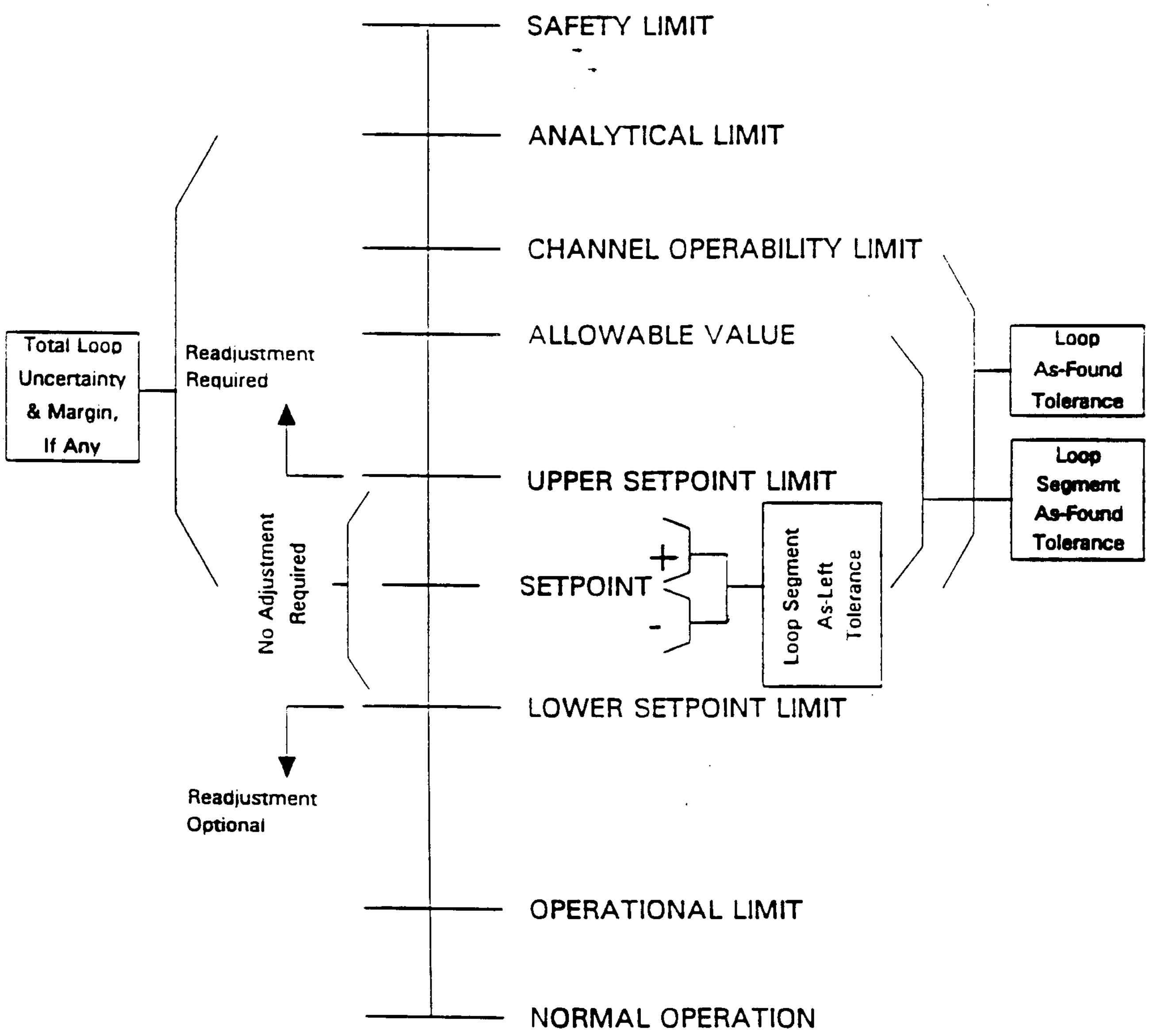


FIGURE III.G-1
LOOP\SETPOINT RELATIONSHIPS

The safety limits are specific values of plant process variables, such as pressure or temperature. They may also be defined by directly calculated process conditions, such as the departure from nuclear boiling ratio (DNBR).

b. Analytical Limit

The accident analyses conducted for each plant, assume protective trips are initiated at certain conservative values prior to a variable reaching the safety limit. Both the assumed values that form the model for such an analyses, and the maximum value that process variables attain in such an analysis, are referred to as analytical limits (AL).

As shown in Figure III.G-1, the safety limit is the uppermost limit that cannot be exceeded without risking potential radioactive releases to the public. To prevent safety limits from being reached, analytical limits are established prior to the safety limits, and are obtained from the results of the safety analysis or from its assumed values. The region between the safety limit and the analytical limit is to provide an additional margin of safety and/or to accommodate any rapid "spikes" or transient overshoots beyond the postulated conditions.

It is important to note that there are relatively few safety limits. Typically, there are numerous analytical limits established, for several types of process conditions, to prevent exceeding a single safety limit. Thus, there may be analytical limits established for RCS temperature, pressurizer level, core power, etc. to prevent exceeding the safety limit associated with RCS pressure.

The determination of Analytical Limits (AL) is the responsibility of the Engineering Discipline which is responsible for the plant system associated with the instrument loop. Each analytical limit and its basis, shall be justified through an engineering calculation or other appropriate means. The value for the analytical limit and the bases for its determination shall be documented in the uncertainty/setpoint calculation.

An evaluation shall be made by the appropriate Engineering Discipline to determine the analytical limit. This evaluation shall take all viable actions necessary to establish the analytical limit and its bases. Such actions may include, but not be limited to - reviewing plant safety analyses, reviewing existing calculations pertaining to the system/instrument loop of concern, reviewing correspondence files with the appropriate vendor, contacting the vendor and/or performing an audit of their files, obtaining and reviewing the original design specifications and/or associated data sheets, contacting other utilities to ascertain what relevant information they may have, and reviewing start-up test reports.

The Technical Specification value may be the only limiting value available. As a last resort, the Technical Specification value could be taken as the analytical limit. However, this would be a very conservative assumption and would result in new setpoints and allowable values closer to the normal operational limits. As discussed later in Section III.G.2.b, moving a setpoint too close to the normal operational limits may be a legitimate safety concern. Thus, using the Technical Specification value as the analytical limit should be avoided, and only implemented after it has been properly evaluated as to its effects on normal operation and plant safety.

c. Limiting Safety System Setting

The second term discussed in 10CFR50.36 for use within the Technical Specifications is the Limiting Safety System Setting (LSSS). The LSSS, as defined in Section II.C is,

> "Settings for automatic protective devices in nuclear reactors that are related to those variables having significant safety functions. A LSSS is chosen to begin protective action before the analytical limit is reached to ensure that the consequences of a design basis accident are not more severe than the safety analysis predicted."

The LSSS is comprised of two components - th trip setpoint and the allowable value. The trip setpoint is the predetermined value at which a device changes state to indicate that the quantity under surveillance has reached the selected value. The allowable value is the limiting value that the trip setpoint can have when tested periodically, beyond which the instrument channel must be evaluated for operability. Thus, the trip setpoint corresponds to the nominal value at which a device is set and expected to change state. The allowable value is the maximum region associated about a setpoint that is still considered to be acceptable for the instrument to fulfill its safety function without risking exceeding the analytical limit. The safety limits and LSSSs are typically defined in the Technical Specifications and the analytical limits are typically defined in the FSAR.

To further illustrate the relationships between the terms discussed above, the RCS Pressure for Harris will be used as an example (Note - any associated head effects have been ignored in the following example for simplicity of illustration). Technical Specifications 2.1.2 define the RCS Pressure safety limit as 2735 psig. Within Table 15.0.6-1 of the Harris FSAR, the high pressurizer pressure trip setpoint is assumed to be 2445 psig for the safety analyses. This is the analytical limit. To ensure that the analytical limit is not exceeded, Technical Specifications 2.2 lists the limiting safety system setting. The limiting safety system setting is composed of the trip setpoint and the allowable value. The trip setpoint is identified as 2385 psig and the allowable value is identified as 2399 psig within Table 2.2-1 of the Harris Technical Specifications. Thus, as long as the trip setpoint for RCS Pressure, and other process variables, are maintained below their allowable values, the safety analyses have ensured that the maximum RCS Pressure achievable under accident conditions will be significantly below the safety limit.

The limits discussed above apply to instrument loops with a protective function. The limits associated with control and indication design bases are treated similarly. Since the control and indication functions are typically not included in the accident analyses, no safety limits, analytical limits, or limiting safety system settings pertain to their settings. However, there is usually a limit associated with control and indication functions and it is frequently referred to as the design limit.

The design limit for control and indication functions is comparable to the analytical limit for protection functions. It is a limit for a measured or calculated variable to prevent undesired conditions such as equipment damage, spurious trips, or challenges to plant safety signals. The design limit may be a calculated value for a particular system or application or it may be a limit specified by the vendor.

The indicated value is like a setpoint except a setpoint results in an automatic action and an indicated value results in a manual action in response to an indication. Depending on the importance of the setpoint or indicated value, corresponding allowable values may also be established similar to the Technical Specification allowable values for the protection functions.

When identifying a limit associated with a particular instrument, it is thus important to understand what that limit represents. It must be clearly understood whether the function is for protection, control, or indication purposes. Once that is confirmed, it must be further clarified as to the type of limit represented by the value and how it relates to the instrument loop's design basis. Otherwise, the design basis may be misinterpreted and/or misapplied.

d. Channel Operability Limit

Although not addressed in the Technical Specifications, another limit exists for determining operability of an instrument channel. This limit, called the Channel Operability Limit (COL), is the loop As-Found tolerance (plus any associated margin) as discussed in Section III.F.3.b.(2). It would be added or subtracted from the setpoint in a manner similar to the allowable value.

Per the Technical Specifications, an instrument loop whose As-Found setpoint exceeds the allowable value in a non-conservative direction must be declared inoperable, and corrective actions taken. However, this determination does not always conclusively demonstrate that the actuation would have occurred at a non-conservative value. This is true because the allowable value only accounts for drift in the tested instruments in the loop, which typically does not include the sensor.

The channel ope ability limit includes the whole loop, from sensor to final actuation device. This limit includes a larger total allowance for drift, which gives rise to the possibility that unused drift in the sensor may offset the drift incurred in the testable portion of the loop. Therefore, if it is feasible to test the entire loop when an allowable value is exceeded, a reportable condition may not exist, as long as, the As-Found allowance for the loop is not exceeded. However, corrective actions must be in accordance with the Technical Specifications when the allowable value is exceeded, regardless of whether or not the channel operability limit was exceeded.

If it is not feasible to test the entire loop, it may be possible to analytically determine whether the channel operability limit would have been exceeded.

e. Operational Limits

These operational limits (OL) are the minimum/maximum values within which a process should be maintained during normal operation. A margin should be maintained between the operational limit(s), and the setpoint limit(s) to allow flexibility for plant maneuvering.

2. <u>Setpoints</u>

As discussed above in Section III.G.1.c, trip setpoints or setpoints (SP) typically refer to an automatic action in response to a process variable achieving or exceeding some predetermined value. An indicated value is similar except that the action taken is manual in response to an indication. The discussions below will refer to the term "setpoint", however, it is intended that such discussions apply to any type of setpoint or indicated value.

a. Types of Setpoints

Setpoints are generally characterized as one of three types: rising, falling, and variable. The setpoint is categorized based on (1) the direction from which a process variable approaches the setpoint, and (2) whether the setpoint has a fixed value or varies as a function of another variable (i.e., time, power, level, temperature, etc.)

Rising setpoints are associated with a process that has a high limit. Action is initiated when the process variable increases to a point equal to, or greater than, the setpoint.

Falling setpoints are associated with a process that has a low limit. Action is initiated when the process variable decreases to a point equal to, or less than, the setpoint.

Variable setpoints can be of either a rising or falling type. The distinction is that in lieu of a fixed value, the setpoint will vary as a function of another parameter or a preset program. A variable setpoint will always be either a rising or a falling setpoint over its entire range. It cannot change from a rising to a falling, or vise versa. Identification of the setpoint type is an important factor when assessing the impact of setpoint inaccuracies.

Figure III.G-2 graphically illustrates both a rising and falling setpoint, and the treatment of loop uncertainties. For a rising setpoint, a conservative setting would be less than the actual limit. Therefore, the loop uncertainties must be subtracted from the analytical limit. For a falling setpoint, a conservative setting would be higher than the actual limit. Therefore, the loop uncertainties must be added to the analytical limit.

b. Calculating Setpoints

Sections III.B, III.C, and III.D discussed the various components of a loop's uncertainty, and Section III.E described how to combine those uncertainties to determine a total loop uncertainty (TLU). The TLU is the maximum potential deviation in the positive and negative direction about the true value of a variable which the loop could consider as the true value of the variable. This can be expressed mathematically as:

$$LV = TV \pm TLU \qquad \text{(Eq. III.G-1)}$$

Where;

LV	=	Loop Value
TV	=	True Value
TLU	=	Total Loop Uncertainty

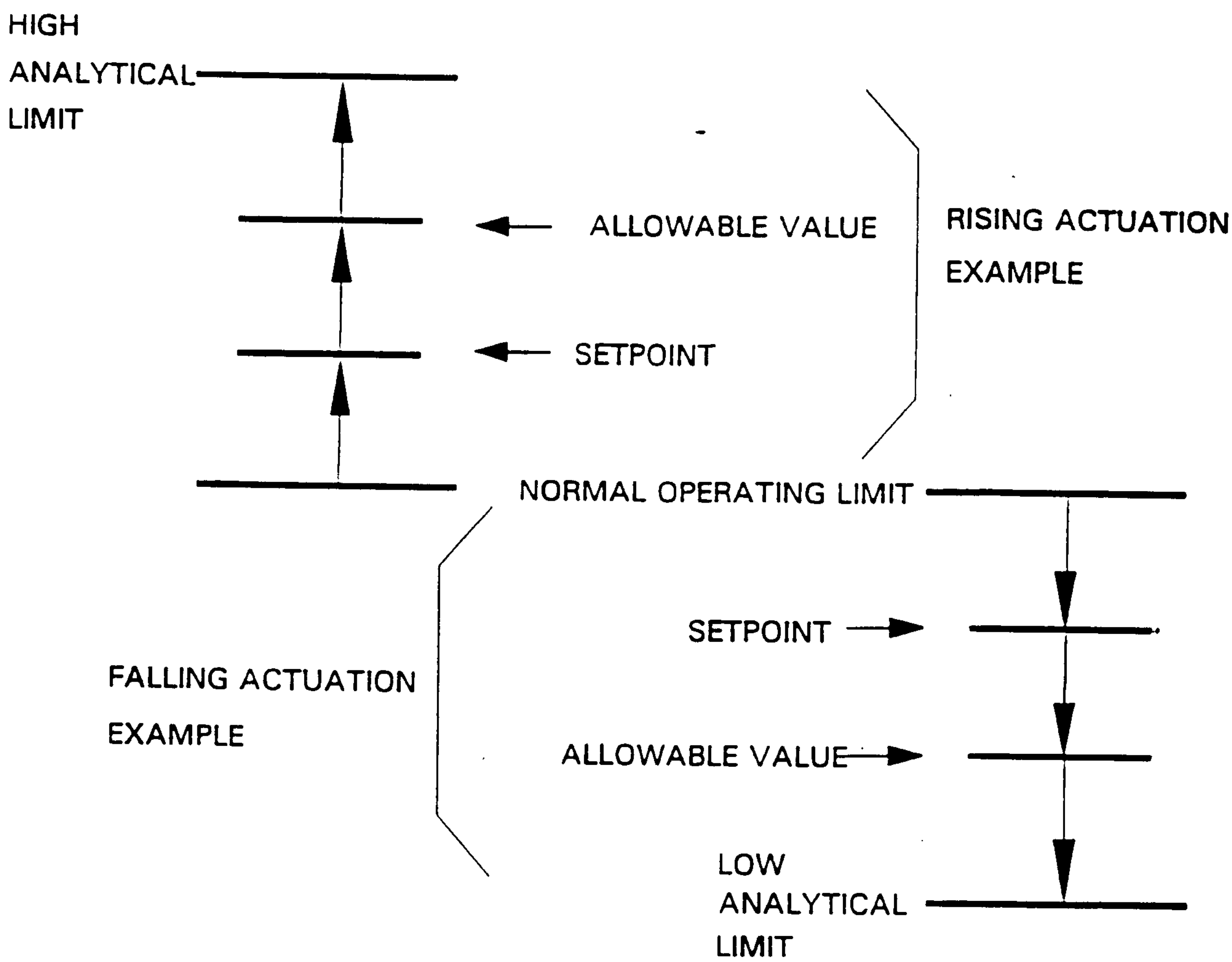


FIGURE III.G-2
SETPOINT TYPES

For calculating setpoints, we have determined the total loop uncertainty but we do not know the true value of the process. What we do know, however, is that the loop value has been analyzed not to exceed a certain value, i.e., the analytical limit (or design limit as applicable). Therefore, we can let the loop value equal the analytical limit, AL:

$$AL = LV \qquad \text{(Eq. III.G-2)}$$

Substituting into Equation III.G-1,

$$AL = TV \pm TLU \qquad \text{(Eq. III.G-3)}$$

For an analytical limit that is higher than the true value of a variable, the equation becomes,

$$AL = TV + TLU \qquad \text{(Eq. III.G-4)}$$

Similarly, for an analytical limit that is lower than the true value of a variable, the equation becomes,

$$AL = TV - TLU \qquad \text{(Eq. III.G-5)}$$

The true value in both these equations represents the maximum true value that the actual process variable may have, which when combined with the maximum expected deviation, will still not exceed the analytical limit. It also represents the maximum value which a setpoint can be assigned and the process be ensured to respond as it was analyzed. As described later in Section III.G.3.a, additional margin may also be used to position the setpoint further away from the analytical limit.

Assuming that no additional margin is used and substituting the setpoint (SP) in for the true value, Equations III.G-4 and III.G-5 can be written as,

$$AL = SP + TLU \qquad \text{(Eq. III.G-6)}$$

and

$$AL = SP - TLU \qquad \text{(Eq. III.G-7)}$$

Rearranging the terms, the setpoint can be determined from the following,

$$SP = AL - TLU \qquad \text{(Eq. III.G-8)}$$

and

$$SP = AL + TLU \qquad \text{(Eq. III.G-9)}$$

Equation III.G-8 represents an analytical limit that is higher than the setpoint and Equation III.G-9 represents an analytical limit that is lower than the setpoint. Another way of viewing it is that Equation III.G-8 applies to a process that must be prevented from rising above a certain analytical limit, and Equation III.G-9 applies to a process that must be prevented from falling below a certain analytical limit. Thus, as discussed in Section III.G.2.a, Equation III.G-8 applies to a rising setpoint and Equation III.G-9 applies to a falling setpoint. They may also be combined into one equation,

$$SP = AL \pm TLU \qquad \text{(Eq. III.G-10)}$$

It is important to understand how the positive and negative terms are used when writing the equation this way. For a rising setpoint, the maximum absolute negative TLU is subtracted (i.e, add the negative value) from the analytical limit. Similarly, for a falling setpoint, the maximum positive TLU is added to the analytical limit.

Figure III.G-2 illustrates both a rising and falling setpoint and the treatment of loop uncertainties. For a rising setpoint, a conservative setting would be less than the limiting value, therefore, the loop uncertainties must be subtracted from the analysis limit. For a falling setpoint, a conservative setting would be higher than the limiting value, therefore, the loop uncertainties must be added to the analytical limit.

Another factor frequently overlooked when establishing a setpoint is the setpoint's proximity to the normal operational limits. If a setpoint is placed too close to the operational limits, it can result in spurious alarms or trips.

Consider the example of the RCS Pressure for Harris discussed in Section III.G.1.c. As stated in Section III.G.1.c, the trip setpoint for RCS Pressure is 2385 psig, however, in actuality the Technical Specifications state the trip setpoint must be $\leq$ 2385 psig. Selecting the trip setpoint as 2250 psig versus 2385 psig would provide additional conservatism that the analytical limit would not be exceeded. Additionally, it would also increase the probability of spurious plant trips. Besides the economic consequences, such trips unnecessarily cycle plant equipment which is only designed for a given number of such trips. Thus, overall plant safety may actually be degraded by moving the setpoint too far away from the analytical limit.

Another illustration of the potential safety significance of placing setpoints too close to their operational limits involves equipment availability and the potential for common mode failures. Consider two trains of an Emergency Core Cooling System (i.e., HPCI, SI, etc,) with their associated pumps. The pumps would typically have trip functions on low suction pressure. If the setpoint for the low suction pressure was established conservatively away from the limiting suction pressure for the pump, it may be set too close to the expected range of the suction pressure. This could cause an inadvertent trip of the pump. Normally, the setpoints for both trains would be set at approximately the same value. Thus, both pumps could potentially trip due to a common mode failure of establishing the setpoints too close to the normal operational values.

When calculating a setpoint, Equations III.G-8 and III.G-9 describe how to ensure a setpoint is far enough away from the analytical limit. A similar approach can be used to ensure that it is far enough away from the operational limits. For a rising setpoint, Equation III.G-8 states that the maximum absolute negative TLU should be subtracted from the analytical limit. To ensure the setpoint is sufficiently away from the operational limit (OL), the maximum positive component of the TLU is added to the OL, as follows:

$$SP = OL + TLU \qquad \text{(Eq. III.G-11)}$$

The value for OL in this equation would be the maximum value the process would be expected to achieve under its normal operational conditions. Similarly, to ensure that the setpoint is sufficiently away from the operational limit for a falling setpoint, the maximum absolute negative component of the TLU would be subtracted from the OL, as follows:

$$SP = OL - TLU \qquad \text{(Eq. III.G-12)}$$

For this equation, the OL represents the minimum value the process would be expected to achieve under its normal operational conditions.

c. Setpoint Tolerances

An upper and lower setpoint limit or tolerance should be established for setpoints. The limits should provide a band around the setpoint which, as a minimum, accounts for the reference accuracy of the periodically tested segment of a loop. This would usually be from the output of a transmitter or detector (i.e., where the test input is injected) up to, and including, the device where calibration measurements are periodically taken during surveillance tests. This is the same as the group As-Left tolerance as discussed in Section III.F.3.b.(2).

Section III.F.3.b describes how the device, group and loop tolerances are established. For a device, the calibration tolerance is normally at least as large as the device's reference accuracy. In some applications, such as when more accurate test equipment is not available, the calibration tolerance may need to be increased beyond the device's reference accuracy.

As a calibration tolerance is widened, it increases its value. This higher value contributes to a higher value for the total loop uncertainty. The higher value for the total loop uncertainty moves the setpoint away from the analytical limit or design limit, as applicable.

Similarly, narrowing the calibration tolerance will move the setpoint closer to the analytical or design limit. Therefore, increasing a tolerance band makes calibrations easier via fewer devices found outside the band and less tuning required to stay within the band. However, increasing the tolerance band also moves a setpoint closer to its operational limits and increases the potential for spurious trips, alarms, etc. Thus, an optimum value should be determined for a device's tolerance and the associated group (i.e. setpoint) and loop tolerances, to allow the most flexibility for both the I&C group to perform their calibrations, and the operations group to operate their equipment.

One method of potentially providing some flexibility for a device tolerance may be to include a calibration tolerance that is not symmetrical. That is, in the direction of interest (falling or rising) the calibration tolerance may be relatively narrow yet broader in the other direction. For example for a rising setpoint, the negative portion of the TLU will be used to establish the setpoint with respect to the analytical limit. Therefore, the tolerance may be tighter in the negative direction and broader in the positive direction (e.g. +10/-5 psig). In such a case, different values would need to be calculated for the positive and negative TLU terms using the respective calibration tolerances.

The tolerance band provides calibration personnel with a measurable calibration band within which the device(s) must be adjusted. In addition, the tolerance band establishes a set of acceptable performance limits against which actual performance can be monitored. As long as the performance of the device(s) remains within these limits, no calibration adjustment would be required. Device(s) found outside of the calibration tolerance would require recalibration to bring the errors back within the tolerance and a review would potentially need to be made to determine if the instrument was, and had been prior to its recalibration, operable.

d. Allowable Values

Technical Specifications typically list, along with an instrument's setpoints, another term called the allowable value which provides an allowance to account for the expected drift in the testable portion of the loop. Usually, the Technical Specifications will state that if a setpoint is found to be less conservative than its allowable value, the loop is to be declared inoperable until the setpoint is restored to within the allowable value. An evaluation is usually made to determine how long such a loop may have been inoperable and any plant operations that may have been affected.

The allowable value defines a limit which the setpoint should be maintained within to show that the uncertainties which are present within the loop when it is periodically tested/calibrated, are consistent with the values used within its uncertainty/setpoint calculation. In other words, it provides an acceptance criteria for the setpoint during the required periodic surveillance test, and from which operability determinations can be made.

The allowable value (error allowance) can be determined from the group As-Found tolerance for that group of instruments periodically tested as discussed in Section III.F.3.b.(2). Normally, this is the accessible portion of the loop excluding the sensor. The allowable value can be determined by adding or subtracting the group As-Found tolerance, as appropriate, to the setpoint such that the allowable setpoint moves closer to the analytical limit. Note that the drift term in Equation III.F-9 would only account for the interval between successive tests (normally 30 days).

Thus for a rising setpoint, the allowable value would be determined by,

$$AV = SP + GAFT \qquad \text{(Eq. III.G-13)}$$

and for a falling setpoint the allowable value would be determined by,

$$AV = SP - GAFT \qquad \text{(Eq. III.G-14)}$$

Where, AV = Allowable Value
SP = Setpoint
GAFT = Group As-Found Tolerance

As discussed in Section III.G.1.d above, the channel operability limit is a value established to encompass the drift from the entire loop, inclusive of the sensor. Whenever the drift from the testable portion of the loop exceeds its allowable value, the drift for the entire loop may still be acceptable if the sensor drift is less than predicted. Although the Technical Specifications must still be followed in assessing loop operability, showing that a loop is still within its channel operability limit is one potential method of justifying a loop's performance.

The channel operability limit is calculated similar to the allowable value, except the Loop As-Found Tolerance is used in place of the Group As-Found Tolerance. For a rising setpoint it is determined by,

$$COL = SP + LAFT \qquad \text{(Eq. III.G-15)}$$

and for a falling setpoint the channel operability limit is determined by,

$$COL = SP - LAFT \qquad \text{(Eq. III.G-16)}$$

Where, COL = Channel Operability Limit
SP = Setpoint
LAFT = Loop As-Found Tolerance

3. Application of Margin

Margin (M) is a term used to describe a general allowance made for determining setpoints. Adding margin has the affect of moving a setpoint further away from the analytical limit (AL) or also known as the design limit (DL). Similarly, removing margin moves a setpoint closer to the analytical limit. Both applications are described in more detail below.

a. Additional Margin

For some loops, the setpoint may be determined to be too close to the analytical limit (or design limit). Such an evaluation may be based on the ever popular "engineering judgement" or it may be more quantitative. For example, the As-Found values for a given loop may be repeatedly exceeding the allowable value and the loop is continually being evaluated for operability. Regardless of the reason, whenever a setpoint is moved further away from the analytical limit (or design limit), it is referred to as "adding margin". Equation III.G-10 shows that a setpoint is calculated by the expression:

$$SP = AL \pm TLU$$

By adding margin (M), the equation becomes,

$$SP = AL \pm TLU \pm M \qquad \text{(Eq. III.G-17)}$$

When margin is added it has the effect of increasing the conservatism of the setpoint. That is the action initiated by the setpoint will occur prior to what it would have occurred without the margin. Caution must be exercised, however, in that too much margin may also lead to spurious trips, nuisance alarms, etc. As discussed in Section III.G.2.b, overall plant performance and plant safety can be degraded because of inadvertent challenges to plant equipment.

Whenever margin is added to a setpoint or determined to be present in an existing setpoint, it should be identified as such within the setpoint calculation. This will assist in any future evaluations of the loop or process system, should modifications be required of the equipment or the safety analyses.

b. Reducing Overconservatisms

As discussed in Section III.E.2, there are several ways of combining uncertainties (linear, SRSS, combinational) that employ varying levels of conservatism. Similarly, there are ways and assumptions used in determining the actual uncertainties that inject varying levels of conservatism. This document has reflected a general approach that may be used efficiently for most setpoints. It is not necessary to fine tune each setpoint to very precise values. Thus, the methods described up to now may introduce certain conservatisms for the sake of convenience in performing the calculations. Some applications have a very narrow region between the normal operating range and the analytical limit (or design limit). For these cases, the conservatism must be reduced as much as practical to prevent inadvertent trips. Presented below are some suggestions which may be used on a case-by-case basis to reduce individual conservatism.

1) Review the timing of the setpoint's actuation (or the time needed for an indication) versus the plant specific accident profiles to determine if the loop's function occurs prior to a harsh environment forming. Also, the accident temperature effect usually occurs immediately after an accident and then dissipates. The accident radiation effect is frequently not a concern until a significant period following an accident. Thus, only one or the other of the effects may need to be included in the total loop uncertainty instead of both.

2) Determine if the specific location of the loop (or components) results in a milder environment than that assigned to the general room or building. For example, a sensor may be shielded by equipment reducing its radiation dose or a sensor may be on the floor of a large open area such that its temperature is less than the average room temperature.

3) Determine if a loop calibration can be performed versus a component-by-component calibration. If not, evaluate whether a loop check can be done following the component-by-component calibration. Either of these minimizes the number of times the M&TE uncertainty must be applied.

4) Ascertain whether more accurate M&TE is available for performing the calibrations. It may be possible to use more accurate equipment if the device is calibrated in the shop versus in the field.

5) Reduce the calibration tolerance for all devices to their minimum acceptable values (typically their reference accuracies).

6) Revise the method of calibration to verify all attributes of each device such that only the calibration tolerance must be included in the total loop uncertainty calculation.

7) Perform a loop specific insulation resistance (IR) calculation instead of relying on a worst case or assumed IR value.

8) Utilize calibration tolerances that are not symmetrical, but are smaller in the direction of interest.

9) Determine if the calibration frequency can be increased to approach the interval used by the vendor for his drift value or, to be even more frequent than that assumed by the vendor.

10) Investigate whether updated information from the vendor can reduce drift or other uncertainties. Also, evaluate if the use of plant As-Found values may be employed for drift rather than the vendor specifications.

11) Modify equipment whereby its calibrated span is closer to its range, and the turndown factor can be decreased or deleted.

12) For indicators and recorders, assess whether another indication (i.e, via the plant computer) may provide a more accurate indication. If possible, scale faces, chart paper, etc. may be changed to reduce the readability error. The substitution of digital displays for analog displays will usually result in a smaller indicator error.

13) Evaluate if sensors can be moved to a more moderate environment.

14) For differential pressure loops, determine if calibrating the sensor at pressure could reduce the static pressure effect.

4. Dead Band and Reset

Dead band and reset are two inter-related control phenomenon which can affect an instrument loop's performance. Dead Band is the term given to the phenomenon that occurs in all instruments upon the reversal of an input signal (i.e., from rising to falling, or falling to rising). A band of non-response, or dead band, exists for a change in input, where no change in output is seen. This is demonstrated graphically in Figure II.C-1. Whenever an input signal changes direction, a discrete amount of reverse signal change has to take place before the output begins to change. This characteristic is inherent in most devices.

Dead band is found in both analog and digital (setpoint) devices. In analog devices, the dead band is part of the basic accuracy of the device, and affects the device's ability to respond to a change in input signal. For digital or setpoint devices, the dead band affects the point at which a device resets after actuation. Generally dead band is an undesirable trait of a control system because of its effect on stability. Many digital applications, though, rely on dead band as an integral part of the control scheme.

To prevent cycling, chatter and subsequent system instability, it is usually necessary to allow a sufficiently large difference (or dead band) between the actuation and reset point of a setpoint device. Some setpoint devices have only a fixed differential between the actuation and reset point. When selecting such a device, an assessment should be made to ensure that the fixed differential is adequate for the application. For devices which have an adjustable differential, the setting for the reset point should be based on system capabilities and required system performance. A sufficient band must be allowed between a device's setpoint and reset point to prevent cycling, and equipment wear due to normal process system variations.

In general, dead band and reset do not have ˙˙ be considered in loop error analysis. The dead band and reset do, however, have to be evaluated during a final setpoint determination.

5. Time Response

The speed, or time response, of both a process, and the I&C system that is monitoring a process, is an important factor in the selection of setpoints. Allowances in setpoint values may be necessary to compensate for specific system, or equipment, time responses which affect the operation of a setpoint. A slow time response can cause a setpoint to be actuated too late to prevent damage of equipment.

The lead time needed to correct an abnormal process condition prior to reaching unacceptable levels may need to be determined, and factored into a setpoint.

Consider the following example,

EXAMPLE:

A setpoint is needed for a pressure switch which serves to maintain a minimum pressure in a system. The pressure switch starts a pump, which requires 5 seconds before it is capable of supplying pressure. If the normal pressure is 100 psi, the system pressure can decrease by 5 psi per second and the absolute minimum pressure to be maintained is 50 psi, the switch would require a setpoint of at least 75 psi. This would ensure that the actual system pressure does not fall below the required minimum before the pump corrects the decrease.

In a similar manner, the time response of an instrument or instrument loop may have to be determined and factored into a setpoint. This happens primarily with processes which have very fast time constraints. Every instrument or loop has a time response, or elapsed time period between the time a process reaches a given setpoint and action is taken. For many instrument loops, this is a matter of a second or less. But for a process condition which could also significantly change within this period of time, a setpoint may have to be lowered or raised to allow for the instrument time response.

ATTACHMENT A

ERROR CALCULATION FORMAT

1. Overview

In order to assist in the development, review and approval processes required for instrument loop error/setpoint calculations, a standard format should be used in the preparation of these calculations. The following format should be used in the generation and/or revision of all future instrument loop error and setpoint calculations. A general discussion of the format is provided below.

Each loop uncertainty/setpoint calculation should contain, as a minimum, the following sections:

- Calculation Cover Sheet
- List of Effective Pages
- Table of Contents
- Objective
- Functional Description
- Loop Diagram
- References
- Inputs and Assumptions
- Calculation of Uncertainties/Setpoints
- Discussion of Results
- Setpoint Relationship Form
- Attachments (as necessary)

Other sections may be added as needed, depending upon the specific application and complexity of the instrument loop. Each of the above sections is briefly described below.

2. Format Details

a. Calculation Cover Sheet

The Calculation Cover Sheet should include the calculation number, revision, title, safety classification, seismic classification, and applicable signatures and dates. The title should directly indicate whether the calculation is just an uncertainty calculation or a setpoint calculation; the system, process, and function (protection, control, indication) being monitored; and the applicable instrument loops.

b. List of Effective Pages

The List of Effective Pages should show all pages in the calculation, including any attachments or appendices. Page numbering should start with the List of Effective Pages, which should be page i. Any subsequent pages up to the start of the calculation (i.e., with the Objective) should use lower case Roman numerals as the page numbers (e.g. ii, v, ix, etc.). Starting with the first page of the calculation, the remaining pages shall be numbered with Arabic numbers (e.g. 2, 5, 9, etc.). Any Attachments, Appendices, Figures shall also be included on the List of Effective Pages. In addition to their consecutive numbers as part of the calculation, Attachments, Appendices, and Figures shall also be numbered as "page __ of __" to indicate how many pages make up the complete Attachment/Appendix/Figure. Only their consecutive page number as part of the calculation need be included in the List of Effective Pages.

c. Table of Contents

The Table of Contents shall include a listing of each section and subsection of the calculation, along with any Attachments, Appendices, and/or Figures. Each section and subsection shall be numbered with Arabic numbers (e.g. 2.1, 4.4, 6.0, etc.). The Table of Contents shall denote Attachments, Appendices, and Figures by their consecutive page number within the calculation and by their total number of pages. Their title/subject shall also be identified within the Table of Contents.

d. Objective

The Objective shall describe what the calculation is intended to achieve. It shall discuss what is being calculated (i.e. uncertainties, setpoints, indicated values, etc.), the reason it is being calculated, and the applicable system and instrument loop numbers.

e. Functional Description

The Functional Description shall describe the functions of the loop(s) (i.e., protection, control, and indication), their safety significance, and the plant conditions for which the calculation is valid. It shall also describe the layout of the loop, any process effects that must be considered, and the general design basis of the instrument's function.

f. Loop Diagram

A Loop Diagram shall be generated to identify each component in the loop by component type, manufacturer/model number, location, and tag number. The diagram shall begin with the loop's relative location to the process, show the primary element or sensor, and progress to each applicable bistable and/or end device. Both the process units being monitored, as well as any electrical units, shall be shown together with their associated range. The diagram is intended to be a simplified "block" diagram, and does not need to include individual termination points.

g. References

The References shall list all documents, and their revision number, that govern, and/or supply, data used in the calculation. References shall be grouped into major subsections (i.e. drawings, vendor data, calibration procedures, other procedures, etc.) and assigned a unique number within that subsection. As a minimum, the following references should be included within the calculation: P&ID, loop diagram, vendor literature (preferably from the vendor technical manual), this design guide, and any applicable Tech Spec or FSAR sections.

h. Inputs and Assumptions

The Inputs and Assumptions section should list any known conditions or values from codes/standards, measured data, functional requirements, performance requirements, design conditions, or other specific requirements. Such conditions may include the normal and accident ranges of the process condition, the normal and accident environmental conditions for each applicable location, the calibrated span of each component, the calibration frequency of each component, etc. The source of each input shall be referenced.

Also included within this section shall be any assumptions necessary to complete the calculation. Assumptions shall be kept to a minimum and specifically identified as an assumption, and not a design input. Information that can be specifically referenced to a source document should be treated as input. Each assumption must state the basis for the assumption, and use of the "engineering judgement" basis shall be minimized.

i. Calculation of Uncertainties/Setpoints

The Calculation of Uncertainties/Setpoints section shall define each individual uncertainty, calculate the total loop uncertainty, and as applicable, calculate the setpoint, allowable value, channel operability limit, and indicated value. Using the loop diagram as a guide, the process measurement uncertainties shall be determined first and progress through all loop components to each appropriate bistable/end device. Error propagation through the loop shall be calculated as discussed in Section 12.2.

As each device in a loop is encountered, the specific error effects for the device shall be listed. Below the device information, the resultant device and loop output errors shall be calculated. Each facet of the loop that exists must be addressed, even if it is only to explain why an uncertainty value is not applicable. The Setpoint Relationship Form shown in Appendix B shall be completed for each instrument loop (or group of loops if <u>all</u> information for a loop is common to other channels).

j. Discussion of Results

The Discussion of Results shall provide the specific results of the calculation, by instrument loop and/or function. The status of the plant to which these results apply shall be described, along with any other clarifying assumptions/conditions. The relationship of the results to any existing values shall be described along with any available margin. If the results necessitate, or potentially necessitate, the change of any existing documents, drawings, procedures, etc., these shall be specifically identified and discussed.

k. Setpoint Relationship Form

The Setpoint Relationship Form shown in Appendix B should be completed for each loop. The form is designed to quickly summarize the individual error terms and how they are combined. The form itself is not important, but rather the information it provides. If, for particular applications, other means are more appropriate to present this information, they may be used instead of this form (e.g. a separate printout of the information, a diagram, etc.).

1. Attachments

Attachments should be used to provide clarification of the information used within the calculation. Frequently, the information used within the calculation may be from a source that is not easily reproducible/recoverable. In such cases, copies of the information should be included with the calculation as an attachment. Such information may include - vendor literature, letters, memos, telecons, specifications, etc.

3. General Guidelines

Some other general information should be considered in developing the calculations. These general guidelines are described below:

a. The level of detail for nonsafety-related instrument loops may vary based on the instrument loop's importance to plant safety, availability, reliability, and personnel safety.

b. Calculations may be performed by "hand" or preferably, by applying the techniques of a computer based word processor. An alternate method would employ a computer based software program. If such a software program has not been verified and validated in accordance with the CP&L Quality Assurance Program, the final calculation must be design verified.

c. All calculated values shall be rounded to the least significant digit. For values that end in five or higher, they shall be rounded up to the next higher significant digit. For values ending in one through four, they shall be rounded down to the lower significant number.

ATTACHMENT B

SETPOINT RELATIONSHIP FORM

The Setpoint Relationship Form is provided to assist in the calculation of total loop uncertainty, setpoints, indicated values, allowable values, reset values, etc. The form is intended to be an aid to the preparer of such calculations and provide the relevant information in a summary format. It is believed that by viewing the pertinent information in a format such as that provided, the overall relationships of the different error and limit terms can be more readily understood. If the user of this document determines that another format is more suitable for their application, then another format can be used as long as all of the applicable information is documented.

Two forms are provided. Form B-1 is for increasing setpoints and Form B-2 is for decreasing setpoints. Only one form should be completed for each setpoint or indicated value. However, loops with more than one setpoint or indicated value may use more than one form to address each individual application.

Each of the two forms is comprised of two separate sheets. The first sheet determines the individual device loop uncertainties, and is the same sheet for both Form B-1 and B-2. One such sheet should be completed for each device in the loop which contributes to the total loop uncertainty.

The first sheet for Forms B-1 and B-2 lists the potential uncertainties that may apply to a given device. Appropriate values should be inserted for each applicable error/effect. Under "TYPE", the user should identify what type of error the value represents: random, bias, dependent, independent. If the error is dependent, the dependency should be explained in the "COMMENTS" field. Any other clarifying information may also be included within the "COMMENTS" field. Using Section III.E.2.c of the design guide, the errors/effects should be combined to determine an overall device uncertainty.

Once all of the uncertainties for the devices have been determined, they should be summarized at the top of the second sheet for Form B-1 or B-2, as appropriate. The process measurement errors, primary element errors, and any other applicable errors should be combined with the device uncertainties to determine the total loop uncertainty. The values for the other parameters should be documented on the second sheet of the form, in the spaces provided. Some values must be obtained from the design bases of the instrument loop, and others must be calculated, as shown.

"SAMPLE"

Attachment ___
Sht. ___ of ___

SETPOINT RELATIONSHIP FORM B-1
INCREASING SETPOINTS

Calc. # __________
Page # ___ Rev. ___

Calc. Title ____________________ Instrument No(s). ____________________

Device Type ____________________ Device Name(s) ________ ________

ERROR/EFFECT	VALUE	TYPE	COMMENTS
Other Effect (1)	OE1 = +___\-___		
Other Effect (2)	OE2 = +___\-___	-	
Other Effect (3)	OE3 = +___\-___		
Insul. Resist. Effect	IR = +___\-___		
Acc. Temp. Effect	ATE = +___\-___		
Acc. Press. Effect	APE = +___\-___		
Acc. Rad. Effect	ARE = +___\-___		
Seismic Effect	SE = +___\-___		
Readability	RE = +___\-___		
Pwr. Supply Effect	PSE = +___\-___		
Static Press. Effect	SPE = +___\-___		
Temp. Effect	TE = +___\-___		
Drift	DR = +___\-___		
M&TE Error	MTE = +___\-___		
Cal. Tolerance	CAL = +___\-___		
Ref. Accuracy	RA = +___\-___		
Total Device Uncertainty (TDU)	TDU = +___\-___		

Note: All errors/effects must be converted to the same basis (i.e. units) prior to entering their values onto the form.

"SAMPLE"

Attachment ___ Sht. ___ of ___

SETPOINT RELATIONSHIP FORM B-1
INCREASING SETPOINTS

Calc. # __________ Page # ___ Rev. ___

Calc. Title ______________________ Instrument No(s). ____________________

Device Uncertainties:

Device 1 = ____________
Device 2 = ____________
Device 3 = ____________
Device 4 = ____________

Process Measurement Effect: PME = ____________

Primary Element Error: PE = ____________

Total Loop Uncertainties: TLU = ____________

Final Equation for TLU = ______________________________________

PARAMETER	VALUE	EQUATION	NOTES
Analytical/Design Limit		N/A	
Margin		N/A	
Other Uncertainties		OU = TLU - LAFT	
Chan. Operability Limit		COL = SP + LAFT	
Loop As-Found Tolerance		LAFT = $[\text{As-Left}_1^2 + DR_2^2 + MTE_1^2 + \ldots + \text{As-Left}_n^2 + DR_n^2 + MTE_n^2]^{0.5}$	1
Allowable Value		AV = SP + GAFT	
Group As-Found Tolerance		GAFT = $[\text{As-Left}_1^2 + DR_2^2 + MTE_1^2 + \ldots + \text{As-Left}_n^2 + DR_n^2 + MTE_n^2]^{0.5}$	2
Setpoint		SP = AL - TLU	
Reset Value		N/A	3
Operational Limit		N/A	4

Note: 1. LAFT = All devices' As-Left, MTE and Drift values, including the sensors.
2. GAFT = All devices' As-Left, MTE and Drift values, except the sensors.
3. Reset value is a fixed or variable value, dependent upon the bistable.
4. Operational Limit is the upper bound of the normal operational limit.
5. Convert all values to the same basis (i.e. units) prior to combining.

"SAMPLE"

Attachment ___
Sht. ___ of ___

SETPOINT RELATIONSHIP FORM B-2
DECREASING SETPOINTS

Calc. # __________
Page # ___ Rev. ___

Calc. Title ____________________ Instrument No(s). ____________________

Device Type ____________________ Device Name(s) ____________________

ERROR/EFFECT	VALUE	TYPE	COMMENTS
Other Effect (1)	OE1 = +___\-___		
Other Effect (2)	OE2 = +___\-___		
Other Effect (3)	OE3 = +___\-___		
Insul. Resist. Effect	IR = +___\-___		
Acc. Temp. Effect	ATE = +___\-___		
Acc. Press. Effect	APE = +___\-___		
Acc. Rad. Effect	ARE = +___\-___		
Seismic Effect	SE = +___\-___		
Readability	RE = +___\-___		
Pwr. Supply Effect	PSE = +___\-___		
Static Press. Effect	SPE = +___\-___		
Temp. Effect	TE = +___\-___		
Drift	DR = +___\-___		
M&TE Error	MTE = +___\-___		
Cal. Tolerance	CAL = +___\-___		
Ref. Accuracy	RA = +___\-___		
Total Device Uncertainty (TDU)	TDU = +___\-___		

Note: All errors/effects must be converted to the same basis (i.e. units) prior to entering their values onto the form.

"SAMPLE"

Attachment ___
Sht. ___ of ___

SETPOINT RELATIONSHIP FORM B-2
DECREASING SETPOINTS

Calc. # __________
Page # ___ Rev. ___

Calc. Title ____________________ Instrument No(s). ____________________

Device Uncertainties: Device 1 = __________
Device 2 = __________
Device 3 = __________
Device 4 = __________

Process Measurement Effect: PME = __________

Primary Element Error: PE = __________

Total Loop Uncertainties: TLU = __________

Final Equation for TLU = ______________________________

PARAMETER	VALUE	EQUATION	NOTES
Operational Limit		N/A	1
Reset Value		N/A	2
Setpoint		SP = AL + TLU	
Group As-Found Tolerance		$GAFT = [As\text{-}Left_1^2 + DR_1^2 + MTE_1^2 \ldots + As\text{-}Left_n^2 + DR_n^2 + MTE_n^2]^{0.5}$	3
Allowable Value		AV = SP - GAFT	
Loop As-Found Tolerance		$LAFT = [As\text{-}Left_1^2 + DR_1^2 + MTE_1^2 \ldots + As\text{-}Left_n^2 + DR_n^2 + MTE_n^2]^{0.5}$	4
Chan. Operability Limit		COL = SP - LAFT	
Other Uncertainties		OU = TLU - LAFT	
Margin		N/A	
Analytical/Design Limit		N/A	

Note:
1. Operational Limit is the lower bound of the normal operational limit.
2. Reset Value is a fixed or variable value, dependent upon the bistable.
3. GAFT = All devices' As-Left, MTE and Drift values, except the sensors.
4. LAFT = All devices' As-Left, MTE and Drift values, including the sensors.
5. Convert all values to the same basis (i.e. units) before combining.

ATTACHMENT C

SPECIFIC GRAVITY DETERMINATION FOR BORIC ACID SOLUTIONS

The most common chemical composition affecting the density of water in PWRs is boric acid. Boric acid is typically provided in either units of "parts per million (ppm)" or "weight percent". The discussion below provides a convenient means of correlating such values to an equivalent specific gravity, that can then be used in making the appropriate corrections for density in the process measurement determination.

A solution of boric acid (B.A.) will have a certain percent by weight (%wt) of boric acid according to the relationship,

$$1 \text{ \%wt B.A.} = \frac{1 \text{ pound B.A.}}{100 \text{ pounds of solution}}$$

By definition,

$$1 \text{ ppm B.A.} = \frac{1 \text{ pound B.A.}}{1{,}000{,}000 \text{ pounds of solution}}$$

Combining these two equations produces,

$$\frac{1 \text{ \%wt B.A.}}{1 \text{ ppm B.A.}} = \frac{1 \text{ pound B.A.}}{100 \text{ pounds of solution}} * \frac{1{,}000{,}000 \text{ pounds of solution}}{1 \text{ pound B.A.}}$$

Simplifying the relationship produces,

$$1 \text{ \%wt B.A.} = 10{,}000 \text{ ppm B.A.}$$

Since concentration is normally stated in ppm boron (B), not ppm B.A., the equation must be modified. Boric acid is H_3BO_3 with a molecular weight of 61.83. Boron's atomic weight is 10.81. Thus, the correction factor becomes,

$$\frac{10.81 \text{ ppm B}}{61.83 \text{ ppm B.A.}}$$

Using this correction factor, the above relationship for boric acid is revised to,

$$1 \text{ \%wt B.A.} = 10{,}000 \text{ ppm B.A.} * \frac{10.81 \text{ ppm B}}{61.83 \text{ ppm B.A.}}$$

1 %wt B.A. = 1748 ppm B

Another way to state this is,

1 ppm B = 0.000572 %wt B.A.

This is the derived conversion factor that will be used in concentration conversions. Next, the conversion factor will be used to determine the Specific Gravity (S.G.) of a solution. The S.G. of a solution of B.A. can be defined by the equation,

$$\text{S.G. of solution} = \frac{[(\%\text{wt } H_2O)(\text{S.G. of } H_2O)] + [(\%\text{wt B.A.})(\text{S.G. of B.A.})]}{100}$$

To find the S.G. of a particular boric acid solution with a known concentration (in ppm Boron) at a certain temperature, follow these steps,

1. Convert the ppm B to %wt B.A. using the derived conversion factor determined above.

2. Determine the water's S.G. (from appropriate tables) for the given temperature.

3. Substitute the values into the equation for the S.G. for a solution.

Consider the following example,

EXAMPLE

Find the S.G. of a 2300 ppm B solution at 100°F.

From steam tables, the S.G. of water at 100°F is determined as 0.99544. From the CRC handbook of Chemistry and Physics, the S.G. of B.A. is determined as 1.435. Using the conversion factor, the ppm B is converted to %wt B.A. as follows,

$$2300 \text{ ppm B} * \frac{0.000572 \text{ \%wt B.A.}}{\text{ppm B}} = 1.3156 \text{ \%wt B.A.}$$

The %wt of water (H_2O) is determined by subtracting the %wt of B.A. from 100%, or

$$\%\text{wt } H_2O = 100 - 1.3156 = 98.6844$$

Substituting the values into the equation for the S.G. for a solution produces,

$$\text{S.G. of solution} = \frac{[(98.6844)(0.99544)] + [(1.3156)(1.435)]}{100}$$

$$\text{S.G. of solution} = 1.0012$$

It should be noted that the S.G.of boric acid is 1.435 at 15°C (about 60°F). Due to the small amount of boric acid in the solution,-the density change of the boric acid due to temperature is negligible. The density change of the water due to temperature is included.

ATTACHMENT D

CONVERSION OF ERROR BASIS

The error basis which provides the most flexible and useful information is "percent of calibrated span". However, different devices may have their error expressed in different bases. The following methods are provided for the user to convert from typical bases to "percent calibrated span". Many of these methods have been described in examples throughout the design guide. However, they are summarized here for the user's convenience.

1. Upper Range Limit

The upper range limit is associated with an instrument which has an adjustable range, and the upper range limit represents the maximum possible range of the instrument. To convert from upper range limit (URL) to percent calibrated span, use the following relationship,

$$\text{Error in \% cal. span} = \frac{(\text{Error in \% URL})(\text{URL})}{(\text{Span})}$$

For example, if the drift accuracy of a transmitter is ±0.5% URL, the span is 0-100 psig, and the URL is 0-400 psig, determine the error in % calibrated span.

$$\text{Error in \% cal. span} = \pm \frac{(0.5\%)\ (400\ \text{psig})}{(100\ \text{psig})}$$

$$\text{Error in \% cal. span} = \pm\ 2.0\%$$

2. MTE Ranges

Measurement and test equipment (MTE) frequently has a range which is different from an instrument's range. Thus, the error for the MTE is given in terms of % of its range and must be converted to % of the instrument's calibrated span. This is done using the following relationship,

$$\text{Error in \% cal. span} = \frac{(\text{MTE Error in \% of range})(\text{MTE Range})}{(\text{Equivalent Instrument Span})}$$

For example, a pressure transmitter has a calibrated span of 0-100 psig. It produces an equivalent signal of 4-20 madc. This is dropped across a 250 ohm resistor at the test point to produce a 1-5 vdc signal. A digital multimeter has a voltage range of 0-25 vdc and an MTE error of ±0.2% of its range. Determine the multimeter's error in % calibrated span of the transmitter.

The transmitter has a range of 0-100 psig which also corresponds to 4-20 madc. Instead of measuring the current, however, the multimeter measures the equivalent voltage across a 250 ohm resistor, or 1-5 vdc. The transmitter's equivalent range is then 1-5 vdc, or 4 vdc (i.e., 5 - 1 = 4 vdc). Substituting this into the above equation produces,

$$\text{Error in \% cal. span} = \pm \frac{(0.2\%)(25 \text{ volts})}{(4 \text{ volts})}$$

$$\text{Error in \% cal. span} = \pm 1.25\%$$

[Note: This is just the error of the multimeter and does not include the error of the resistor, which would also need to be determined for the MTE error.]

3. MTE Error as a Percentage of Reading

For some MTE, its error may be expressed as a percentage of its reading. This is especially common for digital meters. To convert to an error expressed in terms of % calibrated span of the instrument, the following relationship is used,

$$\text{Error in \% cal. span} = \frac{(\text{Error in \% reading})(\text{Reading})}{(\text{Equivalent Instrument Span})}$$

For example, a piece of test equipment has an accuracy of ±0.3% of reading for all scales. The transmitter's calibrated span is 0-100 psig, producing an equivalent signal of 4-20 madc. The test equipment measures this signal as a 1-5 vdc signal across a 250 ohm resistor. The transmitter's setpoint is 50 psig. Determine the test equipment's error in % calibrated span.

At the setpoint of the transmitter, the test eq''ipment should read 3 vdc. This is because the 50 psig setpoint is equal to one half of the transmitter's calibrated span of 0-100 psig. At 50 psig, the transmitter will output a signal of 12 madc. (halfway across the 4-20 madc calibrated span) which will be monitored by the test equipment as 3 vdc (halfway across the 1-5 vdc span). Since the test equipment begins with a reading of 1 vdc, this must be subtracted from the 3 vdc to obtain the effective reading of the test equipment, which is 2 vdc. The equivalent instrument span is 1-5 vdc, or 4 vdc (5 - 1 vdc). Substituting these values into the above equation produces,

$$\text{Error in \% cal. span} = \pm \frac{(0.3\%)(2\text{ vdc})}{(4\text{ vdc})}$$

$$\text{Error in \% cal. span} = \pm\ 0.15\%$$

[Note: This is just the error of the test equipment identified and does not include the error of the resistor, which would also need to be determined for the MTE error.]

4. Bias of a Known Maximum Magnitude

Many times a bias of a known maximum magnitude, must be converted to % calibrated span of the instrument loop. The bias will typically be expressed in terms of units of the process. This is converted to terms of error in % calibrated span by the relationship,

$$\text{Error in \% cal. span} = \frac{(\text{Bias})}{(\text{Span})}$$

For example, the temperature bias in the reference leg of a level transmitter can cause a maximum error of 2 in WC. The transmitter has a span of 250 in WC. Determine the bias error in % calibrated span.

$$\text{Error in \% cal. span} = \frac{(2\text{ in WC})}{(250\text{ in WC})}$$

$$\text{Error in \% cal. span} = 0.8\%$$

5. MTE Error with Rounding of Least Significant Digits

Digital meters have an error associated with the rounding off or truncation of the least significant digits. If the device has more than four or more digits, then the error caused by the rounding of the fourth digit will not add an appreciable amount of error. For devices with three or less digits, the error is determined as follows,

$$\text{Error in \%} = 100 * \frac{(1)}{(10)^n}$$

Where n is the number of significant digits.

For example, a digital multimeter has an error of ± 0.2% of its range plus the error associated with rounding off to the least significant digit. If the meter is used to read 0-10 vdc to ±0.1 vdc the error for the round-off would be,

$$\text{Error in \%} = 100 * \frac{(1)}{(10)^3}$$

$$\text{Error in \%} = \pm 0.1\%$$

Thus, the total error for the multimeter would be ±0.2% + 0.1% or ±0.30%. This would then be converted to error in % calibrated span of the instrument as described in 2 above.

ATTACHMENT E

BNP Site Specific Committments

1. No specific committments have been specified.

ATTACHMENT F

HBR Site Specific Committments

1. No specific committments have been specified.

ATTACHMENT G

SHNPP Site Specific Committments

1. Regulatory Guide 1.105, "Instrument Setpoints for Safety-Related Systems", Revision 1, as identified in SHNPP FSAR, page 1.8-135.

2. Westinghouse Setpoint Methodology , Rev. 1, "Westinghouse Setpoint Methodology for Protection Systems, Shearon Harris".