ENCLOSURE 3

BROWNS FERRY (BFN) TS-447 REQUEST FOR ADDITIONAL INFORMATION

TVA Setpoint Calculation Methodology

part of BFN TS-447 RAI Enclosure 3

B43 000229 001

TENNESSEE VALLEY AUTHORITY
Division of Nuclear Engineering

QA RECORD

Instrumentation & Controls Department

EEB-TI-28

BRANCH TECHNICAL INSTRUCTION

TITLE: SETPOINT CALCULATIONS

This document consists of 188 pages including the Cover Page, Revision Log, Appendixes, etc.

	REVISION R0	R1	R2	R3	R4	R5
ISSUE DATE	10-16-87	10-24-88	10-06-92	02-26-99	11-19-99	2-25-00
PREPARED	R L Brehm	R A Jarrett	R A Jarrett	R A Jarrett	R A Jarrett	RA Jarrett
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REVISION LOG

Title: Setpoint Calculations EEB-TI-28

Revision	Description
0	Initial Issue of EEB-TI-28
1	To add procedure requirements for Setpoint and Scaling documents. Redefine Allowable Value "Av".
2	A complete rewrite to provide additional clarification and guidance with respects to instrumentation uncertainties. This revision of TI-28 combines information from the previous revision of TI-28 and the draft of ISA 67.04, Part II. No methodology changes have been implemented into this revision.
3	Incorporate corrective action required for resolution of PER CHPER980118. This revision deletes the SAR review documentation requirement of section 6.3.3 of this TI. Added references NEDP-2 and SPP 9.3 to Reference section.
4	Update references; fix typo's; additions of sections 4.3.4, 5.14.1.1, 5.16.5, 5.18, and 6.3.7; additions to sections 4.3.3.4, 4.3.3.5, 4.5, 5.2.1, 5.11, Appendix A, Appendix D, Appendix E, and Appendix G; complete rewrite of the Appendix B and C.
5	Revised Appendix K to correct values associated with the K Table on page K-9. This is part of the corrective action for PER 00-000008-00.

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APPENDIXES

1.0 PURPOSE

The purpose of this instruction is to define the minimum requirements for assuring that setpoints and associated scaling have been established within and will be maintained within specified limits for nuclear safety-related instruments used in nuclear power plants.

2.0 SCOPE

This instruction describes the method for determining the acceptability of setpoints for nuclear Safety-related, Technical Specification, Compliance, and Appendix R instrumentation channels. This instruction addresses not only the criteria for ensuring that analytic/safety limits are not exceeded, but also those criteria that must be considered when evaluating setpoints for normal system operation. This instruction does not define what calculations are required for each Site, only how to perform them once the Site defines their scope per Reference 3.9. This instruction applies to all TVA nuclear power generating stations.

This Technical Instruction shall be used for the preparation of all calculations defined in this scope statement as of 90 days from the date of issue of this Instruction. This revision does not require back-fit to previously issued calculations, but shall be applied to any future revisions of these calculations (only for the portion of the calculation being revised).

3.0 REFERENCES

3.1	NRC DG-1045	Draft Regulatory Guide - Instrument Setpoint for Safety-Related Systems, Revision 3, 10/96
3.2	Regulatory Guide 1.105	Instrument Setpoints for Safety-Related Systems, Revision 2, February 1986
3.3	ISA-S67.04, 1982	Setpoints for Nuclear Safety- Related Instrumentation Used in Nuclear Power Plants
3.4	ISA- RP67.04, Part II-1994	Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation
3.5	ISA-DS-51.1, 1979	Process Instrumentation Terminology
3.6	NEDP-1	Design Basis and Design Input Control
3.7	NEP-3.12	Safety Related Setpoints for Instrumentation and Controls - Establishment and Validation
3.8	NEDP-10	Design Output

3.9	SPP-6.7	Instrumentation Setpoint, Scaling, and Calibration Program
3.10	NUREG/CR-3659, PNL-4973	A Mathematical Model for Assessing the Uncertainties of Instrumentation Measurements for Power and Flow of PWR Reactors
3.11	Electrical Design Standard, DS-E18.3.3	Instrumentation and Controls - Instrumentation Symbols and Tabulations (Browns Ferry Nuclear Plant through Bellefonte Nuclear Plant)
3.12	Branch Technical Instruction, EEB-TI-27	Control Loop Response
3.13	Branch Technical Instruction, EEB-TI-30	Instrument Sensing Line Response
3.14	Flow Measurement Engineering Handbook	By R W Miller, McGraw-Hill Book Company, First Edition
3.15	Handbook of Statistical Methods for Engineers and Scientists	By Harrison M Wadsworth, First Edition
3.16	ASME Standard, ASME MFC-3M-89	Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi
3.17	Statistical Methods	By G W Snedecor and W G Cochran, Iowa State University Press/Ames, 8th Edition
3.18	NEDP-5	Design Verification and Interface Control
3.19	NEDP-2	Design Calculation Process Control
3.20	Underground Power Cables	By King and Halfter, Longman Publishers First Edition
3.21	SPP- 9.3	Plant Modifications and Design Change Control
3.22	Not Used	
3.23	ISA-S67.04, Part 1, 1994	Setpoints for Nuclear Safety-Related Instrumentation
3.24	SPP -2.5	Vendor Manual Program

3.25	Draft ISA-TR-67.04.04	ISA Technical Report, "Effects of EMI/RFI on Instrumentation Setpoints and Indicators" (Draft)
3.26	SS E18.14.01	Electrical Standard Specification, "Electromagnetic Interference (EMI) Testing Requirements for Electronic Devices"
3.27	Draft ISA-TR-67.04.06	ISA Technical Report, "Seismic Effects" (Draft)
3.28	Calculation 72186RDM	A Review of Electronic Components in a Radiation Environment of $\leq 5X10^4$ Rads
3.29	TVA-NQA-PLN89-A	Nuclear Quality Assurance Plan
3.30	IEEE Standard 603-1991	"IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations"
3.31	PER No. WBPER940052	PER on TI-28 Sign Convention and SSDs
3.32	Variance Request	R. M. Johnson to J. E. Allen, dated March 14, 1994 (T41 940314 837)
3.33	Variance Approval	H.L Williams to R. M. Johnson, dated April 11, 1994 (B06 940407 001)

4.0 METHODOLOGY FOR THE COMBINING OF UNCERTAINTIES

4.1 Square Root Sum Squares (SRSS) Combination

The SRSS methodology for combining uncertainty terms that are random and independent is an established and accepted analytical technique. The SRSS methodology is a direct application of the central limit theorem, providing a method for determining the limits of a combination of independent and random terms. The probability that all the independent processes under consideration would simultaneously be at their maximum value (i.e., + or -) is very small. The SRSS methodology provides a means to combine individual random uncertainty terms to establish a resultant net uncertainty term with the same level of probability as the individual terms. If an individual uncertainty term is known to consist of both random and bias components, the components should be separated to allow subsequent combination of like components. Bias components shall not be mixed with random components during SRSS combination.

Resultant net uncertainty terms should be determined from individual uncertainty terms based on a common probability level. In some cases, individual uncertainty terms may need to be adjusted to the common probability level. Typically, a probability level corresponding to two standard deviations (2-sigma) is used. Using probability levels corresponding to three and more standard deviations may be unnecessarily conservative, resulting in reduced operating margin. For example, if a reference accuracy for a 99% probability level (3 sigma) is given as ±6 psig, the 95% probability level corresponds approximately to ±4 psig (= 2/3 x 6).

The central limit theorems require that the variables to be combined must be random AND independent. Some statements of the theorem allow individual variables to be either identically or arbitrarily distributed. Then, if the number of components, "n", is large, the distribution of the sum will be approximately normal. Large has been interpreted as 10-30. Another statement of the theorem requires individual variables to be approximately normally distributed, and their variances about equal (none are dominant). If these conditions are met, the sum of the components will be approximately normally distributed even for a relatively small "n". Relatively small has been interpreted as low as 4. In the limiting case, if two individual variables are exactly normal, their sum or SRSS is exactly normal as well.

When a random variable represents the net effect of a large number of smaller, independent, un-measurable causes, the variable can be expected to be approximately normally distributed. The approximation becomes better as the number of contributors increases. Per Reference 3.4, empirical evidence suggests that the normal distribution provides a representation of many physical variables, including instrument uncertainties. This observation is consistent with the fact that most instrument channels are composed of several parts that contribute independent, random uncertainties to the net sum.

Even if the number of devices in a given instrument loop is relatively small, the number of elemental uncertainty sources within the devices can be much larger, making the SRSS summation justifiable.

4.2 Uncertainty Equations

Since all measurements are imperfect attempts to ascertain an exact natural condition, the actual magnitude of the quantity can never be known. Therefore, the actual value of the error in the measurement of a quantity is also unknown. The amount of the error should therefore be discussed only in terms of probabilities. Example: There may be one probability that a measurement is correct to within a certain specified amount and another probability for correctness to within another specified amount. For the purpose of this TI, we will utilize the term "uncertainty" to reflect the distribution of possible errors.

There are a number of recognized methods for combining instrumentation uncertainties. The method discussed by this TI is a combination of statistical and algebraic methods which use statistical Square Root Sum of Squares (SRSS) methods to combine random uncertainties and then algebraically combines the non-random terms with the result. The formulas and discussion below present the basis principles of this methodology.

The basic formula for uncertainty calculations takes the form of:

$$Z = \pm\sqrt{A^2 + B^2 + C^2} \pm |F| + L - M$$

where:

A, B, C - are random and independent uncertainty terms. The terms are zero-centered, approximately normally-distributed, and are represented by a ± sign;

F - arbitrarily-distributed uncertainties and/or biases (unknown sign). The term is used to represent limits of error associated with uncertainties which are not normally distributed and do not have known direction. The magnitude of this term (absolute value) is assumed to contribute to the total uncertainty in a worst-case direction/s and is also represented by a ± sign;

L and M - biases with known direction. The terms can impart an uncertainty in a specific direction and, therefore, have a specific + or - contribution to the total uncertainty;

Z - resultant uncertainty. The resultant uncertainty combines the random uncertainty with the positive and negative components of the non-random terms separately to give a final uncertainty. The positive and negative non-random terms are not algebraically combined before combination with the random component.

The addition of the F, L, and M terms to the A, B, and C uncertainty terms allows the formula to account for influences on total uncertainty that are not random or independent. For biases with known direction, represented by L and M, the terms are combined with only the applicable portion (+ or -) of the random uncertainty. For the uncertainty represented by F, the terms are combined with both portions of the random uncertainty. Since these terms are uncertainties themselves, the positive and negative components of the terms cannot be algebraically combined into a single term. The positive terms of the non-random uncertainties shall be summed separately and the negative terms of the non-random uncertainties shall be summed separately and then individually combined with the random uncertainty to yield a final value. Individual non-random uncertainties are independent probabilities and may not be present simultaneously. Therefore, the individual terms cannot be assumed to offset each other, so positive (+) uncertainties should never be used to cancel out the effects of negative (-) uncertainties or vice versa.

If "R" equals the resultant random uncertainty $(A^2 + B^2 + C^2)^{1/2}$, the total uncertainty is determined by:

$$\pm Z = \pm R \pm |F| + L - M$$

maximum positive uncertainty by:

$$+Z = +R + |F| + L$$

and maximum negative uncertainty by:

$$-Z = -R - |F| - M$$

Using SRSS combination for bias uncertainties presupposes that the bias uncertainties are random and therefore some will be positive and some negative, and that the two classes cancel each other to a certain extent. Since the number of known biases is typically small and they may or may not be present simultaneously, this TI requires conservative algebraic summation for bias uncertainties unless evidence to the contrary is documented in the uncertainty calculation.

The purpose of the setpoint calculation is to ensure that the protective actions occur before analytical limits are reached with a 95% probability at a 95% confidence level (See section 4.3.4 concerning regulatory position associated with the 95%/95% requirement). This conservative philosophy allows applying the SRSS technique only to those uncertainties that are characterized as independent, random and approximately normally-distributed (or otherwise allowed by versions of the central-limit theorem). All other uncertainty components are combined using algebraic summation.

In the determination of the random portion of an uncertainty, situations may arise where two or more random terms are not totally independent of each other but are independent of the other random terms. This dependent relationship can be accommodated within the SRSS methodology by algebraically summing the dependent random terms to make a single independent random term prior to performing the SRSS determination. The formula takes the following form:

$$Z = \pm\sqrt{A^2 + B^2 + C^2 + (D + E)^2} \pm |F| + L - M$$

where: D and E - are random dependent uncertainty terms that are independent of terms A, B, and C

While the basic uncertainty formula can be used for any instrumentation application, care should be taken when applying the formula in applications containing non-linear devices or functions. An uncertainty term for a non-linear device generally has its value expressed in terms of its output signal. While the term can still be random and independent, its magnitude is a function of the input and the transfer function of the device. This requires the calculation of uncertainty for instrument channels containing non-linear devices to be performed for specific values of the input signal. The most common of these in instrumentation and control systems is the square root extractor in a flow channel. For these channels, the uncertainty value changes with the value of flow and, therefore, should be determined for each specific flow rate of interest.

The basic uncertainty combination formula can be applied to the determination of either a device uncertainty or a total instrument channel uncertainty. The results are independent of the order of combination as long as the dependent terms and bias 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 an instrument channel uncertainty, or all of the individual device terms can be combined in one instrument channel uncertainty formula. This TI recommends performing the device uncertainties first and then combining the device uncertainties together to obtain a channel uncertainty. This method ensures that the appropriate information is available for support of Setpoint and Scaling Documents (SSDs). This also allows for propagation of uncertainties through non-linear functions.

4.3 Uncertainty Data

The basic model used in this methodology requires that the user categorize instrument uncertainties as random, bias, or random arbitrarily-distributed bias. It is the purpose of this section to provide an understanding of the categories of instrument uncertainty and some insight into the process of categorizing instrumentation based on performance specifications, test reports, and plant calibration data.

The determination of uncertainty estimates is an iterative process that requires the development of assumptions and verification of assumptions based on actual data. Ultimately, the user is responsible for defending the assumptions that affect the basis of the uncertainty estimates.

It should not be assumed that, since this methodology addresses three categories of uncertainty, all three should be used in each uncertainty determination. Additionally, it should not be assumed that instrument characteristics should fit neatly into a single category. Data may require, for example, that an instrument's static pressure effect be represented as a random uncertainty with an associated bias.

4.3.1 Categories of Uncertainty

4.3.1.1 Random Uncertainties

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

It is usually expected that those instrument uncertainties that a manufacturer specifies as having a ± magnitude are random uncertainties. However, the uncertainty must be zero-centered and approximately normally-distributed to be considered random. After uncertainties have been categorized as random, any dependencies between the random uncertainties should be identified.

1) Independent Uncertainties

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

2) Dependent Uncertainties

Because of the complicated relationships which may exist between the instrument channels and various instrument uncertainties, a dependency may exist between some uncertainties. The methodology presented here provides a conservative means for addressing these dependencies. If, in the user's evaluation, two or more uncertainties are believed to be dependent, then, under this methodology, these uncertainties shall be added algebraically to create a new, larger independent uncertainty.

Dependent uncertainties are those for which the user knows or suspects that a common root cause exists which influences two or more of the uncertainties with a known relationship.

4.3.1.2 Non-Random Uncertainties

1) Bias (Known Sign) or Systematic Uncertainties

A bias is a systematic instrument uncertainty which is predictable for a given set of conditions because of the existence of a known direction (positive or negative).

For example, the static pressure effect of differential pressure transmitters, which exhibits a predictable zero shift because of changes in static pressure, is considered a bias. Additional examples of bias include hydraulic head effects, range offsets, reference leg heatup or flashing, and changes in flow element differential pressure because of process temperature changes. A bias error may have a random uncertainty associated with the magnitude.

2) Arbitrarily-Distributed Uncertainties

Some uncertainties are not normally distributed. Such uncertainties are not eligible for SRSS combinations and are categorized as arbitrarily-distributed uncertainties. Such uncertainties may be random (equally likely to be positive or negative with respect to some value) but extremely non-normal. Other considerations such as non-identicalness of distributions, dominance of an uncertainty due to it's large variance and the number of uncertainties to be summed may cause an uncertainty to be categorized as arbitrarily-distributed.

This type of uncertainty is treated as a bias against both the positive and negative components of a device's uncertainty. Because they are equally likely to have a positive or a negative deviation, worst-case treatment shall be used.

3) Bias (Unknown Sign)

Some bias effects may not have a known sign. Their unpredictable sign shall be conservatively treated by algebraically adding the bias in both the positive and negative directions.

4.3.2 Sign Convention

It must be noted that the sign convention used in the preparation of TI-28 calculations is opposite of the one defined by the Instrument Society of America (ISA). The ISA and TI-28 sign conventions are as follows:

ISA Sign Convention

Error = Indicated Value - True Value

TI-28 Sign Convention

Error = True Value - Indicated Value

As can be seen from these equations, the ISA convention is referenced from the True Value and the TI-28 convention is referenced from the Indicated Value. It is very important that the calculation preparer is aware of both sign conventions. Most of the data (defined as systematic or uni-directional) obtained from instrumentation vendors will be represented in the ISA sign convention and must be changed to the TI-28 convention before use in a TI-28 calculation. Upon obtaining systematic data from the vendor, the calculation preparer must verify and document that the data is per ISA sign convention and then shall reverse the sign for use in the TI-28 calculation.

Example: Using TVA sign convention to address an uncertainty of + 10 psi to - 5 psi means that for a bistable trip value of 100 psig, the actual process pressure may be anywhere between 95 and 110 psig.

4.3.3 Obtaining and Application of Uncertainty Data

In the context of setpoint determination, nuclear plant engineering groups are likely to deal with data from different sources. These include the analysis of field data by plant personnel and the use of manufacturer's specifications.

4.3.3.1 Sources of Uncertainty Data

There are several sources of instrument accuracy data. These are:

1) Manufacturer Specifications

These specifications are the main sources used in performing calculations. The use of this type of data in an uncertainty analysis for normal environmental conditions is conservative. Since all data should fall within the bounds set by the manufacture, using these specified limits for a 95% or even a 99% tolerance interval analysis will lead to a conservative estimate of the error. The referenced specifications must be reviewed and approved per Reference 3.24.

2) Testing Data

This data normally originates from the instrumentation's qualification program such as 10CFR50.49 and Seismic qualification programs. When using this data, the calculation must use the data supported by the Equipment Qualification Binder associated with the specific instrument loop of interest. The testing data may be presented as raw test data or the vendor may provide an analysis of the test data. If only raw test data is provided, a statistical analysis can be performed if there is a sufficient number of samples. If there are not a sufficient number of samples (e.g., 2 or 3) then the worst case error can be used by applying it both systematically and bi-directional.

3) Calibration History

This data source is one of the best sources for specific types of data (specifically drift and reference accuracy) because it normally analyses your plant's instrumentation in it's normal operating environment. The major drawback in using this type of data is the time involved in gathering and performing the statistical data analysis to support it's use. Obtaining enough samples to ensure an appropriate distribution of the population can also be a problem. This source of data is used primarily when there is insufficient vendor documentation or when the calibration history supports smaller drift uncertainties than supplied by the vendor. See Appendix K for details concerning calibration data analysis.

4) Purchase Specifications

Purchase specifications can be used if the vendor can provide sufficient documentation to assure that the error will not exceed a specified value. Caution: The problems with using this type of data is ensuring an adequate specification (e.g., covering or bounding all possible uncertainties) and verifying that the vendor understood and met the specification requirements.

Please note that the use of telex or fax is not recommended by this TI. Any vendor information used to support a TI-28 calculation should be officially submitted to TVA and approved as a QA document. If a telex or a company letter is used to support a Quality Related calculation, the calculation preparer must ensure that the individual that has signed off the telex has the authority to do so for the company. Sales personnel and working level engineers normally do not have this authority. Once the telex or letter is received, it must be entered into and controlled by the vendor manual or EQ binder program.

4.3.3.2 Confidence and Tolerance Intervals

Field measurements at a plant can form the database for statistical analysis using known techniques. Normality tests and knowledge of sample sizes allow determining the closeness of commonly used approximations. These include normality and the closeness of estimators with true population parameters. The parameters population mean (m) and standard deviation (s) are estimated by the sample mean (X) and standard deviation (S). This approximation is made better as the sample size increases.

If these approximations are taken, it is sufficient to describe a confidence interval as a range of values which include (with a pre-assigned probability called the confidence level) the true value of a population parameter. For a normal distribution, a ±1.96S (approximately ±1.96 s) interval has a 95% probability of including the true parameter. Another common interpretation is that 95% of the population is contained within the interval.

If a sample population is known to be small, it may be difficult to justify the above approximations, and it is appropriate to establish uncertainty limits using statistical tolerance intervals. This approach requires the additional statement about the population proportion included in the interval. It is frequently desired to describe a tolerance interval using the sample mean and the sample standard deviation such as X ± K*S. The value of K (tolerance factor) is a function of the sample size, the desired confidence level, the population proportion, and whether the distribution is one-sided or two sided. Tables for the K values can be found in general statistics text books (Under Tolerance and Confidence intervals). See Appendix K concerning statistical data analysis.

Numerical intervals also originate from manufacturer's product specifications. The ± "A" specification may represent a confidence interval (with a specified confidence level and an implicit assumption that estimators closely agree with population parameters) or a tolerance interval (with specified confidence level, population proportion, and sample size).

4.3.3.3 Interpretation of Uncertainty Data

The proper interpretation of uncertainty data is necessary to ensure the validity of the uncertainty calculation. Performance specifications should be provided by instrument vendors. Data should include reference accuracy, drift, environmental effects, and reference conditions. Since performance specifications often describe a product line, any single instrument may perform significantly better than the group specification. If performance summary data is not available or if it does not satisfy the needs of the users, raw test data may need to be re-evaluated or created from additional testing. Discussions with the vendor may provide helpful insight for interpreting performance specifications or test results.

Historically, there have been many different methods of representing numerical uncertainty. Almost all suffer from the ambiguity associated with shorthand notation. The symbol "±", for example, without further explanation, is often interpreted as the symmetric probability interval associated with a random, normally-distributed uncertainty. Further, the confidence level may be assumed to be 50% (probable error), 68.27% (one sigma), 95/45% (two sigma), or 99.73% (three sigma). Still others may assume that the "±" symbol defines the limits of error (reasonable bounds) of bias or non-normally distributed uncertainties.

It is the user's responsibility to avoid improper use of vendor performance data. If a vendor-published value of an uncertainty term (source) is believed to contain a significant bias uncertainty, then it is recommended that the ± value be treated as an estimated limit of error. Simple field tests (repeated measurements) by the user can give an indication of the random component of the published value, if separation of components is desirable. If the term is believed to represent only random uncertainties (no significant bias uncertainties), then the ± value can usually be treated as the 2 sigma probability interval for an approximately normally distributed random uncertainty.

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

The sample size should also be carefully considered prior to adjusting performance data obtained during harsh environment testing to determine the measured net effects on the instrument's performance. The results of such tests describe several mutually exclusive categories of uncertainty. For example, the measured net effects of harsh environment testing contain uncertainty contributions from instrument reference accuracy, M&TE uncertainty, calibration uncertainty and other uncertainties, in addition to harsh environment effects. Sample size may affect the methods used to separate the various constituent uncertainties to identify the uncertainty due strictly to harsh environment effects. A conservative practice is to treat the measured net effects of harsh environment testing on instrument performance as the uncertainty due only to harsh environment testing.

Occasionally select test data may appear inconsistent with the majority of the test data collected. In this situation it may be possible to justify the inconsistent data as outliers. Appendix B provides further discussion on statistical analysis for determining outliers.

Occasionally the situation arises when the test data necessary for an uncertainty calculation is not readily available such as the testing only verified functionally and did take pre and post calibration data. Several approaches may be taken in these cases. If possible it is usually best to obtain the information or a recommendation from the manufacturer or to use actual test results (or other utility experience). Other approaches for <u>non-harsh</u> applications might include performing a similarity analysis which would include circuit analysis of electronic circuits, or using data associated with an instrument made by another manufacturer that uses similar principles of operation, with some appropriate conservatism and justification included.

4.3.3.4 <u>Choosing a Sample Size</u>

When choosing a sampling size in order to establish a mean and it's standard deviation and make inference to the population of interest, several rules need to be remembered:

1) The more samples the better the estimate of the mean value becomes.

2) Definition of the level of confidence is required for your analysis (e.g., 95%, 80%, etc.).

3) As a rule of thumb, a confidence interval of 2 sigma would be appropriate when the sample size is 30 or greater. For smaller sample sizes, refer to standard statistical textbooks.

4) Assuming a normal distribution, as the sample size increases, the distribution changes from a uniformed or mound shaped to a normal distribution. The mean value comes into focus or a more accurate estimate is obtained.

5) The width of the confidence interval increases as the confidence coefficient increases.

6) The larger the size of the sample selected, the more likely it is that the sample will contain offsetting large and small sample values.

7) Definition of the type of analysis that is to be performed is required. There are two types of statistical analysis, Sample and Population. In the Sample analysis, you make inference to the specific set of devices analyzed, where in the Population analysis, you make inference to a larger population using sample data. The Sample analysis will provide smaller uncertainty numbers but they are only good for the samples analyzed. If a Sample analysis is performed on a set of installed transmitters then the results of the analysis are only valid for those installed transmitters. If a transmitter is replaced with a identical model, the analysis is no longer valid. Whereas, performing a Population analysis for the same set of transmitters allows for future replacements while maintaining a valid analysis.

8) It should be noted that the degrees of freedom are dependent on the analysis being performed (e.g., Given 4 devices calibrated 10 times each, the degree of freedom for predicting future operation of these specific S/N devices is 39 (40 - 1). The degree of freedom for predicting future operation of this type of device (general device population will same manufacturer and model number) is 3 (4 - 1)

The objective of statistics is to draw inference about a general population based upon information contained in a sample. Statistical inference in a practical situation contains two elements:(1) the inference and (2) a measure of goodness.

4.3.3.5 Calibration History Data Analysis

Instrument drift values for use in uncertainty calculations can be derived from manufacturer's specifications or from plant specific calibration history, if available. Section 5.4 of this TI provides the guidelines for interpreting the manufacturer's specification for drift and combining values for larger time intervals. This section provides guidelines for a data analysis methodology for plant specific as-found/as-left data to determine a drift value. The user is ultimately responsible for determining how to use the data.

It should be noted that the As-Found/As-Left data may include the combined effects of reference accuracy, inherent drift, measurement and test equipment, humidity, vibration, normal variations during the time period under surveillance. Caution: Do not use the calibration history analysis results to replace M&TE uncertainties in the calculation otherwise the plant will be required to meet 4 to 1 M&TE ratios. TI-28 M&TE uncertainty methodology provides for 1 to 1 M&TE ratios (See section 5.5.1). Additional terms may be included for a particular application as needed. A value for drift as obtained by this methodology could be more conservative than the value of drift as obtained from the vendor because it will include some or all of these other uncertainties.

1) Theory

For the purposes of this section, 95/95 values were chosen as the basis of the examples contained herein. The 95/95 values will bound hardware performance with a 95% probability with a 95% confidence level. The probability value establishes the portion of the population that is included within the tolerance interval. This means that 95% of all past, present, and future values should be bounded by the 95/95 interval value.

The confidence level essentially establishes the repeatability of calculating a value which will fall within the estimated values. This means that if the values were to be recalculated in the future, there is a 95% chance that the values would be bounded by the 95/95 interval values., Using 95/95 values means that we are 95% sure that 95% of all values will be less than the estimated values.

A statistical data base or spreadsheet package such as Lotus, Quattro Pro, Excel, and Math Cad can be used in place of manual methods for large volumes of data. TVA's software procedures must be followed when using these type of software packages.

Analysis of as-found/as-left data begins with establishing the scope of the analysis. Generally, this means identifying the types of equipment being used in the application of interest. Factors, such as process conditions, range, location, and environmental conditions, which may cause one device to behave differently from a duplicate must be determined.

Once the scope has been established, the next step is to obtain the as-found and as-left calibration data. All as found/as left data available should be used to support the assumed distribution. This section describes two methods of analyzing as-found/as-left data. The first method is based on the data being characterized as a normal distribution. The second method does not depend on any specific underlying distribution.

Generally, the data can be represented by a normal distribution. Verification of normality (utilizing more than 30 data points) shall be performed, where possible. For non-normal distributions pass/fail criteria can be established and the resulting pass/fail data is analyzed assuming a binomial distribution (at least 100 data points is recommended to use this method).

Once the calibration data has been obtained, the next step is to determine the changes over the interval of interest. All data should be converted to a common base (e.g., % of span). The surveillance interval should be noted. The difference between the previous as-left value and the successor as-found re-calibration value should be determined. The data should be examined to see if there is a drift effect (uncertainty as function of time). The data should be examined by looking at it as both percent of span and percent of setpoint. If there is a drift effect, the uncertainty or percent error will increase with the increase of the surveillance frequency. It is very important to obtain a variety of surveillance frequencies. If all the frequencies are of the same duration, it is impossible to determine if there is or is not a time relationship. For this case one must make a conservative assumption that the uncertainty at the end of the surveillance interval is all due to drift. It is also important to determine if re-calibration was performed. If re-calibration was not performed or was skipped, the calibration interval can be extended to the next re-calibration of the device. One method of identifying skips is to compare the calibration periods as-found to as left values. If re-calibration was not performed, these values will be equal. If by examination there appears to be increased uncertainty with time, the data may be standardized to a common interval between readings by dividing the time interval between readings and then multiplying by a standardized time interval. This technique conservatively assumes a linear extrapolation of drift. Non-linear functions can be used to model drift if supported by the calibration data.

Once the as-found/as-left data is determined for individual devices, the data can be grouped by model and by groups with similar environmental conditions. When groups have been established, the data can be analyzed. It is expected that most as-found/as-left data will be normally distributed. A method for analyzing this data for 95/95 interval values follows. If, in conducting this analysis, it is determined that the data is not normally distributed, an alternative is described for defining arbitrary pass/fail criteria to establish a binomial distribution.

2) Normal Distribution of Data

One of the three criteria which must be met in-order to use the SRSS methodology is that the random variable possess approximately a normal or bell shape distribution. To determine if the data that is being analyzed possess a normal distribution, a histogram should be developed for the data. The more data used in the analysis and the smaller the intervals for the histogram, the more focused the shape of the distribution will become. The Figure below is an example of a histogram produced by using spreadsheet software. The data points are divided up into bins (See Table 4.3 for an example) and then plotted based upon the number or frequency of data points within a specific bin. Caution: The appropriate bin sizes are critical. If too small or too large bin sizes are chosen, the Histogram will appear to have an uniform distribution.

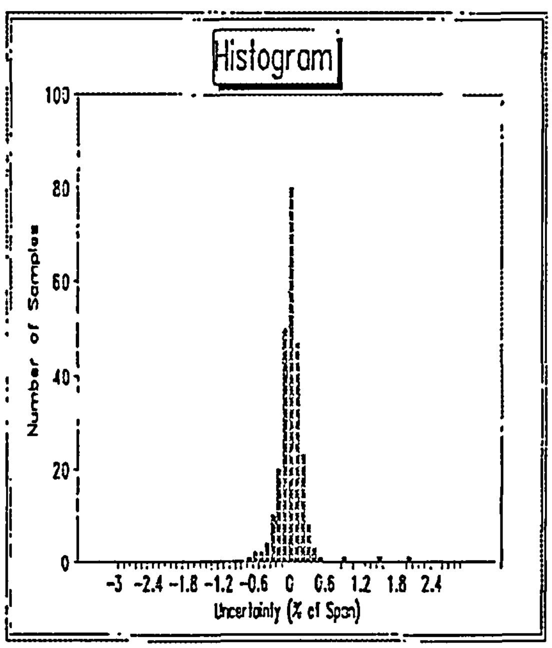
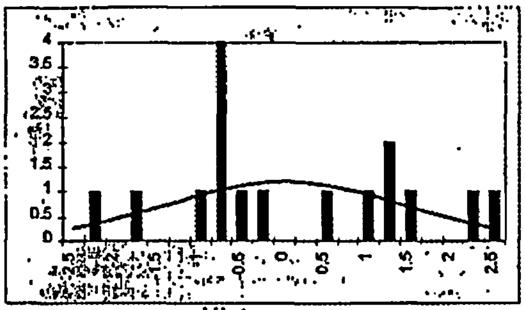
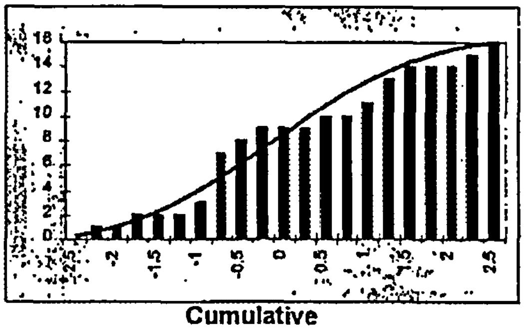


Figure 4.3.3.5

Sometimes histograms are difficult to use to determine normal distribution. An additional method is to use a Cumulative graph to plot the data. The Cumulative plot is generated by summing the Frequency numbers going from negative to positive. See Table 4.3 for the bin and frequency data for these Figures.



Histogram
Figure 4.3.3.6



Cumulative
Figure 4.3.3.7

Bin	*Frequency*	Cumulative Frequency
-2.5	0	0
-2.25	1	1
-2	0	1
-1.75	1	2
-1.5	0	2
-1.25	0	2
-1	1	3
-0.75	4	7
-0.5	1	8
-0.25	1	9
0	0	9
0.25	0	9
0.5	1	10
0.75	0	10
1	1	11
1.25	2	13
1.5	1	14
1.75	0	14
2	0	14
2.25	1	15
2.5	1	16

Table 4.3

3) Other Normality Tests

Once the data has been edited and grouped, the Chi-Square Goodness of Fit Test can be used to assure that the underlying distribution can be represented by a normal distribution. This test assumes a normal distribution and based on the sample mean and deviation, predicts the expected number of observations in each interval. The expected values are compared to the observed values using a histogram. Since this test requires a rather large number of points, it should only be applied to groups with a large population of say 30 or more data points. To use the Chi-Square Goodness Fit Test, consult a statistical reference book.

4) Treatment of Outliers

An outlier is an observation that is significantly different from the rest of the sample. They usually result from mistakes, malfunctioning instrumentation, or measuring device problems. The best way to identify outliers is to perform and examine a graphical representation of the data with appropriate attributes. From the graph, the outliers can be identified by their large deviation from the rest of the sample data. The first and best method of handling outliers is to examine the calibration or testing records associated with that specific outlier. These records should be examined for abnormalities such as documented Work or Maintenance Requests identifying an instrument malfunction. If no documented explanation can be found, a statistical analysis can be used to determine if the outlier is statistical valid or not. Two methods are discuss in Appendix B of this TI.

5) Non-Normal Distributions of Data

There are methods available for analyzing data when the underlying distribution cannot be demonstrated to be a normal distribution. In this TI, it is recommended that non-normal distributions should be conservatively algebraically summed in a bi-directional manner when combining uncertainties. Note that non-normal distributions can result when the value being measured is small with respect to the precision of the measurement.

4.3.3.6 Correction for Set Points with a Single Side of Interest

For many safety-related setpoints, interest is only in the probability that a single value of the process parameter is not exceeded, and the single value is approached only from one direction.

In situations where additional operating margin is desired, the magnitude of the random, approximately normal uncertainty component with a known confidence level may be reduced by accounting for a one-sided area of interest (only one side of the distribution curve is needed to predict the probability that a single value is not exceeded). For example, since instrument manufacturers typically publish instrument performance specifications symmetrically (e.g., reference accuracy + 0.5%), the use of their number predicts the statistical interval that will contain the true value in both directions from the mean. If one is only interested in not exceeding a single value (e.g., +100% power), then the factor 1.645/K can be applied to the random uncertainty. K represents the number of standard deviations desired (for a 95% confidence, a 1.96 standard deviations (sigma) is required and K = 1.96). The individual component uncertainty values should all be expressed in the common, desired confidence level, e.g., 1.96 sigma. For this example, the correction factor-reduces to 0.839, and the effect would be to reduce the random uncertainty (for reference accuracy of ±0.5, this would be 0.839 x 0.5 = ±0.42).

For device uncertainties in which both positive and negative deviations are a concern, the one-sided area of interest factor is inappropriate for that device. An example of this situation is a transmitter whose signal is used for both high and low functions.

4.3.4 Tolerance Limits Requirements

NRC Regulatory Requirement

The NRC's tolerance limit requirements documented in Ref. 3.3 requires a 95% probability level with no confidence level defined.

TI-28's Position

In general, TI-28 calculations have not documented specific tolerance limits (X probability with Y confidence level) associated with the uncertainty data and the data analysis. For TI-28 calculations, the 95% probability limit is a requirement for Safety Related calculations but the 95% confidence limit is not a documented NRC requirement. The 95% confidence limit requirement goes beyond the NRC requirements established in Reference 3.2 and is not always a reasonable requirement for some analyses. There are some areas where a 95% confidence level could not be achieved with existing instrumentation. Some examples would be harsh environment instrumentation where only 2 or 3 devices were tested in the 10CFR50.49 program. For these cases, the required confidence limit multiplier (ie., 38 for two samples) would be so large that the device would not be usable.

In-order to ensure a high confidence level for TVA setpoint calculations, TI-28 provides guidance in several areas to ensure that our uncertainty calculations are performed to a high confidence level. Some examples are the use of normal vendor specification data (the NRC's position in Reference 3.10 is that this data probably has a 95/95 or even a 99/99 tolerance interval); data analysis using small sample sizes should treat the worst case deviations as a plus and minus uncertainty and be combined algebraically; the use of tolerance interval multipliers in drift analysis (based upon actual calibration data) which have not always been 95/95 multipliers but are always very conservative with the documented instrument's performance; the use of conservative M&TE and Ab uncertainty values when compared to actual documented uncertainties; and worst case deltas for temperature variations and calibration frequencies are used to calculate temperature effects and drift effects respectively. Based upon TI-28's methodology, uncertainty calculations are conservative and provide a high probability of assurance that the protective actions will occur before their analytical limits are reached. No added safety value can be seen by the addition of a 95% confidence level requirement. Sometimes when calculated uncertainties are overly conservative problems can occur from premature Operator actions and reduced operating margins which could possibly result in spurious trips and/or transients.

Statistical Drift Analysis using Calibration Data

For Safety Related calculations where calibration data is used to determine instrument drift, a 95/95 statistical analysis is required except where technical justification is provided documenting why a 95% confidence level analysis could not be performed and why a confidence level of less than 95% is acceptable. By performing a 95/95 analysis, this ensures that enough samples (calibration data) are collected to obtain an accurate drift model and reasonable statistical multiplier.

4.3.5 Unbalanced Tolerances

As a result of Reference 3.31 which documented the misinterpretation of the sign convention used in Engineering NESSD's uncertainty data (e.g., Acceptable as Found, Allowable Values, etc.). Engineering's sign convention for uncertainty calculations, as defined in this TI, uses the indicated value as the reference to define error. The NESSD values were used based upon the ISA definition where the actual/true value is used as the reference. This means that the tolerances were implemented opposite to that of the NESSD requirements. Note that this condition does not apply if the SSD uncertainties have been represented as symmetrical tolerances (e.g., ± 5 percent of span) or if represented as defined limits (e.g., < 50 psig). This problem only occurs when the NESSDs uncertainties are represented as non-symmetrical tolerances (Example: + 5 percent and - 7 percent). The primary problem areas in which this occurred were the uncertainties for indication loops where uncertainties are normally represented as tolerances, not limits and for loops where component uncertainties are normally non-symmetrical (e.g., flow loops, radiation monitors, etc.).

To eliminate this problem from occurring in the future, the following guidelines are recommended for future NESSD preparation. Engineering's sign convention will remain as presently defined in this TI with the indicated value used as the reference.

1) The recommended solution is to provide non-symmetrical tolerances as actual calibration values. If this is not possible or is potentially confusing (e.g., multiple operator setpoints/limits), use one of the following methods, 2 or 3.

2) If non-symmetrical calculation uncertainties are to be used in NESSDs, they should be rounded off conservatively to make them symmetrical. This is a conservative method and eliminates interpretation problems. Caution: This would reduce operating margin when defining Allowable Values

   Example: A calculated Av = + 7 percent, - 9 percent of span would be rounded to an Av = ± 7 percent span for use in the SSD.

3) If a reduction in operating margin is not desired, non-symmetrical uncertainties should be clearly defined with respect to the required calibration method used for the loop. This requires that the NESSD states the specific calibration method to be used by the plant (e.g., forward calibration, reverse calibration, etc.). Note that this TI's sign convention directly supports reverse calibration values. These values would need to be converted to ISA sign convention for use in forward calibration procedures. In the supporting calculation or NESSD, the uncertainties used in the NESSD should be converted, if necessary, to match with the plant's calibration method. Any conversion to ISA sign convention shall be clearly noted in the supporting calculation or NESSD. Note: The supporting calculation shall continue to use TI sign convention to address the design limits.

4.4 Calculating Total Channel Uncertainty

The calculation of an instrument channel uncertainty should be done in a clear, straight forward process. The actual calculation can be done with a single loop equation containing all potential uncertainty values or by a series of related term equations. Either way, a specific instrument channel calculation should be laid out to coincide with a channel's layout from process measurement to final output device or devices.

The actual technique and layout of the calculation is influenced by the type of instrument channel being analyzed. While many channels can be analyzed using the basic formulas defined in Section 4.2, channels containing devices with transfer functions such as an amplifier, summer, square root extractor, etc., require special consideration. This is due to the affect the transfer function can have on the incoming signal and it's associated uncertainty. The device's transfer function will act on both the true signal and it's uncertainty to develop an output. Thus, the uncertainty within a signal may be increased or decreased by a device's transfer function, with respect to the true signal.

4.4.1 Application of Equations for the Propagation of Uncertainties Through Functional Devices

If signal conditioning devices such as scalers, amplifiers, summers, square root extractors, multipliers, etc., are used in the instrument channel, the device's transfer function shall be accounted for in the instrument uncertainty calculation. The uncertainty of a signal conditioning device's output can be determined when the uncertainty of the input signal and the uncertainty associated with the device as well as the device's transfer function are known. Using partial derivatives or perturbation techniques, equations can be developed (See Reference 3.4) to determine the output signal uncertainties for several common types of signal conditioning devices. ***Caution: When using this method for non-linear applications, large calculation errors may result if the instrument uncertainty is large in comparison with the actual value of interest (calculated slope does not conservatively envelope the area of interest).*** The calculation preparer must provide verification that conservative results were obtained by using this method. The user must also take care in applying these equations to individual instrument channel uncertainty calculations to ensure that the probability and confidence levels of the data and resulting uncertainty values are maintained. In balancing the requirements of calculation conservatism, probabilities, and operating margins, it may be beneficial to optimize the uncertainty determination by computer simulation techniques.

For channels which contain multiple signals which interact or for channels which contain non-linear transfer function devices, the instrument channel uncertainty must be calculated using propagation equations. The instrument channel uncertainty calculation uses the propagation equations discussed in Section 4.1 to combine uncertainties prior to and downstream of the transfer function device and the equations of Section 4.4.1 to determine the uncertainty through the function.

In dealing with channels containing non-linear transfer functions, the uncertainty value is dependent on the relative magnitude of the input signal. With the input uncertainty held constant, the instrument channel uncertainty will increase as the input signal decreases and vice versa. As a result, it is generally advantageous to calculate the uncertainty of loops containing non-linear devices in terms of specific readings and not percent span. Care must be taken in establishing the proper uncertainty transfer function for non-linear devices since the non-linear devices can skew both the probability levels and the confidence levels of the resulting uncertainty value.

One common method used in engineering calculations is to linearize a non-linear function over a relatively small range of interest. Then errors can be propagated through the device using relatively simple linear techniques. When using this method, care must be taken to account for any modeling uncertainties generated by the linear approximation. One must also ensure that the uncertainty to be propagated is contained in the linearized range.

4.4.2 Application of Basic Statistical Equations

For single instrument channels which do not have transfer functions or their transfer functions are linear, the formulas of Section 4.2 can be used directly to calculate instrument channel uncertainty. The basic formulas may also be applied to multiple signal channels which have linear transfer functions as long as the transfer functions have unity gain. The instrument channel equation would take the form:

$$CU^{+} = +\sqrt{PM^2 + PE^2 + Device_1^2 + Device_2^2 + \ldots Device_n^2} + B_t^{+}$$

and

$$CU^{-} = -\sqrt{PM^2 + PE^2 + Device_1^2 + Device_2^2 + \ldots Device_n^2} - B_t^{-}$$

where:

CU - Channel Uncertainty (CU) at a specific point in the instrument channel; the CU can be calculated for any point in a channel from Device 1 to Device n, as needed,

PM - Random uncertainties that exist in the channel's basic Process Measurement (PM),

PE - Random uncertainties that exist in a channel's Primary Element (PE), if it has one, such as the accuracy of a flow-meter table,

$Device_{1,2,n}$ - Total random uncertainty of each device that makes up the loop from Device 1 through Device n,

B_t^{+} - The total of all positive biases associated with an instrument channel; this would include any uncertainties from PM, PE, or the Devices that could not be combined as a random term (biases and arbitrarily-distributed uncertainties as discussed in section 4.3)

B_i^- - The total of all negative biases associated with an instrument channel; this would include any uncertainties from PM, PE, or the Devices that could not be combined as a random term (biases and arbitrarily-distributed uncertainties as discussed in section 4.3)

The individual device random uncertainties are in themselves a statistical combination of uncertainties. Depending on the type of device, its location, and the specific factors that can affect its accuracy, the determination of the device uncertainty will vary. For example, the device uncertainty may be calculated as:

$$e^+ = + \sqrt{R_e^2 + D_e^2 + TA_e^2 + RAD_e^2 + ICT_e^2} + B^+$$

and

$$e^- = - \sqrt{R_e^2 + D_e^2 + TA_e^2 + RAD_e^2 + ICT_e^2} + B^-$$

where:

e - Uncertainty of a device,
B - Biases associated with the device, if any.

For the purposes of the above example, most of the uncertainties have been considered as random and independent. However, the user must determine the actual characteristics of each uncertainty term and combine them based on the criteria discussed in section 4.2. Additional terms may have to be included for a particular application.

The individual device uncertainty formulas would contain all appropriate terms for a specific device including any bias terms. The final instrument channel formula bias terms, B^+ and B^-, would be the sum of the individual biases. For example, for the total instrument channel, if PM contained a +3.0% reference leg bias, Device 1 contained a ±0.5% calibration arbitrarily distributed uncertainty, and the instrument channel could experience a +1.0% Insulation Resistance (IR) degradation effect:

$$B^+ = B^+_{PM} + B^+_{IR} + B^+_1 = 3.0\% + 1.0\% + 0.5\% = +4.5\%$$

$$B^- = B^-_1 = -0.5\%$$

A instrument channel calculation should account for the effects of each device in the channel on total uncertainty as well as the external (non-instrument induced) effects that act on the total uncertainty. The individual instrument channel device terms would be derived based on the device type. These terms account for both the effect a device has on instrument channel uncertainty due to its own inaccuracies, as well as its affect on instrument channel uncertainty due to its manipulation of incoming uncertainty values.

As with any engineering calculation, proper determination and accounting of engineering units is essential. This can become a major stumbling block to an analysis due to the myriad of ways uncertainty is specified. The basic formula is not affected by units as long as they are consistent. Either actual process measurement units or a representative unit such as percent of calibrated span may be used. This document uses percent of calibrated span as the base unit. This affords a universal appeal to the examples and provides for ease of comparison between different types of instrument channels.

4.5 Setpoint Relationships

The establishment of setpoints and the relationships between a Setpoint, Allowable Value, Analytical Limit, and Safety Limit are discussed in this section. A thorough understanding of these terms is important in order to properly, utilize the total instrument channel uncertainty in the validation of setpoints. Figure 4.5 presents the relative position of the Safety Limit, Analytical Limit, Allowable Value, and the Setpoint with respect to the Normal Operating Point.

Safety Limit

Analytical Limit

Allowable Value

Setpoint

Normal Operating Point

Figure 4.5

Safety Limits are chosen to protect the integrity of physical barriers that guard against the uncontrolled release of radioactivity. The Safety Limits are typically provided in the plant technical specifications and safety analyses. The Analytical Limits are established to ensure that the Safety Limits are not exceeded. The Analytical Limits are developed from event analyses models which consider parameters such as process delays, rod insertion times, reactivity changes, instrument response times, etc. The development of the Analytical Limits and Setpoints (the I&C Engineer may develop but the System Engineer must approve them) are outside the scope of this TI. Establishment of Setpoints and Analytical Limits are the responsibility of the Process System Engineer, not the I&C Engineer as defined in Reference 3.7 which was generated to resolve NRC concerns associated with responsibilities between disciplines. The following section will define the use of the Analytical Limits to calculate the Instrumentation's Allowable Values.

The Allowable Value is a value or values that the Setpoint can have when tested periodically, beyond which the instrument channel shall be evaluated for operability. The Allowable Value ensures that sufficient allocation exists to account for instrument uncertainties that either are not present or are not measured during periodic testing (defined as unmeasurables). For example these may include design basis accident temperature and radiation effects or process dependent effects. This will provide assurance that the Analytical Limit will not be exceeded if the Allowable Value is satisfied. Another calculated variable defined as the Normal Measurable Accuracy (A_N) provides a means to identify unacceptable instrument performance which, if exceeded, may require corrective action.

The standard ISA definition for "Setpoint" is a predetermined value at which a bi-stable device changes state to indicate that the quantity under surveillance has reached the selected value. Another definition of "Setpoint" used at TVA is an Operator Setpoint or Trigger Value at which an Operator takes predetermined corrective actions. The instrumentation used to implement Operator Setpoints are indication loops (e.g., indicators, recorders, and CRT's).

4.6 Allowable Value

Two methods for determining the Allowable Value (A_v) have been developed and are presently in use at TVA. The TI-28 method is illustrated in Figure 4.6. The allowance between the Allowable Value and the Setpoint should be large enough to contain that portion of the instrument channel being tested for the surveillance interval (monthly, quarterly, or refueling) and should account for only the measurable uncertainties, such as:

1) Drift (based on surveillance interval)

2) Instrument calibration uncertainties for the portion of the instrument channel tested

3) Instrument uncertainties during normal operation which are measured during testing

In Figure 4.6 and the discussion which follows, it is assumed that the process increases toward the Analytical Limit. If the process decreases toward the Analytical Limit the directions given would be reversed.

In the first method in Figure 4.6, TI-28's Method, the Allowable Value (A_v) is determined by calculating the instrument channel uncertainty without including the normal measurable uncertainties (A_{nf}) such as those items identified above, (drift, calibration uncertainties, and uncertainties observed during normal operations). This resultant is defined as the unmeasurable uncertainties of the instrument channel. These unmeasurables are then subtracted from (for an upper limit) or added to (for a lower limit) the Analytical Limit (AL) to establish the A_v. Please note that this calculated A_v is a bounding maximum limit. If adequate margin exists between both the setpoint and analytical limit and the setpoint and the operational limit, A_v could be reduced to a lower limit of the Setpoint plus/minus A_{nf}. The following is a mathematical description of A_v.

$$A_v(\max) = (AL - (A_{dbe} - A_{nf})) \equiv \textit{Increasing Setpoint Maximum Limit}$$

$$A_v(\max) = (AL + (A_{dbe} - A_{nf})) \equiv \textit{Decreasing Setpoint Maximum Limit}$$

$$A_v(\min) = SP + A_{nf} \equiv \textit{Increasing Setpoint Minimum Limit}$$

$$A_v(\min) = SP - A_{nf} \equiv \textit{Decreasing Setpoint Minimum Limit}$$

Resulting in the following expressions for defining A_v:

For an increasing setpoint,

$$A_v(\max) \geq A_v \geq A_v(\min)$$

or

$$(AL - (A_{dbe} - A_{nf})) \geq A_v \geq SP + Anf$$

and for a decreasing setpoint,

$$A_v(\max) \leq A_v \leq A_v(\min)$$

or

$$(AL - (A_{dbe} - A_{nf})) \leq A_v \leq SP + Anf$$

A_{dbe} - Design Basis Event Accuracy

As for where to establish A_v within this defined range, it is dependent upon the specific application. The closer A_v is to A_v(max), the lesser the possibility exist for unnecessarily declaring an instrument loop inoperable, but this increases the possibility of having to revise A_v if the Analytical Limit or the instrumentation changes. The closer A_v is to A_v(min), the greater the possibility exist for unnecessarily declaring an instrument loop inoperable, but this decreases the possibility of having to revise A_v if the Analytical Limit or the instrumentation changes. When determining an A_v (specifically a Technical Specification value), the pro's and con's stated above should be carefully weighed in this determination.

The ***second method is used only when performing Westinghouse Setpoint Methodology Calculations*** and calculating the A_v. Then an allowance for the normal measurable instrument uncertainties (drift, calibration uncertainty, and uncertainties observed during normal operation) are calculated. This allowance is then added to the previously established Setpoint to establish the A_v. If the allowance is not determined in a method which is consistent with the method used for the determination of the Setpoint (SRSS vs Algebraic) or the transfer function of the loop being tested is non-linear, then a check calculation must be performed. For example, if a SRSS combination is used for determining the Setpoint and an algebraic combination is used for the allowance between the Setpoint and the A_v, then a check calculation shall be performed. The check calculation should provide assurance that the purpose of the A_v is still satisfied by providing a large enough allowance to account for those uncertainties not measured during the test. If the check calculation identifies that there is not enough of an allowance between the AL and A_v, the A_v must be changed to provide the necessary allowance.

Caution: Some Technical Specification (TS) A_v's are implemented for partial loop surveillance testing (not all of the loop is tested). The components that are not part of the surveillance testing are treated as unmeasurables and are normally tested at less frequent intervals. If the A_v applies to a portion of the loop, this shall be clearly described in the appropriate Setpoint and Scaling Document.

Example: The Westinghouse protection rack equipment (signal conditioning and bistables) are tested on normally every three months but the associated transmitters are tested only every 18 months. The TS A_v is calculated for and applied only to the rack equipment.

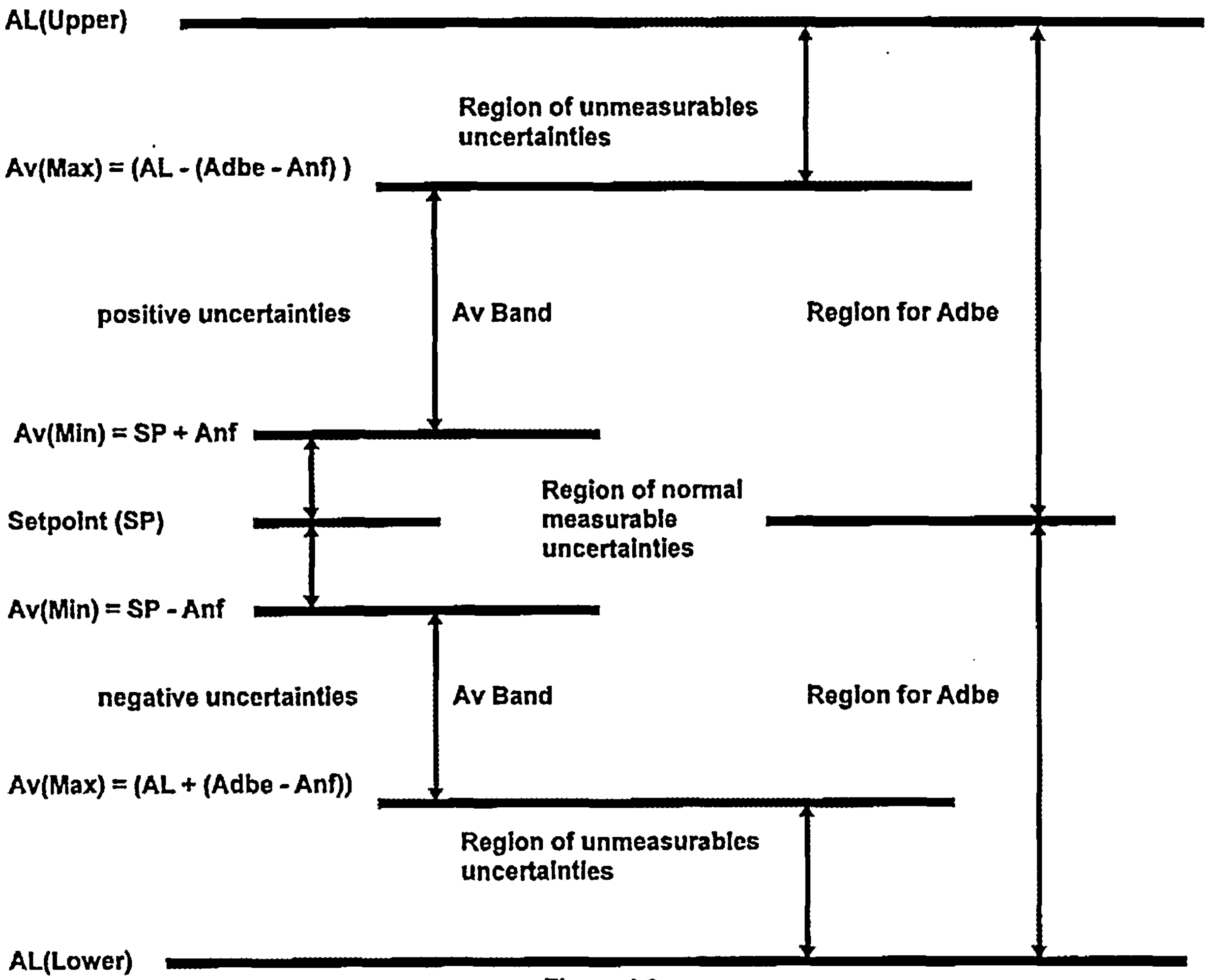


Figure 4.6

5.0 UNCERTAINTY PARAMETERS

5.1 Normal Temperature Effects (TN_e)

Most instruments exhibit a change in output as the ambient temperature to which they are exposed varies during normal plant operation above or below the temperature at which they were last calibrated. This change or temperature effect is an uncertainty and must be accounted for in instrument uncertainty calculations. To estimate the magnitude of the effect, the operating temperature (OT) extremes above or below the calibration temperature (CT) must be defined. Since the calibration temperature is not usually known, the worst case assumption should be made that the CT and the OT were at completely opposite extreme points of the operating temperature range.

When defining the normal temperature effect (TN_e) for a device, the abnormal low and high operating temperatures documented from the applicable environmental drawing should be used as the bounding limits for conservatism. This will bound a worst case scenario where the device is calibrated at either the normal high or low temperature and the device is at the other extreme condition. Since the calibration temperatures and operating temperatures are normally of a random nature (controlled at a defined point with random variations about that point), and if this temperature deviation is being applied to a temperature coefficient which is random, independent, and has a normal distribution, the TN_e should be applied as a random and independent effect.

Once the temperatures are defined, the TN_e for each device can be calculated using the manufacturer's published temperature effect specification. Commonly, the temperature effect is stated in vendor literature in one of the two ways listed below (expression in parentheses is an example). In each expression the temperature component (e.g., per 100°F) is a change in temperature within the vendor's specified range. Either:

Example 5.1.1: TN_e = ± X% span per Y°F (for example ±1.0% span per 100°F)

or

Example 5.1.2: TN_e = ±X1% span at minimum span per Y°F (for example ±5.0% span at minimum span per 100°F)

and

TN_e = ±X2% span at maximum span per Y°F (for example ±1.0% span at maximum span per 100°F)

If the temperature effect cannot be approximated by a linear relationship with temperature, a conservative approach is to use the bounding value for a temperature shift less than Y°F. If the relationship is linear, then the uncertainty can be calculated as follows. For the TN_e as expressed in Example 5.1.1:

$$TN_e = \frac{\pm X\% * \Delta T\,(^\circ F)}{Y^\circ F} \qquad \text{Eqn. (5.1.1)}$$

where:

$$\Delta T = \pm(OT_{max} - OT_{min}) \qquad \text{Eqn. (5.1.2)}$$

For example, using Eqn. 5.1.1 and the value of TN_e in Example 5.1.1 and the abnormal OT varies from 70°F to 120°F for a _T of 50°F,

then,

$$TN_e = \frac{(1.0\%) * (120 - 70)°F}{100°F} \qquad \text{Eqn. (5.1.3)}$$

$$TN_e = \pm 0.5\%span \qquad \text{Eqn. (5.1.4)}$$

For Example 5.1.2, the uncertainty is not only a function of temperature but is a function of span as well. To find the temperature effect for the span of interest, assuming the temperature effect is a linear function of span and temperature, it is necessary to interpolate using the following expression:

X = Calibrated Span
X1 = Minimum Span
X2 = Maximum Span

$$\frac{X - X1}{X2 - X1} = \frac{Calibrated\ Span - Minimum\ Span}{Maximum\ Span - Minimum\ Span} \qquad \text{Eqn. (5.1.5)}$$

Solving Equation 5.1.5 for X,

$$X = \frac{Calibrated\ Span - Minimum\ Span}{Maximum\ Span - Minimum\ Span} * (X2 - X1) + X1 \qquad \text{Eqn. (5.1.6)}$$

If, for example, the span is 55 psi for a transmitter with an adjustable range of 10-100 psi, the uncertainty in Example 5.1.2 for the same temperature conditions assumed in the previous example can be calculated using Equation 5.1.6 then Equation 5.1.1 as follows. In this case, however, X1 and X2 should be converted to process units so that units are the same.

$$X2 = \frac{\pm 1.0\%span}{100^\circ F} * \frac{100\,psia}{span} \qquad \text{Eqn. (5.1.7)}$$

$$X2 = \frac{\pm 1.0\,psia}{100^\circ F} \qquad \text{Eqn. (5.1.8)}$$

$$X = \frac{(55 - 10) * (1.0 - 0.5)}{(100 - 10)} + 0.5 \qquad \text{Eqn. (5.1.9)}$$

$$X = \frac{45 * 0.5}{90} + 0.5 \qquad \text{Eqn. (5.1.10)}$$

$$X = \frac{\pm 0.75\%\,psia}{100^\circ F} \qquad \text{Eqn. (5.1.11)}$$

$$TN_e = \pm \frac{(0.75) * (120 - 70^\circ F)}{100} \qquad \text{Eqn. (5.1.12)}$$

$$TN_e = \pm\ 0.375\,psia \qquad \text{Eqn. (5.1.13)}$$

or in % of calibrated span:

$$TN_e = \pm \frac{0.375\,psia}{55\,psia} * 100\% \qquad \text{Eqn. (5.1.14)}$$

$$TN_e = \pm\ 0.68\%\ of\ calibrated\ span \qquad \text{Eqn. (5.1.15)}$$

This section has dealt with device ambient temperature influence under normal conditions. Accident effects and ambient-induced process uncertainties (such as reference leg heatup) are discussed in Appendix L. If a particular instrument is influenced by the process temperature (e.g., an instrument's temperature is greater then the ambient temperature due to the close proximity of a hot pipe) and exhibits uncertainties under varying process temperatures, a range of expected process temperatures needs to be included and the actual uncertainty calculated.

5.2 Process Pressure Effects

5.2.1 Static Pressure Effects (SP_e)

Some devices exhibit a change in output because of changes in process pressure. A typical static pressure effect coefficient applicable to a differential pressure transmitter where the listed pressure specification is the change in process pressure may look like:

±0.5% span per 1000 psi

This effect can occur when an instrument measuring differential pressure (dP) is calibrated at low static pressure conditions but operated at high static pressure conditions. The cause of this effect is due to the process pressure compression of both of the device's diaphragms in a non-symmetrical manner. To calculate the static pressure effect uncertainty (SPE_e), an Operating Pressure (OP) for which the unit was calibrated to read correctly and Pressure Variation (PV) above or below the OP needs to be determined. Once these points are defined, an expression similar to Equation 5.1.1. can be use to calculate the static pressure effect (given the effect is linear). Normally, the manufacturer lists separate span and zero effects.

This effect can be addressed by several methods:

1) By quantifying the uncertainty within the uncertainty calculation. This is performed by applying the vendor's static pressure coefficient to the pressure difference between calibration and system design operating pressure. This is the preferred method of addressing this effect.

2) By calibrating the device at the normal operating system pressure and applying the vendor's static pressure coefficient to the remaining system pressure variation up to the design pressure. This method is normally not used due to the costs associated with the calibration process associated with this method.

3) By calculating the static pressure shift using the vendor's static pressure coefficient and system design pressure, and then biasing the device's calibration in order to offset this effect in the most conservative direction. An uncertainty associated with the calculated static pressure shift (SECu) must be quantified and addressed in the uncertainty calculation.

A *caution* needs to be discussed here concerning the use of this uncertainty in calculations. The effect shown earlier in this section was represented as random (±). However, additional bias effects may need to be included due to the way the static pressure calibration correction is done. For example, some instruments read low at high static pressure conditions. If they have not been corrected for static pressure effects, a positive bias would need to be included in the uncertainty calculation.

Example 5.2.1: SPE_e = ± X% span per Y psi (for example ±0.5% span per 1000 psi)

The pressurizer level transmitters are calibrated at atmospheric condition and normally operate at 2250 psig.

$$SPE_e = \frac{\pm X\% * \Delta P(psi)}{Y\ \text{psi}} \qquad \text{Eqn. (5.2.1)}$$

where:

$$\Delta P = \pm(Max\ \text{Operating}\ Pressure - Calibration\ Pressure) \qquad \text{Eqn. (5.2.2)}$$

For example, using Eqn. 5.2.1 and the value of SPE_e in Example 5.2.1 and the pressure difference between calibration pressure and the maximum operating pressure

then,

$$SPE_e = \frac{(0.5\%) * (2250 - 0)\ psi}{1000} \qquad \text{Eqn. (5.2.3)}$$

$$SPE_e = \pm 1.125\%\ span \qquad \text{Eqn. (5.2.4)}$$

5.2.2 Over pressure Effects

Another effect related to pressure extremes is the over-pressure effect. This uncertainty is due to over-ranging the pressure sensor and included in the uncertainty calculation.

A device should not have errors associated with an over pressure condition. The device should have been procured to operate within the bounding system pressure conditions. If the device is being used outside of its designed functional range, vendor data (e.g., testing) must be obtained to support
any errors caused by this over pressure condition. Vendor guidance is required to determine if the effect is for a single over pressure event or multiple events.

5.2.3 Process Density Effects due to Pressure Variations

Effects to fluid and gas density due to variations in process pressure are covered in Section 5.7 and Appendix L of this standard.

5.2.4 Ambient Pressure Effects

Ambient pressure variation can cause some gage and absolute pressure instruments to shift up or down scale depending on whether the ambient pressure increases above or decreases below atmospheric pressure. Normally this effect only becomes significant in applications measuring very small pressures (e.g., ± ½ inch of water column) or has very large ambient pressure variations with respect to the pressure being measured. Tornadoes can introduce a large uncertainty due to the resulting de-pressurization event. Pneumatic timers are especially sensitive to tornado de-pressurization.

For the gage pressure instrument, this effect occurs if the reference side of the diaphragm is open to the atmosphere. This is a bias effect. The magnitude and direction will depend upon the variations in atmospheric pressure at that location.

For absolute pressure instruments, this effect occurs when an absolute pressure instrument is used to measure a process that does not have a pressure reference to absolute zero.

5.3 Interpretation of Span and Zero Uncertainties

When using uncertainties that are represented as a split percent of span and zero effect, use the following ISA guidelines. The zero uncertainties may be present anywhere within the calibrated span and are applied using the full magnitude of the effect. The percent of span effect linearly increases from zero percent at zero percent span and increases linearly to full magnitude at 100 percent span.

5.4 Calibration Interval (Drift)

For safety-related devices, the calculation preparer should as a minimum use the Technical Specification or Surveillance Instruction calibration interval plus an overrun allowance of 25% (The additional 25% overrun is based upon the normal overrun allowances of each plant's Technical Specifications). The use of the plant's established calibration frequency requirements are based upon the fact that if the calculation can support the plant's current requirements, there will not be a need to revise plant documents needlessly. It should also be noted that the calibration frequency is the time between calibrations and is not always equivalent to the time between 18 month refueling outages. The plant's calibration procedure or the Technical Specification could require a smaller calibration frequency (e.g., 6 months) which must be considered in establishing the value to be used for drift. The calibration interval is divided by the time interval of the drift coefficient to obtain a multiplier for the uncertainty value of the drift (D_e) coefficient.

Example 5.4.1:

$$D_{e(coeff)} = \frac{\pm 1.0\%}{6\ months} \qquad \textbf{Eqn. (5.4.1)}$$

$$D_e = \frac{22.5\ months}{6\ months} * \pm 1.0\% = \pm 3.75\% \qquad \textbf{Eqn. (5.4.2)}$$

This assumes the drift term is a linear function of time. In the absence of other data, it is considered reasonable, and perhaps conservative, to make this assumption. Other methods for extending drift data may be used. If one can demonstrate that the drift during each drift period is random and independent, the SRSS of the individual drift periods between calibrations may be used. In this case, it would be:

Example 5.4.2:

$$D_e = \pm \sqrt{(1\%)^2 + (1\%)^2 + (1\%)^2 + \left(\frac{4.5}{6}\right) * (1\%)^2} \qquad \text{Eqn. (5.4.3)}$$

Since there are three and three fourths (3¾) 6-month calibration intervals, or:

$$D_e = \pm \sqrt{(3.75) * (1\%)^2} \qquad \text{Eqn. (5.4.4)}$$

$$D_e = \pm 1.94\% \qquad \text{Eqn. (5.4.5)}$$

Some vendor data has supported that the majority of an instrument's drift will occur in the first several months following a calibration and that the instrument output will not drift significantly after the "settle in period." In this case, the 6 month value provided by the vendor may be acceptable for the 22.5 month calibration interval if quality documentation can be obtained to support this scenario.

Whatever method is used, it must be documented in the setpoint uncertainty calculation with supporting documentation.

5.5 Calibration Uncertainty

Calibration is performed to verify that equipment performs to its specifications, and to the extent possible, eliminate bias uncertainties associated with installation and service, for example, static head effects and density compensations. Calibration uncertainty refers to the uncertainties introduced into the instrument channel during the calibration process. This includes uncertainties introduced by test equipment, procedures, and personnel.

This section deals only with calibration uncertainties and how they should be included in the total instrument channel uncertainty calculation. However, other effects, such as installation effects (elevation tolerances), should be accounted for in the uncertainty calculation.

5.5.1 Measuring and Test Equipment (M&TE) Uncertainty

Several effects must be addressed in establishing the overall magnitude of the M&TE uncertainty. These include the reference accuracy of the M&TE, the uncertainty associated with the calibration of the M&TE, the readability of the M&TE by the technician, and the actual application of the M&TE.

5.5.1.1 M&TE Reference Accuracy

When defining the M&TE reference accuracy, the calculation preparer should use the One to One Rule (The M&TE's reference accuracy is as accurate as or better than the reference accuracy of the device being calibrated). It is not recommended that specific M&TE be utilized in specifying M&TE uncertainty for the following reasons:

1) The Plant should have the flexibility to choose the specific M&TE for a specific application at a specific time. The M&TE specified might not be available when needed.

2) Using the One to One Rule normally does not significantly increase the overall loop accuracy due to SRSS combination methodology of the M&TE uncertainties.

3) The Plants' utilize a standard of Four to One (The M&TE is four times as accurate as or better than the device's reference accuracy which is being calibrated). They are administratively prevented from exceeding the One to One Rule. By analyzing for a One to One Ratio, this produces a conservative calculation, allows the Plant some flexibility if needed, and provides a margin zone for M&TE found out of calibration. If the M&TE is not out of calibration by more than the analyzed one to one ratio, re-calibration is not required for the devices calibrated with the subject M&TE.

5.5.1.2 Reference Accuracy of the M&TE Standard

M&TE shall be periodically calibrated to controlled standards to maintain their accuracies. Typically the Reference Accuracy (R_e) of these standards is such that there is an insignificant effect on the overall channel uncertainty. However if a standard does not meet the requirement of 4 to 1 better than the M&TE, this effect may need to be evaluated. If the R_e of the standard is of significant magnitude and is included in the uncertainty calculation, it may be combined with the R_e of the M&TE using the SRSS techniques to establish a single value for the uncertainty of that piece of M&TE. The M&TE uncertainty for a device should include the uncertainty of both the input and the output test equipment. Typically, the input and output calibration test equipment are considered independent. These individual uncertainties may be combined by the SRSS method to establish the overall M&TE uncertainty.

For example:

$$MTE = \sqrt{ICT_e^2 + OCT_e^2 + R_{eSTD}^2} \qquad \text{Eqn. (5.5.1.2)}$$

where:

MTE = Uncertainty of the M&TE
ICT_e = Reference accuracy of the input M&TE
OCT_e = Reference accuracy of the output M&TE
Re_{STD} = Reference accuracy of the controlled standard

5.5.1.3 M&TE Reading Uncertainties

The technician performing an instrument calibration introduces additional uncertainty into the instrument loop. This uncertainty is introduced from the reading of the instruments used in the calibration process. These uncertainties are defined as Input Calibration Test Equipment Reading errors (ICR_e) and Output Calibration Test Equipment Reading errors (OCR_e).

If the piece of M&TE has an analog scale, in addition to the movement uncertainty, the specific use of the scale must be considered in the uncertainty. If the calibration process is arranged such that the divisions are always used, and there is no parallax, it is good engineering judgment that no technician reading uncertainty exists since the pointer can be easily aligned with the fixed markings. If the points to be read could lie between divisions, which is normally the situation, an uncertainty of ± ½ of the smallest division should be assigned as the calibration reading error for each piece of calibration equipment.

If the M&TE has digital indication, an uncertainty associated with the least significant displayed digit must be addressed. Normally this uncertainty can be shown to be insignificant due to its magnitude with respect to the other M&TE uncertainties. This can be performed by assuming that the last digit of the display is off by one and calculating the uncertainty associated with this digit and then combining with the other M&TE uncertainties using SRSS . The SSD should specify the number of digits required per the uncertainty calculation.

As before, any uncertainty assigned because of uncertainties in reading during the calibration process should be converted to the appropriate units and combined with the other M&TE uncertainties (e.g., ICT_e, OCT_e, etc.) to obtain a more correct representation of the calibration process uncertainty.

For example:

$$MTE = \sqrt{ICT_e^2 + OCT_e^2 + ICR_e^2 + OCR_e^2 + R_{eSTD}^2}$$

5.5.1.4 Application of the M&TE Uncertainties

When the calculation preparer is ready to address M&TE uncertainties, the associated calibration procedures (e.g., Surveillance Instructions) should be reviewed to determine how the subject loop is calibrated. The Procedure's Group should also be contacted for guidance in this area (There may be a calibration procedure revision in progress). The calibration configuration of the loop must be determined in-order to appropriately apply the M&TE uncertainties. The loop can be calibrated in three different possible configurations:

1) Loop Calibration

The loop is calibrated by injecting a simulated input at the input of sensing device and final output device is monitored for the determination of the As Found and As Left tolerance values. The individual loop components are adjusted to achieve the As Left tolerances while still in the loop configuration. If a loop calibration is performed, only one input and one output M&TE uncertainty needs to be included.

2) Partial Loop Calibration

The loop is broken up into different sections (not down to a individual component level) to make calibration easier, so there should be a input and output M&TE uncertainties associated with each section of the loop.

3) Component Calibration

Each individual component is calibrated separately without a channel verification, so there should be a input and output M&TE uncertainties associated with each device.

Uncertainty values should be consistent with or bound the uncertainties associated with the M&TE specified in the calibration procedure. This is to allow the technicians performing instrument calibrations to remain within the basis of the setpoint uncertainty calculation and the plant's design basis. This also prevents the unnecessary revision of calibration procedures. If uncertainty calculation imposes more restrictive requirements than used in the existing calibration procedure (e.g., specific model of test equipment to be used and the scale on which the test equipment is to be read) then the calculation preparer should coordinate these requirements with Plant Procedure's Group and document the requirement in the associated setpoint and scaling document.

5.5.2 "As-Found/As-Left" Calibration Values

During calibration of a device, "as-found" and "as-left" data is typically measured and recorded. If practicable, the "as-found" data should be taken without previously exercising the device, thereby providing a better indication of how the device would have performed if called upon by changes in the process. The difference between the "as-found" data of the current calibration and the "as-left" data from the last re-calibration (not necessarily the last calibration period) represents the net affects of several uncertainties, including the reference accuracy and drift of the device over the calibration interval. If the ambient temperature in the area of the device was not the same for the two calibrations, part of the difference between the "as-found" and "as-left" data may be due to temperature effects. "As-found" and "as-left" data may be analyzed to estimate a value for drift for the device, recognizing that variations in environmental conditions and other uncertainties may be present at the time of the calibration, and if appropriate, accounted for when analyzing "as-found" and "as-left" data.

The procedural limits for "as-found" data are typically based on the drift uncertainty allowance for the device and other uncertainties that may be present at the time of calibration. An evaluation of the "as-found" data may be performed to confirm these uncertainties are consistent with values obtained from vendor specifications. It should also be recognized that some of the allowances included in the total instrument channel uncertainty calculation may not be measured in a calibration.

Nominal values and generic device performance data may have been used for calculating instrument uncertainties to aid in the establishment of setpoints for initial plant operation. These nominal values may be refined after sufficient operating experience and plant-specific data is available. Plant-specific data is more representative of each instrument's performance within it's unique installation and application characteristics and can sometimes be used to calculate smaller drift uncertainties. Reducing drift uncertainties allows one to support the revision of setpoints to provide increased margins between setpoints and the expected process conditions during normal plant operating conditions. However, care should be taken to ensure that the use of plant-specific data is based upon accepted statistical principles since limited sample sets may be unnecessarily conservative.

There are other reasons to evaluate the use of plant-specific data rather than nominal values and generic instrument performances.

Example: The conformity of a RTD can be described by RTD-specific data (or curve) rather than the standard curve. The process electronics for a given RTD can then be customized for that particular RTD, improving the accuracy of the instrument channel. The instrument channel uncertainty can then be reduced and the setpoint adjusted, thereby providing additional operating margin between the setpoint and expected process conditions during normal plant operating conditions.

5.5.3 Acceptance Band (A_b)

The Acceptance Band or sometimes referred to as "As Left Value", or "Setting tolerance", is the acceptable parameter variation limits above or below the desired output for a given input standard associated with the calibration of the instrument channel. Typically, this is referred to as the setting tolerance or the width of the "as-left" band about the desired response. To minimize equipment wear and to provide for human factors considerations, a band, rather than a single value, should be specified in the uncertainty calculation. This may be a symmetrical band about a setpoint (e.g., 109% ±1%), or in some cases, a non-symmetrical band about a setpoint (e.g.,110% +0%, -2%). This calibration tolerance is usually based on the reference accuracy of the device being calibrated. However, individual plant calibration philosophies may specify a larger calibration tolerance. The selection of the Acceptance Band for a device is arbitrary but certain guidelines should be followed in its selection:

1) The Acceptance Band shall be large enough to allow the trip setpoints to be easily adjusted between these limits. The acceptance band should always be equal to or greater than the device's reference accuracy.

2) The Acceptance Band should be large enough to envelope the present setting tolerance already established in the associate calibration procedure. The calibration procedure values are field proven (the Plant can calibrate and is agreeable to that setting tolerance). The calculation preparer should NEVER establish an A_b smaller than the calibration procedure value if the analytical limits can be met using the existing calibration procedure value.

5.5.4 Calibration Corrections

Frequently, instrument scaling calculations include corrections to account for the difference in instrument performance or readings between calibration conditions and normal operating conditions, such as static pressure and static head pressure corrections. If these corrections have been made, the setpoint uncertainty calculation does not need to include them (however, the uncertainty of these corrections must be included or justified as insignificant). The fact that these corrections are made during calibration should be identified in the setpoint uncertainty calculation. Calibration of these calibration corrections are discussed in section 5.7.

5.6 Turndown

The term "turndown" (Upper Range Limit {URL}/span) is a dimensionless quantity commonly referred to as the Turndown Factor (TDF). It can be multiplied by an uncertainty term in % URL to convert directly to % span. Note that drift may be stated in % URL or % span. It was given in % URL above simply to illustrate the use of the TDF.

5.7 Calibration Corrections (Static Head, Hot Calibration, etc)

This section will discuss the calibration corrections which must be accounted for during device calibration so that the device will be accurate when it is connected to the process at normal operating conditions. If these following corrections are not made during calibration, they must be addressed in the uncertainty calculation. This section will be broken up into different subsections to address different types of measuring devices.

5.7.1 Differential Pressure Devices used for Level Measurements

There are several calibration corrections which must be accounted for either in the device's initial scaling or as an error in the uncertainty calculation or both.

5.7.1.1 Static Head

If a wet or a filled referenced leg is used, then the initial scaling will need to calculate the force exerted on the dP's diaphragm by this column of liquid. This calculated force (usually measured in inches of water column ("WC) at 68°F) will be used as the reference force (static head) which will be compared to the force exerted by the varying liquid column of the process (process head). The difference between the static head and the process head can be correlated into an actual process level. The static head is calculated by determining the elevation differences between the top of the liquid column in reference leg and the dP's diaphragm, and then multiplying this elevation difference by the specific gravity of the liquid. It is recommended that "inches" be used for the units of elevation difference. This will result in a static head with units of "inches of WC_{68F}". Any uncertainties with respect to elevations or specific gravities must be represented as uncertainties in the calculation.

where:

$$x = ELEV_{High\ Point} - ELEV_{dP}$$

$$H = SG * x$$

H	= Static Head
SG	= Specific Gravity
x	= Elevation height of the reference leg

Some times the reference and process leg may route through several different room which may have different ambient temperatures. For this condition, the reference and process leg elevations should be broken up into several smaller sections of vertical elevation differences and multiplied by the appropriate specific gravity for that section. Then the resultants of these calculations can be algebraically summed to obtain the static head of the legs.

$$H = SG_1 * x_1 + SG_2 * x_2 + \dots SG_n * x_n$$

5.7.1.2 Hot Calibration

For level measurements made using dP devices, the dP to level relationship is a function of liquid's specific gravity in both the reference and process legs. Since the liquid's specific gravity is a function of temperature and pressure, the dP to level relationship is a function of temperature and pressure (primarily temperature due to the minimum compressibility of a liquid). To establish the dP to level relationship, a set of process temperature and pressure conditions (only one temperature and pressure) must be chosen to establish a calibration baseline relationship. From the chosen baseline conditions, a process specific gravity can be calculated which will then be used to calculate a process head. Since only one set of conditions can be used and process may vary over a wide range of conditions, the baseline calibration conditions should be chosen to minimize uncertainties due to process variations.

The following are examples of hot calibration or optimized scaling:

If the dP device is used only at 100% power, the dP to level relationship should be based upon the temperature and pressure conditions at 100% power to minimize process uncertainties. Another example, if the device is used from 0% to 100% power, the dP to level relationship should be chosen somewhere between the 0% and 100% power conditions such as 50% or 75% power in-order to balance the uncertainties bi-directionally.

5.7.1.3 Static Pressure Effect

This effect is discussed in section 5.2.1 of this TI.

5.7.1.4 Analysis of Sealed Capillaries

Sealed capillaries with respect to static head and heatup effects should be treated like any other process or reference leg used in a dP application. Normally a capillary will have a bellows or diaphragm where the capillary interfaces with the process. The bellows usually have a very large diameter compared to the capillary's diameter (a much greater volumetric capability). When the fluid in the capillary expands due to the heatup of the senseline, the density of the liquid decreases but the elevation of the liquid column does not change significantly due to much larger volumetric capability in the bellows or diaphragm area. Using this approach will ensure a bounding analysis.

There is another uncertainty effect associated with the use of seal capillaries. This uncertainty effect is caused by an internal pressure build up within the capillary due elevated temperatures caused the environment (e.g., harsh environment due to an accident). As the temperature increase within the capillary from the initial sealing temperature, the filling fluid within the capillary will start to expand. This fluid expansion causes both the transmitters diaphragm and the sensor diaphragm to displace until an equilibrium point is reach. The displacement of the transmitter diaphragm is the source of the uncertainty. This uncertainty is dependent upon the spring coefficients of both the transmitter and sensor, the surface area of each diaphragm, the fluid expansion coefficient, and the temperature rise from initial filling. Normally the spring coefficient of the sensor is several magnitudes smaller than the transmitter's spring constant so most of the volume expansion or diaphragm displacement occurs in the sensor. The calculation preparer should consult with the vendor concerning how to quantify this effect. ITT Barton has already performed this for their sealed system. If the vendor has not addressed this effect, the calculation preparer should be able to model the system using basic physic equations (e.g., Force = Pressure times Surface Area) and calculate the uncertainty effect.

5.7.2 Differential Pressure Devices used for Flow Measurements

5.7.2.1 Static Head

Static Head is normally not applicable to dP flow measuring devices because the effect cancel out one another. Static head needs only to be addressed if the flow measuring device (e.g., orifice) is mounted in a non-horizontal position (e.g., vertical) where the high and low pressure taps are not the same elevation.

5.7.2.2 Hot Calibration

The effects to a dP flow measurement device is similar to the level measuring device discussed in section 5.7.1.2 of this TI.

5.7.2.3 Static Pressure Effect

This effect is discussed in section 5.2.1 of this TI.

5.7.3 Differential Pressure Devices used for Gaseous Measurements

5.7.3.1 Measuring Small Differential Pressures

If an application is to measure or control a small pressure (e.g., ± ½ inch of WC), density variations in the reference leg or process leg can cause significant uncertainties. For gases (eg., air), temperature, pressure, and relative humidity all can effect the gases density. Normally these variations would be insignificant due to the ratio of the variation's effect to the measurement's magnitude, but when the measurement is small, this ratio can become large and significant.

Example: Due to a LOCA, the Emergency Gas Treatment System ideally controls the annulus to outside differential pressure at ± ½ inch of WC. Due to the temperature differential between the process column of air (inside the annulus) and the reference leg column of air (outside ambient temperature), the dP control point would significantly shift (eg., +0.5"WC) during the winter months (worst case conditions).

5.7.3.2 Effects of Large Pressure Changes on Dry Reference Legs

Another condition in which variations of gas density can effect measurement uncertainties is when a dry (gas filled) and closed (connected to the process) reference leg is utilized and calibrated for a high pressurized condition and the process pressure can vary over a significant range. Since gas is very compressible, pressure variations can significantly effect the gas density.

Example: The Core Flood tank is inerted with Nitrogen gas at a high pressure of 300 psig. A dP device is utilized to measure the water level in the tank and a dry (Nitrogen filled) reference leg is used because the tank liquid is non-condensing. The dP device is located 50 feet below the tank so the reference leg has a large elevation distance. Under accident conditions when the Core Flood tank starts dumping its water into the core, gas expansion occurs as the available tank volume increases caused by the depletion of the water. This gas expansion results in a decrease in the gas density for both the gas in the tank and the reference leg. Due to the combination of the gas density decrease and the large reference leg elevation distance, the force exerted by the reference leg changes significantly thus resulting in a systematic uncertainty.

5.7.4 Pressure Measurements

Gauge pressure measuring devices in the PSI range are not normally sensitive to density changes of the process or waterlegs as were the differential device discussed in this section (5.7). Documented justification must be provided in the uncertainty calculation.

5.7.4.1 Static Head

If the pressure measuring device is liquid filled, a head calculation as described in section 5.7.1.1 is sometimes needed. The calculation preparer should use documented engineering judgment on the significance and importance in the determination of whether to include this correction.

5.8 Evaluating Small Uncertainties

For those cases where uncertainties are combined through the SRSS methodology, those uncertainties whose magnitudes are small in comparison with larger uncertainties have very little effect on the combined uncertainty. A rule of thumb is that any uncertainty whose value is less than one-fifth of the largest value can normally be shown to be insignificant. For example, if two uncertainty values, one of 1.0% and one of 5.0%, are combined through the SRSS methodology, the uncertainty is:

$$A_n = \sqrt{5^2 + 1^2} = 5.1$$

which is only 2 percent larger than the value calculated if the 1% uncertainty was not considered. Even if there were five of the smaller values the overall SRSS uncertainty would be:

$$A_n = \sqrt{5^2 + 1^2 + 1^2 + 1^2 + 1^2 + 1^2} = 5.48$$

which is less than 10 percent larger than the value calculated if the five small uncertainties were ignored.

The potential gains in time and labor from ignoring the small uncertainties are not as large as they might seem. The sources of uncertainties have to be identified, their magnitude has to be quantified, and the quantified values have to be justified. Once these steps have been completed, the SRSS summation is trivial. However, these considerations do lead to the implication that once a value has been determined to be small, further efforts to refine its magnitude are not warranted. All known values should be used or documented (do not discard) in the calculation. Once the reviewer checks that the smaller numbers are negligible, the correctness of the larger uncertainties can be reviewed more completely.

5.9 Response Time

Each calculation must have a response time analysis which addresses all response time delays not covered by the analytical limit calculation. These delays must be compared against the margin allowed for instrument delays in the analytical limits calculation. This comparison should verify that positive margin exists when associated instrument and electrical delays are included. Several examples of possible time delays are: Dropout and pickup times for auxiliary relays; breaker actuation times; instrumentation response times; instrument sensing line response times; snubbers, etc. Additional references which can be valuable in addressing response times are References 3.12 (Control Loop Response) and 3.13 (Instrument Sensing Line Response).

A supportable Technical Justification must be documented in every calculation. The level of justification required is dependent upon the response time margin allowed and the magnitude of the associated time delays. If the response allowance is large with respect to the associated instrumentation and electrical time delays, then a detailed quantitative analysis is not required.

Example: Indication loop - The millisecond delays of the instrumentation and senseline delays are insignificant with respect to the response time of the Operator and his actions.

If the response allowance is small with respect to the associated instrumentation and electrical time delays, then a detailed quantitative analysis is required.

Example: The instrumentation and electrical equipment delays must be less than 1 second. For this case, the cumulative millisecond delays associated with the instrumentation and electrical equipment now become significant with respect to the establishment of the analytical limits. A detailed, quantitative analysis would be required for this example.

Per NRC Information Notice 92-33, the response time delays associated with snubbers, if applicable for the instrumentation loop being analyzed, shall be address in the uncertainty calculation.

5.10 Electrical Relays

5.10.1 Time Delay Relays

From an Instrumentation and Control (I&C) standpoint, Time Delay Relays (TDR) have not been identified as Instrumentation. TDR's have been documented and maintained as Electrical devices which has resulted in some past I&C problems with respects to uncertainties related to response time requirements. Now, any TDR used in a process control circuit is considered instrumentation but will probably still be documented and maintained as an electrical device. Because TDR's are maintained as an electrical device, there are several areas which are different and need further discussion.

1) TDR's do not have unique identifiers like instrumentation which means that they are not listed in the Instrument Tabulation list (I-Tabs) or the Equipment Management System (EMS) which also means that their setpoints are not controlled by the I-Tabs/EMS. To identify a specific TDR and its setpoint, one must find the associated

schematic drawing of the control circuit in which it is used. The TDR will not have an unique identifier as defined by Reference 3.11, but it will have an unique identifier with respect to the circuit (e.g., 63, R5, etc.) and only that circuit. The setpoint will be documented on the schematic drawing along with the TDR. The schematic is the setpoint control document for TDR's until NESSD's are issued.

2) Since TDR's are not part of the I-Tabs/EMS, it is a difficult process to determine the TDR's manufacturer and model numbers. Contract files can be used to determine this, but the recommended method is to use the Site's field verification process, actual walk-down verification.

3) TDR's are not normally maintained by Instrument Maintenance, so the calculation preparer should be aware of this and consult with the proper Maintenance organization when performing calculations on TDR's.

5.10.2 Other Relays

As for other types of electrical relays (e.g., under-voltage, etc.), the same issues will be encountered as was described for the TDR's in the previous section. The settings and tolerances are normally controlled by Relay Setting Sheets approved by Engineering or NESSD's.

5.11 Seismic Effects

Data used for calculating the seismic uncertainty for a device should always originate from test results documented in a TVA approved test report. Sometimes for older instrumentation the testing only verified functionally and did not record any post-seismic uncertainties. Here are three potential resolutions to this situation:

1) Retest or replace the device with one which has adequate documentation.

2) Perform a detailed similarity analysis along with obtaining a seismic analysis from the Civil engineering discipline. The similarity analysis must demonstrate likeness on a discrete component level and identify any potential components which could be sensitive to a seismic event (e.g., variable resistors) which could result in a device uncertainty. If a sensitivity is identified, a design change may be necessary such as a lock nut for the variable resistor. Any resolution will require the approval of the responsible Lead Civil engineer. This method is supported by Reference 3.27.

3) Based upon system response time requirements, device re-calibration by Instrument Maintenance or manual Operator actions my be possible resolutions. This requires written approval from the responsible Nuclear Engineering System Engineer and his Lead Engineer. Also, any resolutions evolving the Plant (e.g., Operations) requires proper coordination with the responsible organization and documentation of any requirements using official design output documents.

5.12 Insulation Resistance Effect (IR_e)

Under conditions of high humidity, radiation, and temperature associated with high energy line breaks (HELB), cables, splices, connectors, terminal blocks, and penetrations may experience a reduction in insulation resistance (IR). The radiation testing is normally performed prior to the temperature testing so that the IR measurements taken during the temperature testing includes the effects of the radiation. The reduction in IR causes an increase in leakage currents between conductors and from individual conductors to ground. Leakage currents are negligibly small under normal, non-accident conditions. If channel calibrations are made, such currents are essentially calibrated out. However, under HELB events the leakage currents may increase, causing an uncertainty in the measurement. The effect can be a concern for circuits with sensitive, low level signals such as current transmitters, RTD's, thermocouple, neutron monitoring instrumentation, etc. It is especially of concern for channels with logarithmic signals (excore detectors, radiation monitors). The circuits of interest must be evaluated individually to determine the number of leakage paths. See Appendix I for further details on IR_e.

5.13 Power Supply Variations

Most electronic instruments exhibit a change in output because of variations in power supply voltage. A typical manufacturer's specification may read

±0.01% span per volt variation

To calculate the uncertainty associated with the power supply effect (PS_e), a normal Operating Voltage (OV) and Voltage Variation (VV) should be determined. Once these points are defined, if the effect is linear, an expression similar to Equation 5.1.1. can be used to calculate the uncertainty associated with the power supply effect. Typically this *uncertainty is very small in comparison to other instrument channel uncertainties.*

5.14 Environmental Effects

5.14.1 Accident Effects

For accident conditions, additional uncertainties associated with the high temperature, pressure, humidity, and radiation environment may need to be included in the instrument uncertainty calculations, as required.

Qualification reports for safety-related instruments normally contain tables, graphs, or both, of accuracy before, during, and after radiation and steam/pressure environmental testing. Many times, manufacturers summarize the results of the qualification testing in their product specification sheets. More detailed information is normally available in the equipment qualification report. This environmental qualification report will be found in the associated TVA instrument's Equipment Qualification (EQ) Binder and is the only source that can be utilized for this uncertainty calculation data. ***New test reports shall be added to the EQ binder prior to using the report for uncertainty data.***

Because of the limited sample size typically found in qualification testing, the conservative approach to assigning uncertainty limits is to use the bounding worst-case uncertainties. Discussions with the vendor may be helpful to gain insight into the behavior of the uncertainty (e.g., should it be considered random or a bias?). Additional information obtained form these discussions must be documented by the vendor in a quality manner (e.g., 10 CFR 50, Appendix B) and also documented in the associated EQ Binder and/or vendor manual.

Using data from the qualification report (or device specific temperature compensation data) in place of design performance specifications (test acceptance criteria), makes it often possible to justify the use of lower uncertainty values. Typically, qualification tests are conducted at the upper extremes of simulated DBE environments so that the results apply to as many plants as possible, each with different requirements. Therefore, it is not always practical or necessary to use the results, at the bounding environmental extremes when the actual requirements are not as limiting.

Some cautions are needed, however, to preclude possible misapplication of the data:

1) The highest uncertainties of all the units tested at the reduced temperature or dose should be used. When extrapolating test data to lower than tested environmental data, the extrapolation will require technical justification and the inclusion of a margin or uncertainty band to address the confidence level of the extrapolation process. Again, discussions with the vendor may provide insight for performing these extrapolations. Without a defined relationship with respects to temperature, IR can not be extrapolated.

2) The units tested should have been tested under identical or equivalent conditions and test sequences.

3) If a reduced temperature is used, ensure that sufficient heatup time existed prior to the readings at that temperature to ensure sufficient thermal equilibrium was reached within the instrument case.

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

Finally, it is sometimes possible to delete or reduce accident uncertainties from calculations based on the timing of the actuation function. For example, accident effects would not have to be considered for a primary reactor trip on low reactor coolant pressure if the trip function is credited for the design basis large break Loss-of-Coolant Accident (LOCA) only. This is true because the trip signal occurs very rapidly during the large immediate pressure decrease. Therefore, it could be documented in a quality manner that the trip function can be accomplished long before the environment becomes harsh enough to begin to affect equipment performance significantly or affect the analysis results. Care shall be taken in using this technique to verify that the most limiting conditions for all of the applicable safety analyses are used.

5.14.1.1 Radiation Effects

There are several issues that need discussion concerning radiation effects.

1) Dose Rate Effects

Electronics are often dose rate dependent. This means that the larger the test dose rate, the greater the resulting instrument error. To make matters worst, testing is usually performed using large dose rates in-order to shorten the length of the testing. If a device's radiation testing is resulting in large errors, testing at a lower and more realistic dose rates (plant's radiation profile) may provide improved results.

2) Radiation Thresholds

Another issue is where does the radiation threshold, the device's accuracy is actually effected by radiation, occur. Reference 3.28 addresses radiation thresholds for a variety of analog and digital components. This calculation along with engineering judgment can be used to justify radiation effects of zero in low radiation environments. Note digital devices are normally radiation intolerant and that levels starting at 1000 rads may result in the complete failure of the device.

3) Normal Radiation Effects

Instrument accuracy data is normally not available at low radiation levels. EQ testing occurs at high doses such as 10 to 50 Mega Rads. A common practice that can be used to address the effects of normal plant radiation effects, such as 1000 rads per calibration period, is to use the engineering judgment "that normal periodic calibration calibrates any low level radiation effects/residuals". Normal plant background radiation levels are usually low enough that instrumentation with designs based upon analog electronics are not effected or the effects are small and the residual is calibrated out. Normal Radiation effects are addressed by defining the instrumentation location and the localized dose rate for that specific area. The normal dose is usually represented as a 40 year Total integrated dose rate which can be divided by calibration frequency such as 1.5 years to get the dose rate for a calibration period. Generic Radiation calculation, Reference 3.28, documents that analog electronics are un-effected at levels less than 10^4 rads. If the instrumentation is based upon analog electronics and is less than 10^4 rads, engineering judgment can be used with the generic radiation calculation as the basis of that engineering judgment. If the radiation levels are 10^4 rads or greater, a component specific analysis based upon Ref 3.28 could be used to justify no effects at higher dose rates or calibration history can be analyzed to determine if there is any drift outside the expected drift value which would also support no normal radiation effects. If the deviation between calibrations is within the expected drift allowance, an engineering judgment can be made that any radiation effect is within the drift tolerance allowed in the accuracy calculation. Radiation testing is another method of determining a value for radiation effects.

5.14.2 EMI/RFI Effects

Per NRC regulatory requirements, the instrumentation must be qualified to operate in it's expected environment. Electromagnetic Interference/ Radio Frequency Interference commonly know as EMI/RFI is part of the instrument's expected environment. Newly procured Safety-Related instrumentation must be meet Reference 3.26 for EMI/RFI susceptibility and emissions through testing. As for existing instrumentation (without testing) operational experience is sufficient to address EMI/RFI. Operation experience results in the identification of any real EMI/RFI problems. These problems are addressed through design changes or administrative controls such as posting of signs that prohibit use of radios in certain sensitive areas of the plants.

With respect to EMI/RFI effects on accuracy, Reference 3.24 states that EMI/RFI uncertainties for DO NOT need to be added to setpoint calculations. EMI/RFI are normally transient in nature (only appear when a failure or a electrical disturbance has occurred). It is not possible to quantify EMI/RFI effects and any possible transient EMI/RFI effects will be reduced through qualification testing and corrective actions resulting from operating experience problems.

5.15 Process Measurement Effects

Another source of instrument channel uncertainty that is not directly caused by equipment is process measurement effects. These are uncertainties induced by the physical characteristics or properties of the process that is being measured. The decisions related to classifying process measurement uncertainties as random or bias should follow the guidance presented in Section 4.0.

Several types of process uncertainties may be encountered in instrumentation design. A few of the most common process uncertainty terms are discussed in the Appendices F and L. The applicability of all possible process measurement effects should be considered when preparing uncertainty calculations.

5.16 Indication Reading Error ($INDR_e$)

5.16.1 Linear Analog Indication

If the indication device has an analog scale, in addition to the movement uncertainty the specific use of the scale should be considered to the uncertainty. An uncertainty of ± ½ of the smallest division should be assigned as the Indication Reading Error.

5.16.2 Non-Linear Analog Indication

5.16.2.1 Logarithm Scales

Logarithm Scales are utilized to get a wide process range on a single indication. Due to the non-linearity of the indicating device, the calculation preparer should determine the specific points that the Operator will be utilizing and the corresponding division/s. An uncertainty of ± ½ of the specific largest division of interest should be assigned as the Indication Reading Error for the channel.

5.16.2.2 Square Root Scales

Square Root Scales are utilized to correlate differential pressure (dP) to flow rate. This is done when the instrument channel does not have an electronic square root extractor to linearize the dP to flow rate relationship. Due to the non-linearity of the indicating device, the calculation preparer should determine the specific points that the Operator will be utilizing and the corresponding division/s. An uncertainty of ± ½ of the specific largest division of interest should be assigned as the Indication Reading Error for the channel. Usually these scales are not readable below the bottom third of the indication.

5.16.3 Digital Indication

If the indication has digital indication, an uncertainty associated with the least significant displayed digit must be addressed. Normally this uncertainty can be shown to be insignificant due to its magnitude with respect to the other channel uncertainties. This can be performed by assuming that the least significant digit of the display is off by one and calculating the uncertainty associated with this digit and then combining with the other channel uncertainties using SRSS . The SSD should specify the number of digits required per the calculation.

5.16.4 Recorders

The uncertainties associated with recorders should be addressed in the same manner as the analog indicator discussed in section 5.16. The one difference between recorders and indicators is that recorders have changeable chart paper so the smallest division could possible vary unless the type of chart paper is controlled. Since Operation is responsible for recorder chart paper, not Instrument Maintenance or the Procedures Group, NESSD's can not be used to control recorder chart paper. Site Engineering must establish a method to control this process.

5.16.5 Combining ICRe with Ab to reduce Uncertainties

During calibration, the best reading expected on an indicator or recorder is to the nearest 1/2 minor division of the scale. As an example, consider a calibration input of 5 psig with an expected output tolerance of ± 3 psig. The output is expected, to be somewhere between 2 and 8, neither of which can be read. The indicated value below is "close" to 10 psig. The ICRe would be 1/2 the minor division or 5 psig

```
0         10        20
|---------|---------|
```

The reading error is a deviation from the true indicated value and should be included as part of Anf (either an independent error or as part of Ab). In the example above, the best solution is to include the reading error in Ab (i.e., Ab = ± 5 psig). Otherwise the effects of treating Ab and ICRe separately would result in a larger combined uncertainty effect of 5.8 psig $(5^2 + 3^2)^{0.5}$ with a more restrictive Ab.

A second, independent reading error exist when the operator reads the instrument. For example, if the true indicated value is some value other than a multiple of 1/2 a minor division, the operator must estimate the value (This estimate will be within 1/2 a minor division). As an example, consider a true indicated value of 8 psig (true indication consists of the process value plus other loop uncertainties). The operator sees a value somewhere between 5 and 10. Since the indicated value is close to 10, this should be the recorded value.

```
0         10        20
|---------|---------|
```

The distinction between the reading errors is that the technician's reading error is a value judged to be the output for a standard input while the operator's reading error is a value judged to be the process value. Bounding the reading error with Ab to nearest readable 1/2 minor division will minimize the calibration reading error ICRe. Nonetheless, the operator reading error INDRe must be included independently.

5.17 Westinghouse Methodology Calculations

This section applies to only the Watts Bar and Sequoyah Nuclear Plants. For the instrumentation performing Reactor Protection and Safety Injection functions, the Westinghouse Setpoint Methodology shall be used to perform uncertainty calculations for these functions. Both WBN and SQN have this methodology defined in their associated Westinghouse Setpoint Methodology Document (WSMD). Since the WSMD is not a TVA document (Westinghouse document), it is recommended that it be turned into a TVA calculation in order to maintain it in an As-Constructed status. Most of these uncertainty calculations are performed by Westinghouse and documented in the WSMD's. If TVA performs the calculation instead of Westinghouse, TVA shall follow the Westinghouse Methodology for their respective plant.

5.18 Averaging and Uncertainties

5.18.1 Averaging Effects on Instrument Uncertainties

When several independent measurements are used to determine a parameter, the uncertainties can be averaged with one another using the following SRSS methodology.

$$Average = \frac{(X1+e1)+(X2+e2)+(X3+e3)+(X4+e4)}{n} \qquad \text{Eqn. 5.18.1}$$

The equation development will be simplified by assuming that 4 redundant devices will be average together along with their associated uncertainties. Since the devices are redundant and are measuring the same parameter, there uncertainties will be equal so e = e1 = e2 = e3 = e4 and X = X1 = X2 = X3 = X4.

Substituting e and X into Eqn. 5.18.1:

$$Average = \frac{(X+e)+(X+e)+(X+e)+(X+e)}{n} \qquad \text{Eqn. 5.18.2}$$

$$Average = X+\frac{e}{n}+\frac{e}{n}+\frac{e}{n}+\frac{e}{n} \qquad \text{Eqn. 5.18.3}$$

$$Average = X+\frac{1}{n}*(e+e+e+e) = X+\left[\frac{1}{n}*(n*e)\right] \qquad \text{Eqn. 5.18.4}$$

Combining the uncertainties using SRSS results in the following:

$$Average_{SRSS} = X + \frac{1}{n} * \sqrt{e^2 + e^2 + e^2 + e^2} = X + \left[\frac{1}{n} * \sqrt{n * e^2}\right]$$ **Eqn. 5.18.5**

Let $n = \left(\sqrt{n}\right)^2$

Substituting for n: $$Average_{SRSS} = X + \frac{1}{\left(\sqrt{n}\right)^2} * \sqrt{n * e^2}$$ **Eqn. 5.18.6**

Arranging Eqn. 5.18.6 $$Average_{SRSS} = X + \frac{1}{\left(\sqrt{n}\right)^2} * \sqrt{n} * e$$ **Eqn. 5.18.7**

Simplifying Eqn. 5.18.7 yields $$Average_{SRSS} = X + \frac{e}{\sqrt{n}}$$ **Eqn. 5.18.8**

Subtracting the process value (X) leaves the total uncertainty of the averaged measurement:

$$Average_{SRSS} = X + \frac{e}{\sqrt{n}} - X = \frac{e}{\sqrt{n}}$$ **Eqn. 5.18.9**

5.18.2 Weighted Averaging Effects on Instrument Uncertainties

Where: a, b, c, d = Weighting ratio of the whole. Example: If a, b, c, and d were equally weight, the weighting ratio would be 1/n or ¼. The sum of the weights should equal to 1.

X_n = the value of a process parameter
e_n = the uncertainty associated with the process measurement

$$Weighted\_Average = a*(X1+e1)+ b*(X2+e2)+ c*(X3+e3)+ d*(X4+e4) \quad \text{Eqn. 5.18.10}$$

The equation development will be simplified by assuming that 4 redundant devices will be average together along with their associated uncertainties. Since the devices are redundant and are measuring the same parameter, there uncertainties will be equal so e = e1 = e2 = e3 = e4 and X = X1 = X2 = X3 = X4.

$$Weighted\_Average = a*(X+e)+ b*(X+e)+ c*(X+e)+ d*(X+e) \quad \text{Eqn. 5.18.11}$$

Expanding the Eqn. 5.18.10 yields:

$$Weighted\_Average = a*X+a*e+ b*X+b*e+ c*X+c*e+ d*X+d*e \quad \text{Eqn. 5.18.12}$$

Grouping the process value term and the uncertainty terms yields:

$$Weighted\_Average = X*(a+b+c+d)+(a*e+ b*e+c*e+d*e) \quad \text{Eqn. 5.18.13}$$

Combining the uncertainties using SRSS results in the following:

$$Weighted\_Average_{SRSS} = X*(a+b+c+d)+\sqrt{(a*e)^2+ (b*e)^2+(c*e)^2+(d*e)^2} \quad \text{Eqn. 5.18.14}$$

Simplifying the Eqn. 5.18.14 yields:

$$Weighted\_Average_{SRSS} = X*(a+b+c+d)+\sqrt{e^2*(a^2+ b^2+c^2+d^2)} \quad \text{Eqn. 5.18.15}$$

$$Weighted\_Average_{SRSS} = X*(a+b+c+d)+e*\sqrt{a^2+b^2+c^2+d^2} \quad \text{Eqn. 5.18.16}$$

Subtracting the process value (X) leaves the total uncertainty of the weighted average measurement:

$$Weighted\_Average_{SRSS} = X*(a+b+c+d)+e*\sqrt{a^2+b^2+c^2+d^2}-[X*(a+b+c+d)] \quad \text{Eqn. 5.18.17}$$

$$Weighted\_Average_{SRSS} = e*\sqrt{a^2+b^2+c^2+d^2} \quad \text{Eqn. 5.18.18}$$

6.0 PREPARING AND ISSUING AN UNCERTAINTY CALCULATION

The instrument uncertainty calculations shall be performed according to the requirements of this Technical Instruction. The details of the calculation methods are outlined in this section.

6.1 Determining Loop Function(s)

Before the preparation of any uncertainty calculation, ask yourself several technically based questions:

1) For what function/s am I performing this calculation?

2) What is this calculation accomplishing with respect to the verification of the Safety of the Plant?

3) What is the range of the process and environmental conditions being measured?

4) What are the Analytical and Operational limits for the specific functions being analyzed?

All of the questions should be addressed in the supporting analytical limits calculation and/or system design criteria document. The bottom line is before starting the preparation of a uncertainty calculation, become knowledgeable of all the instrumentation's system functions and verify that the system documentation required for the calculation exists.

6.2 Obtaining Analytical and Operational Limit(s)

The Analytical and Operational Limit(s) shall be obtained from the Plant's Design Criteria and/or System Engineer within Nuclear Engineering. These limits must be supported by a QA calculation. Most of these limits will originate from a Nuclear or Mechanical process engineer although the Electrical group will provide a few limits such as Emergency Diesel Generator electrical requirements.

6.3 Format and Content

This section will describe the upper tier mechanics of preparing, checking, and issuing a calculation. The format and review requirements defined in this TI are intended to structure the calculation process and fulfill the upper tier requirements of References 3.18 and 3.19.

6.3.1 Cover Sheet

Use the standard Nuclear Engineering Calculation cover sheet as described in Reference 3.19. All blanks must be filled in by the calculation preparer. The cover sheet should have the calculation's number of pages (including attachment's pages) and the number of attachments.

6.3.2 **Revision Log**

Each calculation must have a Revision Log sheet/s. Each calculation revision shall have a brief description of the change/s made to the calculation.

6.3.3 **SAR Review**

For each calculation revision as required by Reference 3.19 (for new or revised calculations not associated with a design change) and Reference 3.21 (calculation associated with Design Changes), a review of all applicable Safety Analysis Report (SAR) sections must be performed to determine if any of the calculation changes affect (conflict with) the SAR. Any subsequent actions are controlled by said procedures. The SAR includes the Final Safety Analysis Report, Technical Specification, any pending SAR submittals, etc.

6.3.4 **Independent Review**

For each calculation revision level, an Independent Review shall be performed and documented per the requirements of Reference 3.18.

6.3.5 **Table of Content**

Provide a Table of Content section in compliance with Reference 3.19.

6.3.6 **References**

The reference section should be organized in a manner to facilitate maintenance through the normal design change process. The reference section should be divided into two sub-sections to efficiently ensure that references are maintained up-to-date.

1) Direct Design Input - This sub-section should reference all reference material which directly affect the calculation. Example: If the reference material could be changed in the future and could possible change the results of the calculation, then this reference should be listed as Direct Design Input.

2) Information Only - This sub-section should contain references which are in the calculation for information only purposes, have very little possibility of change (e.g., physics equations), or have no impact on the calculation if changed.

If the references are attachments to the calculation, the associated attachment number should be provided with the reference.

6.3.7 Definitions and Abbreviations

A standard set of definitions and abbreviations shall be provided in each calculation. These definitions and abbreviations (along with the standard ISA definitions and the definitions in this instruction) will be all that are required for most applications. Additional definitions and abbreviations may be added as required. The following is a list of standard TI-28 abbreviations:

<u>Abbreviations</u>

Aa	-	Accident Accuracy
Adbe	-	Design Basis Accuracy
Ab	-	Acceptance Band
AL	-	Analytical Limit
An	-	Normal Accuracy
Anf	-	Normal Measurable Accuracy
As	-	Seismic Accuracy
Aas	-	Accident plus Seismic Accuracy
Av	-	Allowable Value
CPM		Counts Per Minute
CS	-	Calibrated Span
De	-	Drift error
dP	-	Differential Pressure
Ebd		Bistable Drift Error
Ebs		bistable inaccuracy
Ect		current transmission inaccuracy
Eed		energy dependence inaccuracy
Efa		field alignment error
Efac		factory alignment error
Eimp		Imprecision

E'ncr		net count rate inaccuracy
Encr		net count inaccuracy
Epc		primary calibration error
EQ	-	Equipment Qualification
FS	-	Full Scale
ICRe	-	Input Calibration Test equipment reading error
ICTe	-	Input Calibration Test equipment error
INDRe	-	Indication Reading error
IRe	-	Insulation Resistance error
K	-	Coefficient (normally a Coefficient for flow conversion)
M	-	Margin
mA	-	milli - amps
M&TE	-	Maintenance and Test Equipment
mR/hR		millirems per hour
OCRe	-	Output Calibration Test equipment reading error
OCTe	-	Output Calibration Test equipment error
ρ	-	density
PRCSe	-	Process error
PSEe	-	Power Supply Effect
Q	-	Volumetric Flowrate
QR	-	Quality Related
Re	-	Repeatability
RADe	-	Accident Radiation effect
Rleg	-	Reference Leg
RNDe	-	Normal Radiation effect
Se	-	Seismic effect

SECu	-	Static Pressure Correction uncertainty
SG	-	Specific Gravity
SL	-	Safety Limit
SP	-	Setpoint
SPe	-	Static Pressure effect
SR	-	Safety Related
SRSS	-	Square Root Sum of the Squares
SSD	-	Setpoint and Scaling Document
TAe	-	Accident Temperature effect
TNe	-	Normal Temperature effect
TS	-	Technical Specification
URL	-	Upper Range Limit
v	-	Specific Volume
W	-	Mass Flowrate
WC	-	inches of Water Column
Wle	-	Waterleg Heatup effect

6.3.8 Loop Component List

This page should contain a list of loops which are covered by this calculation and a list of the components in each loop. The components should be identified by instrument numbers or equipment numbers.

6.3.9 Purpose

The purpose and scope of the calculation should be included in this section of the calculation. The calculation may be a uncertainty calculation used for Post Accident Monitoring or could be for a setpoint and scaling calculation.

6.3.10 Assumptions

The assumption section is to document any unverified assumptions (UVA's) established in the calculation. It is recommended practice that calculations should not be issued with UVA's. This recommendation is based upon the past problems with the resolutions of UVA's. If a calculation is issued with an UVA, several things <u>must</u> be performed.

1) Document the UVA in the assumption section of the calculation and check the UVA block on the cover sheet. Checking the UVA block will ensure that the UVA gets tracked and resolved by way of the normal design process.

2) Document along with the UVA the method to be used to resolve the UVA. This provides credibility that the UVA can be resolved and resolved in a realistic manner.

3) Document along with the UVA the required time frame for resolving the UVA (e.g., Resolution required prior to entrance into Mode 2 or system operability). This provides a priority for scheduling purposes.

Please note again that it is strongly recommended that UVA's <u>should</u> not be used.

6.3.11 Loop Information

This section should provide a brief description of the function of the loop, a description of the equipment being monitored and/or controlled by the loop, identification of the controlling parameters.

Loop Requirements and Limits - (Two formats are provided)

One should be used if the loop contains a bistable, and the other sheet should be used if the loop is used for indication.

1) Bistable

Response Time -	A statement should be provided for the instrument loop actuation time. The statement should justify the adequacy of the estimated response time. The effect of slow instrument response time may have to be considered in the calculation of the setpoint on certain loops. The required response time, if available, should be documented here.
Analytical Limits -	The value of the analytical limits should be documented here.
Operational Limits -	The normal operating value of the variables for each loop should be documented here.
Setpoints -	The setpoint should be documented here.
Reset -	If reset is defined as an important factor, it should be treated as a setpoint. If applicable, analytic limits and uncertainties must be addressed for the reset function.

2) Indication

Response Time -	A statement should be provided for the instrument loop actuation time justifying the adequacy of the estimated response time.
Required Accuracy -	The required accuracy or Operator setpoints for the loop should be documented here.
Indicated Range -	The indicated range should be documented here.

6.3.12 Requirements

The requirement section should contain any requirement established by the calculation (e.g., required calibration frequency). If the calculation is supporting a design change (DCN) which has not been implement, it is recommended that the portions of the DCN which effect instrument accuracy should be specifically addressed in this section (e.g., condensation pot elevations). This will allow any DCN variations (e.g., Field changes - FDCN's) to be evaluated quickly and effectively. Any requirements established in the calculation must have a valid Nuclear Engineering output document (see Reference 3.8) to transmit the requirements to the plant. Sole documentation in the calculation is not acceptable because the calculation is design input, not design output.

6.3.13 Component Input Data

This section contains all the data (e.g., instrumentation uncertainty values, environmental profiles, etc.) which is used to support the calculation. All input data must have a reference noted with the data.

Complete data for the components should be provided. Separate sheets should be utilized for each component. Data such as manufacturer, model number, range, location, environmental data, and tap elevations should be provided. Radiation and temperature data for the device may be obtained from the environmental data drawings. Location specific radiation doses, if required, should be obtained from the Nuclear analysis group.

The component data section should list the various uncertainty components which are used in the calculations. All data shall be provided with a reference number to document the source of the data. Additionally, space shall be provided for note (number) identifications. Notes may be required in addition to the references for data or documentation.

Consideration must be given to the function of the component. Even though some components are located in an environmentally harsh area for certain accidents, the device may not be required to function when the environment is harsh. Therefore, the environmental errors may not be required in the calculation. The Category and Operating times for the subject loop shall be provided.

Another variable which must be considered is duration of service. Certain components may be required for such a short time period that the environmental error can be neglected.

6.3.14 Analysis/Methodology

This section contains the actual equations, design basis conditions, and calculations used to calculate the following <u>typical</u> component and loop parameters:

A_n - Normal Accuracy
$A_{N'}$ - Normal Measurable Accuracy
A_s - Seismic Accuracy
A_a - Accident Accuracy
A_{as} - Accident plus Seismic Accuracy
A_v - Allowable Value
$PRCS_e$ - Process Measurement Uncertainty
WL_e - Reference/Water Leg Uncertainty

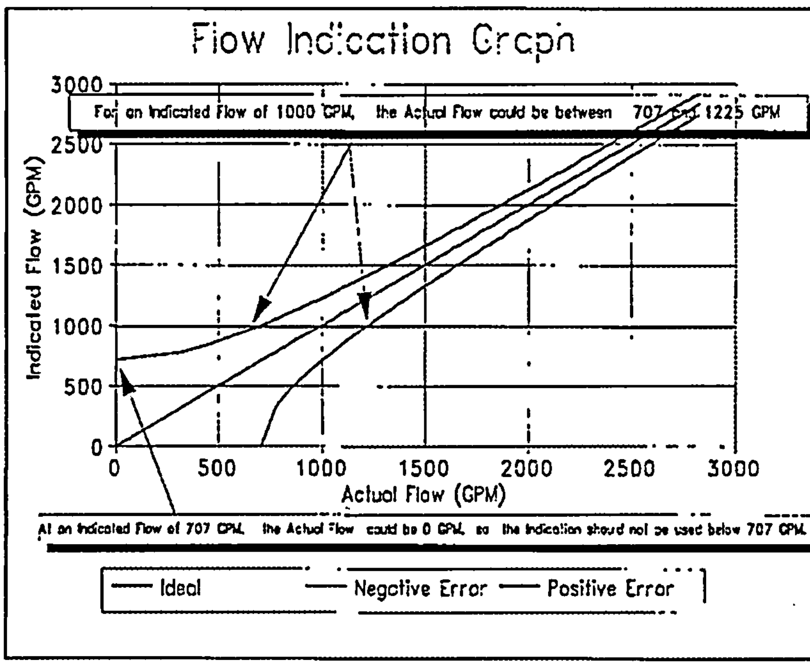
This section should also contain the scaling calculations and process units to calibration units conversion calculation needed to support the associated Setpoint and Scaling Documents (See Appendix A for details on SSD preparation).

6.3.15 Graphs/Loop Diagrams

6.3.15.1 Graphs for Indicators and Recorders

For all calculations performed for indicators and recorders, a graphical representation of the actual or true variation versus the indicated variation shall be provided in the calculation.

Example:



6.3.15.2 Loop Diagrams

The standard for loop diagrams has not been issued so there is presently no defined direction for producing loop diagrams. A functional loop diagram should be provided indicating all of the major components in the instrument loop along with their associated instrument numbers. The use of the control logic diagrams is recommended as an interim replacement. If a detailed loop diagram is going to be produced to support a SSD, the drawing would need adequate detail so that an Instrument Tech could use the drawing to perform calibration and testing.

6.3.15.3 Instrument Sensing Diagram

An instrument sensing diagram shall be provided. This diagram shall indicate elevation data (and any other physical characteristics) which help describe the instrument's physical location important to the calculations for loops with instruments requiring head correction.

6.3.16 Summary of Results

The Summary of Results section shall contain the results of the loop accuracy calculation. The following values shall be represented on a setpoint stick in this section:

A_n	- Normal Accuracy
A_{nf}	- Normal Measurable Accuracy
A_s	- Seismic Accuracy
A_a	- Accident Accuracy
A_{as}	- Accident plus Seismic Accuracy
A_v	- Allowable Value
SP	- Setpoint
AL	- Analytical Limit (Upper and Lower)
A_b	- Acceptance Band

Example:

______ Upper AL   Margin ____

______ SP + A_{as} (For recalibration after a SSE)

______ SP + A_a

______ SP + A_s

______ SP + A_n

______ SP

______ SP - A_n

______ SP - A_s

______ SP - A_a

______ SP - A_{as} (For re-calibration after a SSE)

______ Lower AL   Margin ____

A_{as} ____   Re-calibration Required After SSE - Yes ___ No ___
A_v ____
A_{nf} ____
A_b ____

6.3.17 Conclusions

The Conclusion section of the calculation should contain a brief description of whether the loop's setpoint will fulfill the Analytical Limit/s with the inclusion of instrumentation uncertainties. If the setpoint is not acceptable, the Condition Adverse to Quality (e.g., PER Number) shall be documented in the conclusion section.

6.3.18 Appendices

Appendices are a part of the calculation and can be used to sectionalize specialty calculations within the subject calculation (e.g., process error calculation).

6.3.19 Attachments

The attachment is for providing information in the calculation for information purposes only. This section should be used to attach information that clarifies the calculation or information that is not readily retrievable from document control (DCRM). The attachment section should be used freely in order to establish a calculation which is stand alone. Common sense must also be exercised to minimize the amount of paper. Examples of commonly used attachments:

- Vendor specification sheets
- Pertinent sections of the Analytical Limits calculation
- Quality Information Release's
- Calibration cards
- Equipment Qualification test reports (EQ Binder's version)
- Excerpts from Text Books

Please note that the attachment section does not undergo the QA design review process as defined in Reference 3.18 , so if there is an analysis which requires QA design review, then the subject analysis should be issued in a separate QA document or in an appendix to the subject calculation.

6.3.20 Calculation Numbering

The following is the recommended method for numbering calculations.

TI28-AA-BBB-CC-DDD-EEEE

AA - Quality Code	MS - Minimum Essential Set, QR - Quality Related, NS -Non-Safety
BBB - Unit Number	001 - Unit 1 only 002 - Unit 2 only 012 - Units 1 and 2 123 - Units 1, 2, and 3

Setpoint Calculations
EEB-TI-28

CC - Sensor UNID	LT - Level Transmitter PS - Pressure Switch
DDD - System No.	003 - Feedwater System 068 - Reactor Coolant System
EEEE - Loop No.	0125

Example: TI28-MS-001-LT-063-050

This loop number identifies the calculation was prepared per TI-28, it is a Minimum Essential Set (MS) calculation, a Unit 1 calculation only, a level loop (LT), it is in the Safety Injection System (63), and is a calculation involving loop number 50.

6.3.21 Calculation Tracking System (CTS)

Each calculation requires the preparation and submittal of a CTS form along with the issuing of the calculation. Refer to the Sites' specific procedures for information.

Appendix A

Preparation of Setpoint and Scaling Documents

1.0 PURPOSE AND SCOPE

This Appendix provides instructions by which Engineering prepares setpoint and scaling information for other site organizations as issued and controlled design output, which is needed to fulfill the requirements of Reference 3.29, Section 9.5. This Appendix covers both safety and non-safety related instrumentation, including Time Delay Relays, and implements a portion of Reference 3.9.

2.0 DEFINITIONS

2.1 **Acceptable As Found - Component (A_{fc})** - The Acceptable As Found value (A_{fc}) is the same as the normal measurable accuracy (A_{nf}). These errors are associated with normal (non-accident) conditions. A_b is also included in A_{nf}. This value is used only when calibrating as individual components or partial loops. The units shall be consistent with the associated loop calibration instructions.

2.2 **Acceptable As Left - Component (A_{lc})** - Used when calibrating as individual components or a partial loop. The Acceptable As Left (A_{lc}) value is the component's A_b. The Units shall be consistent with the associated loop calibration instructions.

2.3 **Acceptable As Found - Loop (A_{fl})** - The Acceptable As Found value (A_{fl}) is the same as the normal measurable accuracy (A_{nf}). These errors are associated with normal (non-accident) conditions. The Acceptance Band (A_b) is also included in A_{nf}. This value is used only when calibrating as a loop. The units shall be consistent with the associated loop calibration instructions.

2.4 **Acceptable As Left - Loop (A_{ll})** - Used only when calibrating as a loop. The Acceptable as Left (A_{ll}) value is the square root of the sum of the squares of each component's A_{lc}. The units shall be consistent with the associated loop calibration instructions.

2.5 **Setpoint and Scaling Document (SSD)** - A design output document which identifies individual instrument setpoint and scaling requirements, required to support the intended design function of the instrumentation.

2.6 **Time Delay Relay** - An electrical or pneumatic device used to make or break a circuit after a desired amount of time has passed after an initiating signal.

2.7 KS - Per Reference 3.11, K represents a time variable and S represents a switch. These letters are combined here to represent a time delay relay. However where UNID numbers are assigned for time delay relays, the UNID number shall be used.

3.0 PROCEDURE FOR PREPARATION, REVISION, AND MAINTENANCE OF SSDs

3.1 Preparation of SSDs

3.1.1 Loop Number

Place the subject loop number in this section. Except for time delay relays as noted below, the loop number should contain the unit, sensor type, system ID, and the specific loop number. Example: A unit 1 loop measuring level (L) in the feedwater system (Sys. 3) with a specific loop number of 50 would be represented by 1-L-3-50.

For those time delay relays with no assigned UNID, the loop number should contain unit; "KS" for type; system ID; and "0" in order to place the SSD at the first of the system in the Controlled SSD Manuals; and sequence number, where the first SSDs done for any system would utilize sequence number 1, the next would utilize sequence number 2, and so on. Example: The first time delay relay SSDs done for system 70 on Unit 1 would have a loop number of 1-KS-70-0-1. For time delay relays with an assigned UNID, the loop number should contain the unit, Sensor type, System ID, and the specific loop number.

3.1.2 Loop Function

List all functions for the portion of the loop covered by the SSD. For those loops with some device(s) included in multiple calculations (TVA and/or Westinghouse Setpoint Methodology or Precaution, Limitation and Setpoint Document Calculations, the most stringent calculation requirements shall be applied in calibrating the device(s). These requirements shall be specified on the SSD and the source of the requirement if other than the referenced supporting calculation, shall be noted and referenced.

3.1.3 Quality Related Functions

The SSD should identify if any of the instruments are Quality Related by marking the QR "Yes" box.

3.1.4 Loop Accuracy Function

List each function associated with the loop and covered by the SSD on an individual line. Example: A loop has three associated functions: (1) Indication, (2) RPS input, and (3) Main Control Room (MCR) alarm. Each function should be placed on a different line.

3.1.5 Allowable Value - A_v (Loop)

This block should contain the calculated loop A_v developed from a supporting uncertainty calculation. This block is only applicable to safety related instrumentation. For non-safety related compliance instruments, the Technical Specification requirement should be used in place of AL and A_v calculated. This block should contain the calculated loop A_v for each function covered by the SSD developed from a supporting setpoint calculation. As to whether A_v should include static head (if applicable), each site should address this issue with respect to each Site's Technical Specification format. It should always be clearly identified if static head is included. A_v is not applicable unless the performance of a safety or Technical Specification function is involved.

For instrument loops that have existing Technical Specification A_v's, if the existing Technical Specification is shown to be conservative with respect to the calculated A_v, the existing Technical Specification should be retained. If the Technical Specification A_v is found to be non-conservative, then immediate and appropriate corrective action shall be taken. The A_v documented in the SSD shall never disagree with an issued Technical Specification A_v. The calculated A_v from the associated calculated should be provided in the Notes and Comments section and labeled for information use only. This will inform the plant that if the Technical Specification A_v is ever violated there may be extra margin to justify continued operation of the plant.

If the A_v applies to only a portion of the instrument loop (e.g., Westinghouse protection racks at SQNP or WBNP), the loop A_v shall be provided using a note. In this note, the Loop A_v shall be provided with instructions to the plant that if the partial loop A_v or A_{nf} is exceeded during the surveillance testing, the entire loop must be tested and verified using the calculated Loop A_v.

3.1.6 Acceptable As Found (Loop) - A_{f}

For quality-related instrument loops only, this block should contain the calculated loop A_{lf} for each function covered by the SSD from a supporting uncertainty calculation. This block is applicable to all instrumentation. For non-quality related instrument loops, A_{lf} is equal to the square root of the sum of the squares of each component's acceptable as found. This will be documented on the SSD Comments and Notes Form. "A_{lf}" should be presented as a plus or minus tolerance and all units shall be consistent with the associated loop calibration instructions.

3.1.7 Acceptable As Left (Loop) - A_{ll}

For quality-related instrument loops this block should contain the calculated loop "A_{ll}" from a supporting uncertainty calculation. For non-quality related instrument loops, acceptable as left is equal to the square root of the sum of the squares of each component's acceptable as left. This will be documented on the SSD Comments and Notes Form. "A_{ll}" should be presented as a plus or minus tolerance and all units shall be consistent with the associated loop calibration instructions.

3.1.8 Acceptable As Found (Component) - A_{fc}

This block should contain the calculated component A_{lf} from a supporting uncertainty calculation for quality-related loops. For non-quality related loops, component acceptable as found is equal to two times the manufacturer's reference accuracy for the component (allows for R_a and A_b) plus drift over the listed interval between calibrations (see 3.1.16). Drift may be obtained from manufacturer's literature or historical data. Sources of information and justification must be documented under references and on the SSD Comments and Note Sheet, respectively. "A_{fc}" should be presented as a plus or minus tolerance and all units shall be consistent with the associated loop calibration instructions.

3.1.9 Acceptable as Left (Component) - A_{lc}

For quality-related instrument loops this block should contain the component's A_L used in a supporting uncertainty calculation. For non-quality related loops, component acceptable as left is equal to the manufacturer's reference accuracy. The value and source of information must be documented under references and on the SSD Comments and Note Sheet, respectively. "A_{lc}" should be presented as a plus or minus tolerance and all units shall be consistent with the associated loop calibration instructions.

3.1.10 Loop Components

These blocks should contain all the components covered by the SSD. It is recommended that no more than three components be listed per sheet.

3.1.11 Process Range/Setpoint

This block should have the **process** range and setpoint where applicable. Supporting calculations, instrument tabs, and/or System Design Criteria should be used as source of references. This value should be the analytical process range and or setpoint (not the calibration value) so static head correction and hot calibration values should not be reflected in this value. Process units shall be used. The activation state for the process shall be shown (e.g., 50 psig INC).

3.1.12 Input Calibration Value

This block should have the input range end points required for calibration, or the setpoint, (as applicable) in units which are consistent with the associated calibration instructions. These values shall include any static head or bias values. Reset differential values for switches should also be addressed on the row directly below the actuation value (setpoint). These values should reflect the input values as they pertain to the component's transfer function (Refer to 3.1.22). The input calibration values shall include static heads if applicable (Refer to 3.1.18).

3.1.13 Output Calibration Value

This block should have the output range end points specified in the instrument's output units. To represent the actuation state for bistables with contact type output, use CL INCR for closure increasing, CL DECR for closure decreasing, open OP INCR for open increasing, or open OP DECR for open decreasing. For bistables with electronic type outputs, use ENG INCR for energized on increasing, ENG DECR for energized on decreasing, DENG INCR for de-energized on increasing, or DENG DECR for de-energized on decreasing, to define. Reset differential values for switches should also be addressed on the row directly below the actuation value.

3.1.14 Component Description

In the blocks under this section, list the instrument's manufacturer, model number, contract number which contains the instrument's specifications, and physical location (see Subsection 3.1.15). Also list the design range specified by the manufacturer. The calculation should be used as the source of this information.

3.1.15 Location

For each instrument, define the location by specifying elevation, and column lines or azimuth. Specify panel if applicable.

3.1.16 Calibration Frequency Requirements

This block shall reflect the calibration frequency used in a supporting calculation as the maximum interval between calibrations for quality-related instruments. The calibration interval should be coordinated with Instrument Maintenance for non-quality related instruments.

3.1.17 Calibration Equipment Accuracy Requirements

This block shall reflect the test equipment accuracy and any specific calibration equipment used in a supporting calculation for quality-related instruments. This block should list the specific calculation M&TE accuracy values defined for each component. These value should be defined using calibration units such as ICTe (Transmitter) = +/- 0.5 "WC. For non-quality related instruments, specify 1 to 1 with the manufacturer's reference accuracy. If a Digital Meter (DM) was used in the calculation to support no reading error, DM must be listed as a requirement in this section.

3.1.18 Static Head Value

For quality-related instrument loops, the static head value used to determine the process input values should be obtained from the applicable plant calibration Instructions (e.g., Surveillance Instructions (SI), Technical Instructions (TI), Instrument Maintenance Instructions, etc.) and then compared against a calculated value based upon approved design input. If the two values agree, then the calculated value shall be documented as design input in accordance with Ref. 3.6 and used as the source for the static head value. Use plant TI and/or SSD's if an SI does not exist. If the calculated value and the SI value differ, documented QA'd field verification will be required to resolve any differences.

Where the senseline configuration has yet to be installed, document the calculated value as design input in accordance with Ref. 3.6 and use it as the source for static head. ***Caution: Verify that the senselines, condensate pots, and transmitter location output drawings have well defined installation tolerances.***

For non-quality related loops, review As Designed (AD), As Constructed (AC), or Configuration Control (CCD) drawings as appropriate to determine elevations of the instrument, instrument taps, and/or condensate pot as required to compute static head value (where appropriate). Compute static head value based on elevations considered and the normal temperature for the application. Document the basis for the value on the SSD Comments And Note Sheet. Any instrument loop which can effect plant availability (e.g., can trip the plant) should be treated the same as quality related instruments.

3.1.19 Technical Specification

Define any technical specification requirements associated with the loop. To identify the requirements, list the specific technical specification section in which the requirement is found.

3.1.20 References

All references should have the revision level, where applicable.

3.1.21 Use of Westinghouse Methodology

This section is only applicable to SQNP and WBNP. The following methodology is from the appropriate Westinghouse Setpoint Methodology Document (WSMD) and must be used when determining A_V's and A_N's for any safety-related NSSS loops covered by the subject WSMD. Note that this A_V defined for the SSD is a rack allowable value, not a loop allowable. The rack allowable value must be defined under the loop section because this is also the Technical Specification value used to support periodic surveillance testing. A Loop A_V is not defined by the WSMD but has been defined below. The Loop A_V could be used to determine if the Analytical Limit had been exceeded. Use the comments and notes form to define the loop allowable value. The following error components are discussed in detail in the subject WSMD:

RD = Rack Drift
SD = Sensor Drift
RCA = Rack Calibration Accuracy
SCA = Sensor Calibration Accuracy
RMTE = Rack Measurement and Test Equipment Accuracy
SMTE = Sensor Measurement and Test Equipment Accuracy
RCSA = Rack Comparator Setting Accuracy
EA = Environmental Allowance
A = Statistically combined unmeasurables
S = Sensor's Acceptable as Found value
TA = Total Allowance (Instrument Accuracy Allowance in the Safety Analysis)
SL = Safety Analytical Limit from WSMD (convert to percent of span)
CSA = Channel Statistical Allowance

Caution: Convert all values to percent of span before applying these equations.

Definition of Acceptance as Found Values/Tolerances the Sensor and Rack Components for WSMD loops:

$$Anf(sensor) = S = SD + SCA + SMTE$$

$$Anf(rack) = R = RD + RCA + RMTE + RCSA$$

Technical Specification A_v for per WSMD:

$$Av\ (rack) = T_1 = RD + RCA + RMTE + RCSA$$

or the most restrictive or smallest value calculated for either T_1 or T_2 is used to define the Tech Spec A_v.

$$Av\ (rack) = T_2 = TA - \sqrt{A + S^2} - EA$$

Where:

$$TA = |SL - Trip\ Setpoint|$$

$$A = PMA^2 + PEA^2 + SPE^2 + STE^2 + RTE^2$$

Calculated Loop A_v:

$$Av_{LOOP} = SL - (CSA - \sqrt{R^2 + S^2}) \quad \textit{Increasing Setpoint}$$

$$Av_{LOOP} = SL + (CSA - \sqrt{R^2 + S^2}) \quad \textit{Decreasing Setpoint}$$

3.1.22 Transfer Functions

List the transfer function showing the input/output relationship. Sufficient information should be available to generate a 5-point calibration procedure.

Example: For a transmitter calibrated 139-27" H_20 of differential pressure to obtain a 10-50 mA output, the transfer function would be as follows:

$$Output\ (mA) = \frac{40mA * (139\ H_2O - Input\ (H_2O))}{112\ H_2O} + 10mA \pm 0.2mA$$

3.1.23 Loop Diagrams

Since the standard for Loop Diagrams has not been issued, SSDs can be issued without loop diagrams.

3.1.24 Comments and Notes

The comments and notes form is to be used if sufficient room on the SSD form is not available.

part of BFN TS-447 RAI Enclosure 3

Appendix A

Preparation of Setpoint and Scaling Documents

SETPOINT AND SCALING DOCUMENT FORM

Loop ID ____________
Sheet ______ c/o ______

Setpoint And Scaling Document						
Loop Number			Quality-Related? Yes ☐ No ☐ Safety-Related? Yes ☐ No ☐			
Loop Function						
Loop Accuracy Function			Allowable Value	Acceptable As Found		Acceptable As Left
Loop Components No.	UNID No.	Process Range/Setpoint	Calibration Value Input	Output	Acceptable As Found	Acceptable As Left
Component Description No.	Manufacturer / Model Number				Original Contract No.	Location

Additional Calibration Requirements:

Calibration Frequency Requirements:

Calibration Equipment Accuracy Requirements:

Static Head Value;
Technical Specifications/TRM/ODCM Sections Applicable: ____________

References:

No.		No.	

Prepared ____________ Date ______ Checked ____________ Date ______
Systems Engineering Concurrence ____________ Date ______

SSD TRANSFER FUNCTIONS FORM

Loop ID ______________
Sheet ______ c/o ______

TRANSFER FUNCTIONS			
Component No. ________			
Component No. ________			
Component No. ________			
Component No. ________			
Component No. ________			
Prepared ____________	Date ________	Checked ____________	Date ____________

SSD LOOP DIAGRAM FORM

Loop ID ____________
Sheet ______ c/o ______

Loop Diagram
Prepared __________ Date ________ Checked __________ Date __________

SSD COMMENTS AND NOTES FORM

Loop ID ______________
Sheet _____ c/o _____

Comments and Notes
Prepared ____________ Date ________ Checked ____________ Date ____________

SSD ANALYSIS FORM

Loop ID ________________
Sheet ______ c/o _____

Analysis
Prepared _______________ Date _________ Checked ____________ Date _______________

Appendix B

Determination of Statistical Outliers

There are several methods that can be used to determine if outlying data points are statistically invalid and should not be used to prevent these points from skewing your statistical analysis. Two methods will be discussed here but note there are other acceptable methods as long as they are justified in the calculation. As you have chosen a specific probability and confidence level in your statistical analysis, the same must be done when evaluating outliers. The two statistical approaches that will be discussed here are the T-Test and the Maximum Normal Residual (MNR) method.

It should be emphasized that the evaluation of outliers is a one time only evaluation, not an iterative evaluation. The threshold for throwing out outliers should be determined once using all the data.

T-Test

To determine outliers, the T-Test can be used. The extreme studentized deviate is calculated as follows:

If: $T = \frac{x_s - x}{s} > CV_{n/95\%}$ then Xs is an outlier

where:

T = the extreme studentized deviate for comparison to Table B.1 on the next page

x_s = the extreme observation

x = the sample group mean

s = the standard deviation of the sample group mean

CV = the critical value for a t-distribution (see Table B.1) for n degrees of freedom at X% probability

n = degrees of freedom for analysis. It should be noted that the degrees of freedom are dependent on the analysis being performed (e.g., Given 4 devices calibrated 10 times each, the degree of freedom for predicting future operation of these specific S/N devices is 39 (40 - 1). The degree of freedom for predicting future operation of this type of device (general device population with same manufacturer and model number) is 3 (4 - 1)

Caution: If a suspected outlier deviates by a large magnitude from the rest of the samples, the classical T-test can fail to identify the outlier as an invalid sample. This results because one subtracts a mean which has moved toward the outlier and because one divides by a standard deviation which has exploded in magnitude. If the deviation is large (engineering judgment is required to make a decision as to what is large with respect to the specific application), the median (middle point) value should be used in place of the mean, the standard deviation recalculated based upon the median value, and the T-test should be recalculated. To determine if the T-test is valid, the mean and median values should not deviate significantly.

f T exceeds the critical value for a t-distribution given in Table B.1 at the desired significance level for example, the extreme observation is considered to be an outlier. Once the outlier is identified it is removed from the data set. Removal of outliers should be done with care so as not to remove valid data points. See Reference 3.15, Section 16, for additional information concerning the T-test.

Critical Values (CV) of t

Probability Levels

Samples	80%	90%	95%	98%	99%	Degrees of Freedom (n)
2	3.078	6.314	12.706	31.821	63.657	1
3	1.886	2.920	4.303	6.965	9.925	2
4	1.638	2.353	3.182	4.541	5.841	3
5	1.533	2.132	2.776	3.747	4.604	4
6	1.476	2.015	2.571	3.365	4.032	5
7	1.440	1.943	2.447	3.143	3.707	6
8	1.415	1.895	2.365	2.998	3.499	7
9	1.397	1.860	2.306	2.896	3.355	8
10	1.383	1.833	2.262	2.821	3.250	9
11	1.372	1.812	2.228	2.764	3.169	10
12	1.363	1.796	2.201	2.718	3.106	11
13	1.356	1.782	2.179	2.681	3.055	12
14	1.350	1.771	2.160	2.650	3.012	13
15	1.345	1.761	2.145	2.624	2.977	14
16	1.341	1.753	2.131	2.602	2.947	15
17	1.337	1.746	2.120	2.583	2.921	16
18	1.333	1.740	2.110	2.567	2.898	17
19	1.330	1.734	2.101	2.552	2.878	18
20	1.328	1.729	2.093	2.539	2.861	19
21	1.325	1.725	2.086	2.528	2.845	20
22	1.323	1.721	2.080	2.518	2.831	21
23	1.321	1.717	2.074	2.508	2.819	22
24	1.319	1.714	2.069	2.500	2.807	23
25	1.318	1.711	2.064	2.492	2.797	24
26	1.316	1.708	2.060	2.485	2.787	25
27	1.315	1.706	2.056	2.479	2.779	26
28	1.314	1.703	2.052	2.473	2.771	27
29	1.313	1.701	2.048	2.467	2.763	28
30	1.311	1.699	2.045	2.462	2.756	29
inf.	1.282	1.645	1.960	2.326	2.576	inf.

Table B.1 - ***All values from this table are from Reference 3.15, Table A.4***

Appendix B

Determination of Statistical Outliers

MNR Method

Another test that may be used is the Maximum Normal Residual (MNR) method. The MNR table below provides the criterion for the evaluation of various sample sizes at 95% and 99% confidence levels. In order to determine if the outlier is an extreme observation that can be thrown out, the method of evaluating the suspect data point(s) is to first calculate the criterion value (equations are listed in Table B.2) based upon the sample size[1], and then compare it to the value in the appropriate significance column. If the calculated criterion value is larger than the significance factor, it can be concluded that the data point is extreme and can be dropped from further evaluations. The test of a second suspect data point should be performed based upon the reduced number of samples. For additional information, refer to reference 3.17, Section 15.

To solve for a criterion value, the uncertainty value for each sample must be placed in either an ascending or descending order which is based upon the outlier's sign convention. The criterion variables are define according:

X_n = the outlier's uncertainty
X_{n-1} = the uncertainty value one place from the outlier
X_{n-2} = the uncertainty value two places from the outlier
X_1 = the furthest most uncertainty form the outlier
X_2 = the next to the furthest most uncertainty form the outlier

Maximum Nominal Residual Table

Samples n	Confidence Level 95%	99%	Criterion Value (CV)
3	.941	.988	$\frac{X_n - X_{n-1}}{X_n - X_1}$
4	.765	.889	
5	.642	.780	
6	.560	.698	
7	.507	.637	
8	.554	.683	$\frac{X_n - X_{n-1}}{X_n - X_2}$
9	.512	.635	
10	.477	.597	
11	.576	.679	$\frac{X_n - X_{n-2}}{X_n - X_2}$
12	.546	.642	
13	.521	.615	
14	.546	.641	$\frac{X_n - X_{n-2}}{X_n - X_1}$
15	.525	.616	
17	.490	.577	
20	.450	.535	
25	.406	.489	

Table B.2 - *All values from this table are from Reference 3.17, Table A16*

Footnote 1 - See discussion of sample size and degree of freedom (S-1). They are dependent upon the analysis objectives.

Appendix C

Compliance Instrumentation

This appendix provides guidelines that a Plant can use to address it's requirement to address instrumentation accuracy for Technical Specification Compliance Instrumentation. Compliance Instrumentation is used to ensure that normal plant operation is within the initial conditions assumed in the plant's Design Basis Event Analysis. The Compliance Calculation Program verifies that the instrumentation being used has both adequate accuracy and appropriate range. This Appendix will discuss how to develop and implement a Compliance Program. The methods discussed here are not the only methods that can be used in developing a program but are being provided as guidance to reduce work scope and costs.

Developing a Compliance Instrument List

The first step in the implementation of a Compliance Calculation Program, is to define what plant parameters are required to be monitored per the Plant Technical Specification. Other documents may contain additional licensing requirements such as the Technical Requirement Manual and the Offsite Dose Calculation Manual. A review of all of these documents should be performed and a listing made of each plant parameter with the associated surveillance requirement number and the value to be verified. Once a listing of the parameters that require verification has been established, the Tech Spec values can be evaluated to determine if they are the actual analysis limits, if the instrument uncertainties have already been accounted for in the analysis, or if instrument uncertainties are not a factor in the verification of the Compliance parameter. Concurrent with the evaluation of the limits, the actual instrument loops being used to verify the plant parameters can be identified by reviewing plant procedures.

Plant Procedure Road Map

To determine what instrumentation is being used for Tech Spec verification and if instrument uncertainty is a factor, it is necessary to review the plant's implementing instruction or procedure (SI's , TI's, etc.). Each plant maintains a procedure that documents what procedures fulfill or implement each Tech Spec requirement. This road map procedure can be used to get you to the appropriate implementing procedures. The plant may also maintain a Compliance Instrument List procedure which list the specific Compliance Instruments by systems and lists the associated implementing procedure/s. The Compliance Instrument list is a very useful tool for moving around within the plant procedure system.

Reducing Work Scope

Significant time and cost savings can be realized if the Compliance Calculation Program is scoped properly on the front end of the project. Three very important questions should be addressed for each Compliance parameter.

First Question: Is instrument accuracy a factor in the verification or determination of a Compliance parameter? If accuracy is not a factor then calculations and NESSDs are not required per Reference 3.9. Some examples where accuracy is not a factor is as follows:

Channel Checks

As defined in the Technical Specification's definition section, a Channel Check (a comparison of redundant indications) is a qualitative check not a quantitative one, so a precision calculation to quantify specific uncertainties is not required. The Channel Check is to identify the occurrence of gross type failures.

Appendix C

Compliance Instrumentation

Gross Performance Checks

Some tests such as check valve integrity look for indications of gross failures/degradations where normal instrumentation uncertainty is small with respect to an acceptance criteria based upon gross failure. For the example of check valve integrity, the test may monitor pressure on the upstream side of the check valve while varying the downstream side pressure to see if any pressure changes occur. This is a gross performance check which would not require calculations and NESSDs. If the test were monitoring to verify an actual leakage flowrate, then instrument uncertainty could be a factor in the test and calculations and NESSDs would be required.

Insignificant Inputs of Calculated Compliance Parameters

Some Compliance parameters are not directly measured but are calculated based upon multiple inputs. When the uncertainty of one of the inputs is significantly larger than the other inputs, the smaller uncertainties of these inputs can become insignificant when combined with the large uncertainty using SRSS methodology. An example of this is a Liquid Effluent Radiation Monitor isolation setpoint which is based upon the Radiation Monitor uncertainty (±50%), Cooling Tower Blowdown flow (±5000 gpm), and Steam Generator Blowdown flow (±20 gpm). When combined using the Release Rate Equation in the ODCM and evaluating the effects of the ±20 gpm of uncertainty with respects to the other uncertainties, the Steam Generator Blowdown flow uncertainty of ±20 gpm is insignificant.

Second Question: Is the compliance instrument a permanent plant instrument or is it a test instrument? If the instrument/s used in the plant implementing procedure are not permanent plant instruments such as test instruments, then NESSDs are not required per Reference 3.9. An example of this is where for ASME Section XI Pump Performance Testing, test instruments are temporarily hooked up to take measurements. The Section XI program is responsible for instrument uncertainties of their test instruments. On the other hand if permanent instruments are used for ASME Section XI testing then calculations and NESSDs would be required.

Third Question: Can the instrument be calibrated? If the instrument can not be calibrated, then there is no need for a NESSD to define calibration requirements. There may be a need for a demonstrated accuracy calculation and periodic test requirements. An example of this is the WBN Diesel Generator Air Start pressure gauges which are used to verify that air start pressure is greater than 200 psig. The pressure gauges are not adjustable but have an accuracy requirement of ±10 psig. Since the gauges can not be calibrated, they must be replaced if found outside of the required accuracy during the periodic surveillance checks. For some cases, the associated System Description Document may be a more appropriate NE output document then a NESSD for testing requirements.

Implementation of Instrument Uncertainties into Technical Specifications

This next section addresses how to best implement calculated instrument uncertainties into the Tech Spec Compliance Program.

Tech Spec versus Surveillance Instruction Control

There are two possible methods of implementing instrument uncertainties into Tech Spec Compliance program. One is to actually include the instrument uncertainties into the Tech Spec limit. This would require a Tech Spec limit change to include the uncertainties along with Surveillance Instruction changes, possible FSAR changes, etc. The Tech Spec Limit would also become a hardware dependent number meaning that if a device in the compliance instrument loop was replaced with a less accurate device, the Tech Spec limit would require changing. An additional allowance could be added along with the uncertainties to cover this, but this would reduce plant operating margin needlessly. The other method of implementing instrument uncertainties is to back off the Tech Spec limit by the calculated uncertainties in the Surveillance Instruction performing the Tech Spec compliance function. This would not require a Tech Spec change and would allow the instrument uncertainties to be controlled by the Surveillance Instruction. Now if a device in the compliance instrument loop was changed out with one that is less accurate, only the SI would be effected and an additional hardware allowance would not be required. This provides the plant with the flexibility for change through the normal design change process without a NRC Tech Spec submittal and provides the plant with maximum operating margin.

Calculated Compliance Limits

Once the instrument uncertainties have been calculated and Tech Spec limit has been adjusted to include these uncertainties, this new limit must be defined in an NESSD. This new calculated compliance limit will be defined as the Tech Spec Operability Limit. See Appendix A for the Compliance NESSD form. The following equations are to be used to establish Tech Spec Operability Limits.

$$OP_{limit} = \textit{Tech Spec Limit} - LAn \ \textit{(Increasing direction)}$$

$$OP_{limit} = \textit{Tech Spec Limit} + LAn \ \textit{(Decreasing direction)}$$

Some Compliance limits can not be directly verified but must be calculated using multiple instrument loops as input such as Secondary Calorimetric or RCS Identified Leakage calculations. For this type of instrument loops, the combined effect of all of the loop uncertainties must be calculated to address the Tech Spec Compliance Limit. The individual instrument loop NESSDs should represent the Tech Spec Operability Limit as a tolerance such as ±1% of span. It is the recommendation of this TI that the Normal Measurable As Found (Anf) tolerance be used for this limit. The overall Tech Spec Operability Limit with the combined loop instrument uncertainties should also be defined in a NESSD note associated with the Tech Spec Operability Limit. System Description/Design Criteria documents or other appropriate output documents may be used to document the overall Tech Spec Operability Limit.

Allowable Value (Av) for Compliance Loops

The calculation of an Allowable Value for a Compliance loop is no different than a Safety Related loop. See section 4.6 of this TI for appropriate equations. Indicators are normally used for Tech Spec Compliance verification at a specific point (ie., Level = 370,000 gallons), so the Av can be calculated for the specific point of interest similar to a setpoint's Av. A NESSD note should be used to define the Av in order to provide needed clarification. The following is an example of how this note should read.

Note: For indicator loop, an input of 371,400 gallons (X inches of water at the transmitter), the indicator must read greater than or equal to 370,400 gallons.

For this example the AL = 370,00 gallons, Av = 370,400 gallons, and OP_{limit} = 371,400 gallons.

Alarm Setpoints

When establishing a Tech Spec Operability Limit at a different value from the Tech Spec Compliance Limit, an evaluation should be performed to determine if any associated alarm setpoints are impacted. Many Tech Spec Compliance limits have associated alarm setpoints that are to alert the Operator that a Tech Spec parameter is approaching its Tech Spec Limit. These setpoints are normally close to the Tech Spec Limit and could be impacted when a Tech Spec Operability Limit is established to include instrument uncertainties. What is meant by being impacted is that the alarm setpoint should actuate before exceeding the Tech Spec Operability Limit, not the Tech Spec Compliance Limit. If alarm setpoint/s require changing, interface with Operations on where to establish the new setpoint/s. Instrument uncertainties should not be a determining factor when establishing new alarm setpoints because:

1) Including uncertainties on top of the new Tech Spec Operability Limit would probably result in nuisance alarms.

2) The Tech Spec Compliance verification is normally performed by periodically verifying an indicator, and the alarm is an Operator aid to provide an early warning so there are no requirements to address instrument uncertainties for alarm setpoints. The probability of indicator/bistable interaction is low based upon the following:

   a) The Tech Spec Operability Limit is normally established using the Indicator's loop uncertainty (LAn_i).
   b) The alarm bistable is normally part of the indicator loop thus having the same sensor and process uncertainties.
   c) The bistable's uncertainty is normally less than or equal to the indicator's uncertainty due to no reading uncertainties and greater calibration precision.
   d) An Operator response allowance is normally included between the Tech Spec Operability Limit and the alarm setpoint.

Calculations in NESSDs

Based on the References 3.32 and 3.33, the uncertainty calculations for Compliance instruments may be performed and documented in the body of the NESSD, with the computations on the NESSD Analysis form, rather than in a separately issued calculation. These NESSDs, including the analysis, shall be in accordance with the requirements of References 3.8 and 3.19 except for format. Design verification shall be in accordance with Reference 3.18; however, the requirements of this TI are more limiting than Reference 3.18 in that the Design Verifier is required to be the checker and the Design Verification Method is required to be "Design Review". One block of the Comments and Notes Form shall be headed "Calculation Design Verification (Independent Review)." This block will state that the method of Design Verification was Design Review, shall list appropriate comments about the review, and shall be signed and dated above a Design Verifier/Date line.

Specifics for the approach for Acceptable As Found, Acceptable As Left, Allowable Value, Normal Loop Accuracy, Calibration Frequency Requirements, Calibration Equipment Accuracy Requirements, CTS, and Unverified Assumptions are described below.

Acceptable As Found for loop and for component and Acceptable As Left for loop and component are as described in this TI for safety-related loops except that the values are based on the analysis in the NESSD rather than a separate calculation.

Allowable value for Compliance instruments shall be computed as described in this TI with the exception that margin may be based on a limit established by analysis of a condition less severe than Design Basis Event mitigation.

Normal loop accuracy (An) shall also be computed for these loops and recorded on the Analysis form. If the required accuracy or limit is not supplied by the Design Engineering organization which is responsible for the system of which the loop is a part such as Nuclear, Mechanical, or Electrical, then the Responsible Design

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Compliance Instrumentation

Nuclear, Mechanical, or Electrical Engineer shall sign on the Analysis form to indicate that the loop accuracy is acceptable.

The Calibration Frequency requirements and Calibration Equipment Accuracy requirements are as described in this TI for safety-related instrument loops, except that they are based on the analysis in the NESSDs rather than a separately issued calculation.

The minimum CTS requirements of Reference 3.19, shall be met. The NESSD number (Instrument Loop Number) shall be the Calculation Branch/Project Identifier number on the CTS form. The Calculation title shall be entered on the CTS form as "NESSD For Loop X" with the appropriate loop number substituted for "X". The DCN issuing the NESSD as well as any Requirements Calculation, where applicable, shall be listed on the CTS form as predecessors. If setpoint or scaling are established or verified, the Instrument Tabulation shall be listed as a successor. The RIMS number of the DCN which issued the NESSD shall be entered on the CTS form as the RIMS number of the calculation. When the DCN is field complete and the NESSDs are RIMSed and issued as stand alone documents, a copy of the distributing memorandum (but not a copy of the NESSDS) showing the RIMS number of each NESSD shall be sent to Calculation Library, with a note on the distribution memorandum stating, "Please update the CTS RIMS number on the listed NESSDs as shown." The NESSDs will not be controlled by the Calculation Library, but through DCRM which will maintain and distribute controlled copies of the NESSDs. Therefore, the Calculation Library will not need copies of the NESSDs to input the CTS data.

Neither unverified assumptions nor special or limiting conditions are permitted in the NESSDs/Analyses following this process. If unverified assumptions or special or limiting conditions are necessary, follow the process for safety-related NESSDs.

All NESSDs must be in accordance with Reference 3.18 except as noted by this section.

Performing Compliance Calculations

When performing uncertainty calculations for compliance instrumentation, a calculation should be produced to document the instrumentation's acceptability with respect to ensuring the maintenance of the initial conditions of the plant's Design Basis Event Analysis. Since compliance instrumentation is used only during normal plant operations, the calculation can exclude certain uncertainty parameters such as harsh environmental effects and seismic effects. Parameters which typically need to be addressed are:

- Reference Accuracy
- Drift
- Normal Temperature Effect
- M&TE Accuracy
- Acceptance Band
- Reading Error
- Normal Waterleg error (WL_e) and Process error ($PRCS_e$) if applicable

Several parameters could be eliminated or reduced if the plant performed the following activities:

Reference Accuracy

Reference Accuracy could be reduced to the Repeatability error if the device is used at only one point within its range and the accuracy verified at that specific point and exercising in only the direction of interest. This would eliminate any hysteresis effects.

Appendix C

Compliance Instrumentation

Drift

If the instrument is calibrated immediately before use, drift can be eliminated. Also see the "Calibration Data Analysis" section of this Appendix C for additional methods of reducing/eliminatingdrift effects.

Normal Temperature Effect

The normal temperature effect can be reduced by reducing the analyzed temperature deviation from the temperature at calibration. Since Safety-Related calculations take a conservative approach in the definition of this temperature deviation, a more realistic approach could be used. Presently the temperature delta is calculated as the difference between the high and low abnormal temperatures from the environmental drawings. Since the abnormal conditions are only present a small percentage of the time, using the normal highs and lows would provide more realistic results. A further reduction could be achieved by obtaining the actual temperature for the previous and present calibration temperatures. From the actual temperatures, an additional reduction or elimination could be achieved.

M&TE Accuracy

Analyze the actual calibration M&TE used.

Reading Error

Reading uncertainties can be eliminated by using a digital output reading device with proper resolution. Indicator color banding is a another approach which could be used for eliminating Reading uncertainties. Tech Spec Compliance indicators are normally color banded to accent the Tech Spec Operability limits. If the indicator is color banded, the Tech Spec Operability limit is actually on a indicator tick mark (the color band edge), so that the Operator does not have any reading uncertainties. The operability determination question is not what is the actual value but is the indicator needle above or below the color band edge or Tech Spec Operability limit.

Required Confidence Level for Compliance Calculations

When performing uncertainty calculations for Compliance instruments, the goal of the calculation is to obtain a realistic, normal operation uncertainty value for the instruments. The calculation should not be overly conservative because conservatism takes away usable operating margin from the plant. On the other hand, the calculation should not be under conservative or the Compliance instrument could be found outside it's Allowable Value, meaning the plant could have been operating outside its design basis analysis. What is desired is a value that is realistically bounding but not overly conservative. To require a 95%/95% tolerance limit calculation for Compliance, would result in a very conservative analysis. To define a lower tolerance limit such as 95%/75% would really have no usable meaning except to define a smaller multiplier when performing a statistical analysis calculation which is still adding in additional conservatism. Instead of performing a 95%/95% analysis, the calculation should be performed to achieve realistic results. The normal vendor specification values should still be used and applicable process errors should be factored in but there are areas where more realistic approach is justifiable and several are defined in the following sections.

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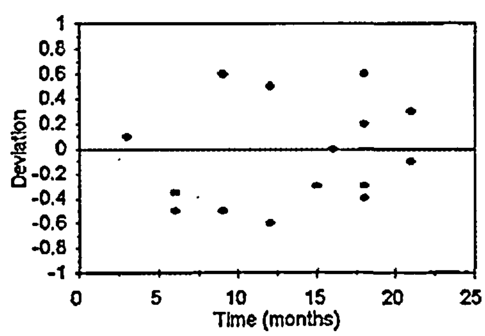
Compliance Instrumentation

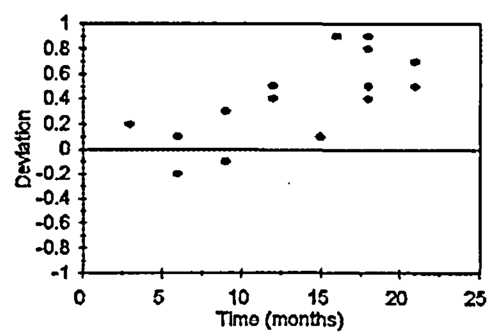
Calibration Data Analysis

Time Dependency

A statistical analysis of calibration data should be examined using a spreadsheet and plotting the data with "Time" on the X-axis and "Deviation from Previous As Left" on the Y-axis. From the graph, the viewer can determine if there appears to be a time dependency relationship. Does the "Deviation from Previous As Left" data increase in the negative or positive direction thus indicating time dependent drift? Is the data scattered with smaller deviations corresponding to larger time intervals thus indicating not a time dependency, but more representative of a repeatability phenomena?



A Non Time Dependent Phenomena



Time Dependent Phenomena

How to Determine a Realistic Number from the Calibration Data

Instead of performing the standard statistical analysis (calculation of mean and standard deviation values) and applying a tolerance limit multiplier, the following are possible alternatives:

Note: The following recommended methods require a large sampling of the population of interest, meaning a minimum of 10 to 15 samples from calibration data of the actual instruments being analyzed.

Examine the graph of Time versus Deviation and select a value which bounds all or a majority of the samples. This number could be used as a bounding value and algebraically summed with the other devices uncertainties. If your analysis has a large number of samples, then a pattern may be developed in which an argument can be made to justify using SRSS methodology to combine the uncertainties.

Example: If a majority of the samples fall within ±0.5% with a few samples scattered between -0.75% to -1.25% and +0.75% to +1.25%, a possible combination method would be to algebraically sum the ±0.5% and SRSS the ±0.75%. This would result in a more realistic value than algebraically summing the entire ±1.25%.

The bottom line is to use a large sample size to establish a good representation, and determine a realistic drift value in which you have a high level confidence.

Appendix D

Considerations for Digital Processing

In channels using digital signal processing equipment, uncertainties are introduced by hardware for conversions between analog and digital domains and by the algorithms for digital arithmetic operations. Values for Analog to Digital (A/D) and Digital to Analog (D/A) conversion uncertainties may be obtained from the device's manufacturer or through testing. Sources of uncertainty may include: precision of computation, rounding or truncation uncertainties, process variable changes during the deadband between data acquisition sampling scans, and inaccuracies of algorithms for transcendental functions or empirical curve fitting. The nature of the uncertainties contributed by the software (that is whether they are statistical or algebraic) must be identified by the software designer. When the uncertainties are characterized and quantified, they can be combined by using propagation methods.

This section presents a discussion on digital signal processing and the uncertainties involved with respect to determining instrument channel setpoints for a digital system. The analog signal is received by the digital processor, filtered, digitized, manipulated, converted back into analog form, filtered again, and sent out. The digital processor is treated as a black box; therefore the discussion that follows is applicable to many different types of digital processors. The digital processor is programmed to run a controlled algorithm. Basic functions performed are addition, subtraction, multiplication and division as well as data storage. The digital processor is the most likely component to introduce rounding and truncation errors.

The analog input signal should first be processed by a filter to reduce aliasing noise introduced by signal frequencies that are high relative to the sampling rate. The filtered signal is sampled at a fixed rate and the amplitude of the signal held long enough to permit conversion to a digital word. The digital words are manipulated by the processor based on the controlled algorithm. The manipulated digital words are converted back to analog form, and the analog output signal is smoothed by a reconstruction filter to remove high frequency components.

Several factors affect the quality of the representation of analog signals by digitized signals. The sampling rate affects aliasing noise, the sampling pulse width affects analog reconstruction noise, the sampling stability affects jitter noise, and the digitizing accuracy affects the quantization noise.

1.0 Sampling Rate Uncertainty

If the digital sampling rate is higher than twice the highest frequency of the analog signal, then the sampled signal is a good representation of the analog input signal and contains all the significant information. If the analog signal contains frequencies which are too high with respect to the sampling rate, aliasing uncertainty will be introduced. Anti-aliasing bandlimiting filters can be used to minimize the aliasing uncertainty or else it should be accounted for in setpoint calculations.

2.0 Signal Reconstruction Uncertainty

Some information is lost when the digitized signal is sampled and held for conversion back to analog form after digital manipulation. This uncertainty is typically linear and about ± ½ LSB (Least Significant Bit).

3.0 Jitter Uncertainty

The samples of the input signal are taken at periodic intervals. If the sampling periods are not stable, an uncertainty corresponding to the rate of change of the sampled signal will be introduced. The jitter uncertainty is insignificant if the clock is crystal controlled, which it is in the majority of cases.

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Considerations for Digital Processing

4.0 Digitizing Uncertainty

When the input signal is sampled, a digital word is generated that represents the amplitude of the signal at that time. The signal voltage must be divided into a finite number of levels which can be defined by a digital word "n" bits long. This word will describe 2^n different voltage steps. The signal levels between these steps will go undetected. The digitizing uncertainty (also known as the quantizing uncertainty) can be expressed in terms of the total mean square error voltage between the exact and the quantized samples of the signal. An inherent digitizing uncertainty of ± ½ LSB typically exists. The higher the number of bits in the conversion process, the smaller the digitizing uncertainty is.

5.0 Miscellaneous Uncertainties

Analog to digital converters also introduce offset uncertainty, e.g. the first transition may not occur at exactly ± ½ LSB. Gain uncertainty is introduced when the difference between the values at which the first transition and the last transition occurs is not equal. Linearity uncertainty is introduced when the difference between the transition values are not all equal.

For digital to analog conversion, the maximum linearity uncertainty occurs at full scale when all bits are in saturation. The linearity determines the relative accuracy of the converters. Deviations from linearity once the converters are calibrated is absolute uncertainty. Power supply effects may also be considered for unregulated power supplies.

6.0 Truncation and Rounding Uncertainties

The effect of truncation or rounding depends on whether fixed point or floating point arithmetic is used and how negative numbers are represented and should be considered as a possible uncertainty.

Appendix E

ASME Section 11 Uncertainty Calculations

1.0 PURPOSE:

ASME section 11 testing related uncertainty calculations are a special class of uncertainty determination separate from the TI-28 based Normal, Seismic, Accident calculations. The basis for the ASME uncertainty calculation is to determine the best uncertainty of the device under known controlled conditions while the basis of the TI-28 formal uncertainty calculation is to calculate a bounding worst case uncertainty that encompasses the worst case conditions of environment, power, and process conditions. The TI-28 calculation is therefore conservative as compared to the ASME test requirements and would result in excessive conservatism and potential inoperable equipment determinations if utilized. This appendix will discuss the methods of evaluating instrumentation for determining it's uncertainty under known controlled conditions for determination of ASME section 11 inaccuracies. As an example, the ASME testing performed to verify pump operability at the SQNP by flow measurement will be discussed.

2.0 SCOPE:

This instruction is applicable to all calculations related to special testing and ASME equipment functional testing where the operating conditions are known and controlled.

3.0 REFERENCE:

3.1 SQNP calculation for Auxiliary feedwater pump operability determination SQN-CSS-021 (B25880429331).

3.2 Flow Measurement Engineering Handbook, R.W.Miller, McGraw Hill 1983

4.0 GENERAL:

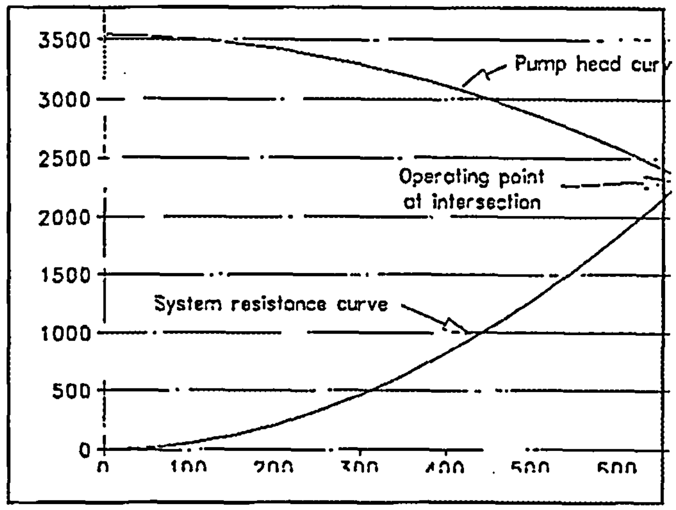
When evaluating a test performed for ASME section 11, the instrumentation must be examined for determination of acceptability related to uncertainty. Most ASME tests utilize testing at low power and flow conditions to draw a conclusion of acceptable operation at full power/flow conditions. Because of this method most insitu instrumentation will be operating in the low end of their calibration which is not desirable especially for flow instrumentation. Also at low power and flow conditions, the process conditions and sensing technique can contribute large errors.

Review of the sensing technique is essential as in the use of flow sensors (e.g., pitot tubes or restricting orifices) which have different errors associated with them (Refer to Reference 3.2). Also important is instrumentation historical performance (calibration history).

In general after review of the instrumentation sensing technique and instrument historical performance (See appendix K), the resulting instrument uncertainties can be combined with the system flow resistance curves and pump curves to yield corrected (derated) curves (or other process curve depending on particular test of interest). The system process curves represent the relationship between the measured parameters such as flow, pressure drop, etc.. so that they can be converted to like units and combined. For this example, the intersection of the system piping resistance curve with the pump head curve for a given pump speed yields the operating point of the system. It indicates the flow at rated conditions which in this case is the parameter of interest which must be shown to be above some minimum value to prove system operability or determine system degradation.

5.0 REQUIRED INPUT DATA:

The following information is required to make a determination of instrument and system acceptability:



- Descriptive test method (SI, SOI, etc.)
- Test instrument calibration records
- Process sensing techniques also specific process information requirements, the example requires:

- Pump head
- System resistance curves
- Minimum system flow limit

6.0 TECHNICAL INSTRUCTIONS:

The example discussed here is the evaluation of the acceptability of the auxiliary feedwater pumps at SQNP. The test measures pump discharge pressure and flow during 50 GPM recirculation flow conditions. Based upon pump head curves and system piping resistance curves, it is to be determined if the pump could produce the required flow at full power. The two measured parameters are flow and pump head. These two parameters cannot be directly combined since they represent different parameters. The pump head curve shows the relationship between the pump head and flow and is used to convert the measurements to common units of flow.

The evaluation of inaccuracy is a multi step process consisting of:

1) Review the test procedures and determine the instruments to be used in performing the testing.

2) Determine the instrumentation range and transfer functions

3) Determine the process sensing technique and associated uncertainties at operating test conditions

4) Collect instrumentation calibration records and determine the devices past inaccuracies by statistical reduction of as-found minus as-left device settings. This statistical reduction should also determine if there is a time relationship of inaccuracy versus calibration interval. As a less accurate measure of inaccuracy, the device's vendor ratings can be utilized taking into account all variables of power supply voltage, temperature, vibration, ... etc. but this will be too conservative in most cases.

After evaluating the above information and documenting the device inaccuracies, the system process curves must be evaluated to determine how to combine the individual instrument inaccuracies into a single system inaccuracy term. For the example, the pump curve is a plot of pump flow versus the head developed by the pump at a given speed. This curve can be used to convert the measured DP measurement inaccuracies into Dflow inaccuracies at the measured pressure and speed conditions.

Starting with the general equation of flow as a function of pressure:

$$flow|_{pressure} = f(p)$$

Where p is the nominal setpoint and p_e is the error about the nominal pressure. Then the flow error for a corresponding pressure error at a particular pressure is:

$$\Delta flow = \frac{f(p + p_{error}) - f(p - p_{error})}{2}$$

This flow error can now be directly combined with the flow measurement error by either the SRSS method or ALGEBRAIC addition to yield an equivalent total flow error at each pressure of interest. These calculated values are then subtracted and added to the ideal pump curves to yield a corrected pump curve representing the uncertainty of the instrumentation and testing techniques. If the device inaccuracies are based upon the actual tested calibration of the device, the inaccuracy is a known bias and should be algebraically added to the other errors. If the inaccuracy is based on past calibration histories and the data shows a normal and random distribution, the inaccuracies then can be combined via the SRSS method.

The same type of analysis can be performed on the flow and pressure readings related to the system pipe resistance curve. This would result in a corrected system resistance curve. These corrected curves can then be provided to the system engineer for determination of equipment acceptability.

Appendix F

Flow Loop Uncertainties

This appendix is applicable specifically to differential pressure flow measurement devices, primarily restrictive types (e.g., orifice plate measurements). Heated reference, ultrasonic, magnetic flux flow measurement devices are not covered in this appendix.

The Flow vs Differential Pressure Relationship

Due to the non-linearity relationship of the developed pressure across the flow element and the correlating flowing condition, the transfer function of this relationship must be defined in order to convert the uncertainties into a corresponding linear values of flow. For flow measurements using a differential pressure (dP) measurement, the following mathematical expression is used to define the dP to flow relationship:

$$Q = K * \sqrt{dp} \qquad \textbf{Eqn. (F-1)}$$

where:
Q = Flow
dP = differential pressure
K = Constant (K is a function of process operating conditions and geometries. For this appendix, K will be assumed as a constant. Refer to reference 3.14 for further details)

Graphically this relationship can be shown as follows:

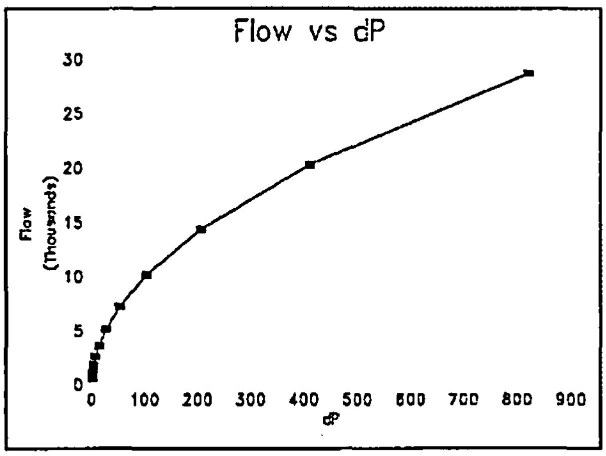


Figure F-1

Addressing Non-Linearities of Flow Loop

When performing an uncertainty calculation for a flow loop, one should calculate the individual uncertainties associated with each device or component in the loop as would be performed for any other type of instrumentation loop. If the flow loop has a square root extractor (SRE) device, note that the uncertainties downstream of the SRE device have different units (e.g., mA, GPM, etc.) than the upstream components (e.g., inches of H_2O). To combine the upstream and downstream uncertainties, one must propagate one side of the uncertainties through the transfer equation, F-1, in order to obtain common units. Normally the analytical limits will be expressed in terms of the process or output units (GPM or lbm/hr), so it is recommended that the upstream uncertainties be propagated through the transfer equation and then combined with the downstream uncertainties. Since the dP to Flow relationship is non-linear, the uncertainties must be propagated through the transfer equation at the point or setpoint of interest in order to obtain a correct gain factor. Example: The lower the setpoint is the larger the gain factor becomes. Meaning uncertainties in the lower portion of the instrument's loop range will have a greater effect on the its output than those same uncertainties applied in the upper range of the instrument loop.

By applying the upstream uncertainties, dP_e, and using Equation F-1, the effects to the setpoint of interest is

$$Q_e = K * \sqrt{dP + dP_e} \qquad \text{Eqn. (F-2)}$$

defined by the following equation.

$$Q_{err} = Q - Q_e \qquad \text{Eqn. (F-3)}$$

To determine the net effect of the upstream uncertainties, Equation 7-2 is subtracted from Equation 7-1,

Example:

Given

dP Setpoint	= 10 inches of H_2O
K	= 1000
dP_e	= -2 inches of H_2O

$$Q = 1000 * \sqrt{10} = 3162.28\ GPM \qquad \text{Eqn. (F-4)}$$

$$Q_e = 1000 * \sqrt{10 - 2} = 2828.43\ GPM \qquad \text{Eqn. (F-5)}$$

$$Q_{err} = 3162.28 - 2828.43 = 333.85\ GPM \qquad \text{Eqn. (F-6)}$$

Solving for Equations F-1 and F-2 using the given values above and then solving Equation 7-3,

To demonstrate the gain factor, the same uncertainty of -2 inches of H_2O will be applied to a higher setpoint

$$Q = 1000 * \sqrt{50} = 7071.07\ GPM \qquad \text{Eqn. (F-7)}$$

$$Q_e = 1000 * \sqrt{50 - 2} = 6928.20\ GPM \qquad \text{Eqn. (F-8)}$$

$$Q_{err} = 7071.07 - 6928.20 = 142.87\ GPM \qquad \text{Eqn. (F-9)}$$

within the instrument loop's range. Reperforming the calculation at a setpoint of 50 inches of H_2O results in the following, As can be seen by comparing the results of Equation F-6 and F-9, the resultant uncertainty, Q_{err} is greater at the lower setpoint due to the larger gain factor that was previously discuss.

Propagation of Both Random and Systematic Uncertainties

For some flow loops, the upstream uncertainties consist of both random and systematic uncertainties. The random and systematic uncertainties could be algebraically summed and then propagated through the transfer function, but the resultant would consist of a mixture of random and systematic uncertainties. A method is needed to separate the resultant components of the random and systematic uncertainty terms so that they can be appropriately combined with their respective downstream counterparts. If the systematic uncertainties are positive, then it is conservative to propagate the uncertainties separately through the transfer function. If the systematic uncertainties are negative, then separate propagation could be non-conservative. The most conservative approach for handling negative uncertainty propagation would be to algebraically sum the resultant uncertainty with the downstream uncertainties, but this TI requires at a minimum the separation of the random and systematic components of the resultant using the following conservative method:

1) Combine the random and systematic upstream uncertainties by algebraic summation,
2) Determine the ideal Q using Equation F-1.
3) Propagate the uncertainties from Step 1 through the transfer function using Equation F-2,
4) Propagate only the systematic uncertainties through the transfer function using Equation F-2,
5) Subtract the resultant in step 4 from the resultant in Step 2 to obtain the propagated systematic uncertainty,
6) Subtract the resultant in step 3 from the resultant in Step 4 to obtain the propagated random uncertainty,

Addressing of Flow Uncertainties

The following section addresses one of the most common uncertainty's seen in flow applications. For a complete listing see Reference 3.16.

Varying Fluid Density Effects on Flow Orifice Accuracy

In many nuclear plant applications, process liquid and gas flow is measured using orifice plates and

$$Q = K * A * \sqrt{\frac{dp}{\rho}} \qquad \text{Eqn. (F-10)}$$

$$W = K * A * \sqrt{dp * \rho} \qquad \text{Eqn. (F-11)}$$

differential pressure transmitters. The measurement of concern is either the volumetric flow rate or the mass flow rate. Many reference books and standards have been written using a wide variety of terminology to describe the mathematics of flow measurement, but in basic, simplified form the governing equations are:

Q	= volumetric flow rate
W	= mass flow rate
A	= cross-sectional area of the pipe
dP	= differential pressure measured across the orifice
ρ	= density of the fluid
K	= constant related to the beta ratio, units of measurement, and various correction factors

As shown in Equations (F-10) and (F-11), the density of the fluid has a direct influence on the mass flow rate and an inverse effect on volumetric flow rate. Normally, a particular flow metering installation is calibrated or sized for an assumed normal operating density condition. As long as the actual flowing conditions match the assumed density, related process errors should not be created. However, some systems, such as safety injection, perform dual roles in plant operation. During normal operation these system can be aligned to inject makeup to the reactor coolant system from sources of relatively low temperature water. During the recirculation phase of a LOCA, the pump suction is shifted to the containment sump, which contains water at much higher temperatures.

If the flow measuring system has been calibrated for the normal low-temperature condition, significant process uncertainties can be induced under accident conditions, when the higher temperature water (lower density) is flowing. Of course, the flow measurement could be automatically compensated for density variations, but this is not the usual practice except on systems such as feedwater, steam, or reactor coolant flow.

To examine the effects of changing fluid density conditions, a liquid flow process shall be discussed. Examining Equation (F-10), it is observed for all practical purposes that K and A are constants. Actually, temperature affects K and A due to thermal expansion of the orifice, but this is assumed to be constant for this discussion to quantify the effects of density alone. If the volumetric flow rate, Q, is held constant, a decrease in density will cause a decrease in differential pressure (dP), which causes an uncertainty. This occurs because the differential transmitter has been calibrated for a particular differential pressure corresponding to that flow rate. The lower dP causes the transmitter to indicate a lower flow rate.

Assuming Q remains constant between the base condition (DENSITY 1, that for which the instrument is calibrated) and the actual condition (DENSITY 2), an equality can be written between the base flow rate (Q1) and actual flow rate (Q2) as shown below:

$$Q_2 = Q_1 \qquad \text{Eqn. (F-12)}$$

$$K * A * \sqrt{\frac{dp_2}{\rho_2}} = K * A * \sqrt{\frac{dp_1}{\rho_1}} \qquad \text{Eqn. (F-13)}$$

or

$$\sqrt{\frac{dp_2}{\rho_2}} = \sqrt{\frac{dp_1}{\rho_1}} \qquad \text{Eqn. (F-14)}$$

$$\frac{dP_2}{dP_1} = \frac{\rho_2}{\rho_1} \qquad \text{Eqn. (F-15)}$$

Appendix F

Flow Loop Uncertainties

Because density is the reciprocal of specific volume of fluid (n_f), Equation (F-15) may be rewritten as

$$\frac{dP_2}{dP_1} = \frac{v_{f1}}{v_{f2}} \qquad \text{Eqn. (F-16)}$$

This equation shows that for an increasing temperature from condition (1) to condition (2), the differential

$$dP_e = dP_1 - dP_2 \text{ (TVA Sign Convention)} \qquad \text{Eqn. (F-17)}$$

pressure decreases. Therefore, the uncertainty, dP_e, is equal to

$$dP_2 = dP_1 * \frac{v_{f1}}{v_{f2}} \qquad \text{Eqn. (F-18)}$$

Rewriting dP_2 from Equation (F-16) as

$$dP_e = dP_1 * \left[1 - \left(\frac{v_{f1}}{v_{f2}}\right)\right] \qquad \text{Eqn. (F-19)}$$

and substituting in Equation (F-17) yields

It is observed in Equation (F-19), which is the equation for density effect on volumetric flow, that the absolute effect is maximized when dP_1 is maximized. This occurs at the upper end of the calibrated differential pressure span for which the transmitter is calibrated. This is also maximum calibrated flow. The effect varies from positive values for temperatures above the base value ($n_{f1} > n_{f2}$), to zero for temperatures equal to the base value ($n_{f1} = n_{f2}$), and finally to negative values for temperatures below the base value ($n_{f1} < n_{f2}$). For mass flow, the equation can be derived in a similar fashion. Note that this method derives the differential pressure error which can be converted to a flow rate error using the flow versus differential pressure relationship for the orifice.

As an example of the use of Equation (F-19), assume an orifice plate is used to measure flow in a water system that is normally at 120°F. The orifice is sized to produce 100 inches of water at 100 gpm at 120°F and 1000 psia. Assume further that under accident conditions the temperature rises to 300°F/1000 psia at an actual flow of 50 gpm. It is desired to find DP_e and the indicated flow.

$$Q = K * \sqrt{dp}$$

The first step is to determine the relationship between Q and dP. This is defined by Equation (F-1).

Appendix F

Flow Loop Uncertainties

This assumes that K, A, and ρ are constants for the particular situation. Plugging a dP = 100 and a Q = 100 into this equation yields,

$$100 = K * \sqrt{100}$$

$$K = \frac{100}{10} = 10$$

$$Q = 10 * \sqrt{dP} \qquad \text{Eqn. (F-20)}$$

Thus,

Therefore, using Equation (F-20) at the accident flow rate of 50 gpm, we can solve for dP_1 as follows,

$$Q = 10 * \sqrt{dP_1} \qquad \text{Eqn. (F-21)}$$

$$50 = 10 * \sqrt{dP_1} \qquad \text{Eqn. (F-22)}$$

$$dP_1 = \frac{(50)^2}{(10)^2} = 25 \text{ inches of } H_2O \qquad \text{Eqn. (F-23)}$$

or

Using the thermodynamic steam tables,

$$v_f 1\,(120^\circ F\ /\ 1000\,psia) = 0.01616\,\frac{ft^3}{lbm} \qquad \text{Eqn. (F-24)}$$

$$v_f 2\,(300^\circ F\ /\ 1000\,psia) = 0.01738\,\frac{ft^3}{lbm} \qquad \text{Eqn. (F-25)}$$

Substituting Equations (F-23), (F-24), and (F-25) into Equation (F-19) yields,

$$dP_e = 25 * \left[1 - \left(\frac{0.01616}{0.01738}\right)\right] = +\ 1.755 \text{ inches of } H_2O \qquad \text{Eqn. (F-26)}$$

This can be converted to percent of span, of course, by dividing dP_e by the calibrated dP span and multiplying the result by 100%. Therefore, the rise in temperature reduces the actual differential pressure input to the transmitter to 25 - 1.755 = 23.245 inches of H_2O. Substituting this value for dP into Equation (F-20) yields an indicated flow of:

$$Q = 10 * \sqrt{23.245} = 48.2\ gpm \qquad \text{Eqn. (F-27)}$$

Effects of Piping Configuration on Flow Accuracy

Bends, fittings, and valves in piping systems, cause flow turbulence. This can cause process measurement uncertainties to be introduced into the flow elements. ASME has published guidance (See Reference 3.16) for various types of installation examples to show the minimum acceptable upstream/downstream lengths of straight pipe before and after flow elements. Following this ASME guidance helps reduce the effects of this turbulence. The piping arrangement showing locations of values, bends, fittings, etc., can usually be obtained from piping isometric drawings. Based upon industry guidance, if both the minimum upstream and downstream straight pipe lengths are met, the resultant flow measurement uncertainty for the piping configuration (not including instrumentation uncertainties) shall be assigned a value of ± 0.5% of span. If the minimum criteria can not be met, this value should be determined based upon an evaluation of the piping configuration and field measurement data.

Appendix G

Glossary/Definitions

Acceptable as Found - Component (A_{fc})

The Component Acceptable as Found value (A_{fc}) is the same as the normal measurable accuracy (A_{nf}). These errors are associated with normal (non-accident) conditions. A_b is also included in A_{nf}. This value is used only when calibrating as individual components or partial loops.

Acceptable as Found - Loop (A_{fl})

The Loop Acceptable as Found value is the same as the normal measurable accuracy (A_{nf}). These errors are associated with normal (non-accident) conditions. The acceptance band (A_b) is also included in A_{nf}. This value is used only when calibrating as a loop.

Acceptable as Left - Component (A_{lc})

Used when calibrating as individual components, or a partial loop. The Acceptable as Left (A_{lc}) value is the component's A_b as defined by a supporting calculation.

Acceptable as Left - Loop (A_{ll})

Used only when calibrating as a loop. The Acceptable as Left (A_{ll}) value is the square root of the sum of the squares of each components A_b.

Acceptance Band (A_b)

During calibration or calibration checks, the required deviation from the true value deemed acceptable without requiring readjustment. (An acceptance band should be selected such that the instrument inaccuracies fall within the band.) A_b should never be less than reference accuracy.

"Rule of Thumb" - A_b = 1 * (Reference Accuracy)

Accident Accuracy (A_a)

Accuracy of a device in a harsh environment caused by a Design Basis Event accident (excluding a seismic event).

The following is a list of <u>typical</u> errors which result in A_a:

Drift	D_a
Repeatability	R_a
DBE temperature errors	TA_a
DBE radiation errors	RAD_a
Water Leg errors	WL_a
Acceptance band	A_b
Calibration errors	
Miscellaneous DBE errors (as required)	

Accuracy

The degree of conformity of an indicated value to a recognized accepted standard value, or ideal value. (ISA)

Appendix G

Glossary/Definitions

Allowable Value (A_v)

A limiting value that the trip setpoint can have when tested periodically, beyond which the instrument channel may be declared inoperable and appropriate action should be taken.

Analytical Limits (AL)

The limit of a measured or calculated variable established by the safety analysis to ensure that a safety limit is not exceeded. The analytical limits are established by the system engineer per Reference 3.7.

Arbitrarily Distributed Uncertainty

This term is used in this TI to denote uncertainties which do not have a normal distribution.

Bias

An uncertainty component which consistently has the same algebraic sign, and is expressed as an estimated limit of error.

Bistable

A device which changes state when a preselected signal value is reached.

Calibrated Span (CS)

See definition for Span.

Conformity

Of a curve, the closeness to which it approximates a specified curve (e.g., logarithmic, parabolic, cubic, etc.)

Confidence Interval

An interval, computed from sample values. Intervals so constructed will straddle the estimated parameter 100 * (1 - a) percent of the time in repeated sampling. The quantity, (1 - a), is called the confidence coefficient.

Counting Statistics

The detector is a pulse producing scintillation counter and subject to counting statistic uncertainties based on the monitor's time constant or count time (The system totals counts during a set period of time). The uncertainty is based on the distribution of disintegrations over this finite period of time. Thus the uncertainty is based on the length of time the process is monitored, i.e., the certainty that a given time period has captured a representative count.

Appendix G

Glossary/Definitions

Dead band

In process instrumentation, the range through which an input signal may be varied, upon reversal of direction, without initiating an observable change in output signal.

Degree of Freedom

The definition of Degree of Freedom is "n-1" with "n" being the sample size of interest. The sample size/degrees of freedom depends on the analysis being performed. For example, given 4 devices each calibrate 10 times, there are two degrees of freedom possible. Case 1 is (40 - 1) for predicting future operation of these S/N devices, and Case 2 is (4 -1) for predicting future operation of this type device (general population).

Dependent Uncertainty

Uncertainty components 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.

Design Basis Event (DBE)

Postulated events used in the design to establish the acceptable performance requirements for the structures, systems, and components (Reference 3.30).

Design Basis Event Accuracy (A_{dbe})

A_{dbe} is the greater of the Accident Accuracy (A_a) or the Post Seismic Accuracy (A_s).

Design Basis Event Analysis

That analysis used to determine safety system responses to design basis events.

Deviation

Any departure from a desired value or expected value or pattern.

Device

An apparatus for performing a prescribed function.

Drift

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

Dynamic Response

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

Appendix G

Glossary/Definitions

Effect

A change in output produced by some outside phenomenon, such as elevated temperature, pressure, humidity, or radiation.

Element

A component of a device or system.

Energy Dependence error (EeD)

The difference in response of the detector to varying energy. The detector has a different sensitivity for each isotope it observes, the spread of these sensitivities is the error due to energy dependence. Normally the expected isotopes will be predominantly Xe-133. Plant procedures use the specific calibration factor analyzed by Engineering. Therefore, the energy dependence is accounted for and need not be considered as an uncertainty in this calculation.

Error

In process instrumentation, the algebraic difference between the indicated and the ideal value of the measured signal. It is the quantity which algebraically added to the indication gives the ideal value. Note: This definition is the opposite of the ISA definition.

Factory Alignment error (Efac)

This term accounts for the uncertainty associated with taking reference reading with the check source. Mounting variation of the source is the cause of this uncertainty.

Field Alignment error (Efa)

The uncertainty associated with calibration of the equipment in the field. The uncertainty of calibration is accounted for via the M&TE uncertainties included in this calculation, i.e., ICTe, ICRe, OCTe, OCRe, and Ab. Thus field alignment error is not included as a separate term so as to confirm to the EEB-TI-28 convention.

Foldover

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

Full Span

Full span is defined as the "maximum adjustable range."

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.

Appendix G

Glossary/Definitions

Imprecision (Eimp)

The statistical uncertainty resulting from unknown radiation energy level concentrations, which affect detector efficiency, coupled with the response time of the readout module electronics. See Counting Statistic definition.

Independent Uncertainty

Uncertainty components are independent of each other if their magnitudes or algebraic signs are not significantly correlated.

Instrument Channel

An arrangement of components and devices as required to generate a single protective action signal when required by a generating station condition. An instrument channel loses its identity where single protective action signals are combined.

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.

Limiting Safety System Setting (LSSS)

Limiting Safety System Settings are settings for automatic protective devices related to those variables having significant safety functions.

Linearity

The closeness to which a curve approximates a straight line.

Margin

In setpoint determination, margin is an allowance added to the instrument channel uncertainty. Margin moves the setpoint further away from the analytical limit.

Module

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

Net count rate inaccuracy (E'ncr)

The error in the measured radiation level due to various drift and environmental effects from the detector to the readout module

Normal Accuracy (A_n)

Accuracy of a device located in an environment not affected by an accident, or prior to an accident.

Normal Measurable Accuracy (A_{nf})

These errors are associated with normal (non-accident) conditions. The errors may be detected during a calibration. The acceptance band is also included in A_{nf}. The following is a list of typical errors included in the calculation of A_{nf}.

Drift	D_e
Repeatability	R_e
Acceptance band	A_b
Calibration errors	

Normalization

Where instrument accuracy has been stated in terms other than percent of span, modifying the accuracy term as stated to be percent of span.

Nuclear Safety-Related Instrumentation

That which is essential to:

1) Provide emergency reactor shutdown

2) Provide containment isolation

3) Provide reactor core cooling

4) Provide for containment or reactor heat removal

5) Prevent or mitigate a significant release of radioactive material to the environment; or is otherwise essential to provide reasonable assurance that a nuclear power plant can be operated without undue risk to the health and safety of the public.

Operating Conditions, Normal

The range of operating conditions within which a device is designed to operate and for which operating influences are stated.

Operating Conditions, Reference

The range of operating conditions of a device within which operating influences are negligible.

Operating Influence

The change in a performance characteristic caused by a change in a specified operating condition from reference operating condition, all other conditions being held with in the limits of reference operating conditions.

Appendix G

Glossary/Definitions

Operating Limit

A limit between a system's normal operating range and an associated protective setpoint. This limit is defined by the amount of process variation which may be expected (normal or transient) in the direction of the protective setpoint.

Overrange Limit

The maximum input that can be applied to a device without causing damage or permanent change in performance.

Post-Seismic Accuracy (A_s)

A normal accuracy plus residual accuracy effects following a seismic event.

Primary Calibration error (Epc)

This term account for the uncertainty of the primary calibration of the detector. A known source gas which is NBS traceable is routed through a prototype detector sample chamber or a mock-up of process stream to be monitored. The uncertainty of the source gas concentration and the geometry of the sample technique is attributed to Epc.

Process Measurement Errors ($PRSC_e$)

Process errors that include those inherent in the measurement technique, for example fluid stratification effects on temperature measurements, or the effect of fluid density changes on level measurement.

Process Measurement Instrumentation

An instrument or group of instruments that convert a physical process parameter such as temperature, pressure, etc., to a useable, measurable parameter such as current, voltage, etc.

Process Noise

Random fluctuation of the process variable. These fluctuations are due to disturbances generated in the process by various physical processes.

Protective Action

The initiation of a signal or operation of equipment within the protection system or protective action system to accomplish a protective function in response to a generating station condition having reached a limit specified in the design basis.

Protective Function

The sensing of one or more variables associated with a particular generating station condition, the signal processing, and the initiation and completion of the protective action within the values of the variables established in the design basis.

Appendix G

Glossary/Definitions

Protection system

The electrical and mechanical devices (measured process variables to protective action system input terminals) involved in generating those signals associated with the protective functions. These signals include those that initiate reactor trip, engineered safety features, and auxiliary supporting features.

Qualification Maintenance Data Sheet (QMDS)

A form used to document, assemble, maintain, and transmit special maintenance activities required to maintain environmental qualification of safety-related electrical equipment located in harsh environments.

Random

Describing a variable whose value at a particular future instant cannot be predicted exactly, but can only be estimated by a probability distribution function.

Range

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

Reference Junction

That thermocouple junction which is at a known or referenced temperature.

Note: The reference junction is physically that point at which the thermocouple or thermocouple extension wires are connected to a device or where the thermocouple is connected to a pair of lead wires, usually copper.

Reference Junction Compensation

A means of counteracting the effect of temperature variations of the reference junction, when allowed to vary within specified limits.

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.

Reproducibility

In process instrumentation, 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: It is usually measured as a 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 time during which drift may not be included.

Note 2: Reproducibility includes hysteresis, dead band, and repeatability.

Note 3: Between repeated measurements the input may vary over the range and operating conditions may vary within normal operating conditions.

Response Time

The time interval from when the monitored variable exceeds its trip setpoint until a protective action is performed.

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.

Saturation

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

Scale Factor

The factor by which the number of scale divisions indicated or recorded by an instrument should be multiplied to compute the value of the measured variable.

Seismic Error (S_e)

Component residual accuracy effects following a seismic event.

Self-Heating

Internal heating resulting form electric energy dissipated within a device.

Sensitivity

The ratio of the change in output magnitude to the change of the input which causes it after the steady-state has been reached.

Sensor

The portion of an instrument channel which responds to changes in a plant variable or condition and converts the measured process variable into an electric or pneumatic signal.

Setpoint (SP)

A predetermined level at which a bistable device changes state to indicate that the quantity under surveillance has reached the selected value, a controller's control point is reached, or an Operator takes action.

Glossary/Definitions

Signal Conditioning

One or more devices that perform signal conversion, buffering, isolation, or mathematical operations on the signal as needed.

Signal Interface

The physical means (cables, connectors, etc.) by which the process signal is propagated from the process measurement device through the signal conditioning device of the instrument channel to the actuation device.

Span

The algebraic difference between the upper and lower values of a calibrated range.

Span Shift

Any change in slope of the input-output curve.

Systematic Error

An error which, in the course of a number of measurements made under the same conditions of the same value of a given quantity, either remains constant in absolute value and sign or varies according to a definite law when the conditions change. In this instruction a systematic error is a fixed error of known magnitude and sign. (See bias error)

Test Interval

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

Tolerance

The allowable variation from a specified or true value.

Transducer

An element or device which receives information in the form of one quantity and converts it to information in the form of the same or another quantity.

Transfer Function

A mathematical representation describing the relationship between the output of a device with respect to a defined input for that device.

Transient

In process instrumentation, the behavior of a variable during transition between two steady-states.

Transient Overshoot

The maximum excursion beyond the final steady state value of output as the result of an input change.

Transmitter

A transducer which responds to a measured variable by means of a sensing element, and converts it to a standardized transmission signal which is a function only of the measured variable.

Trip Setpoint

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

Turndown

The ratio of the range of an instrument to the calibrated span.

Variable, Measured

A quantity, property, or condition which is measured.

Uncertainty

The amount of error in an instrument channel which represents the distribution of possible errors within some probability and confidence level.

Upper Range Limit (URL)

The maximum span adjustment or maximum usable range for an instrument.

Appendix H

Example Calculation

Caution: The following information in this Appendix is to only provide the calculation preparer direction concerning format and a level of professional quality. This Appendix should not be used for technical input for preparation of TI-28 calculations.

part of BFN TS-447 RAI Enclosure 3

Appendix II

Example Calculation

SITE ENGINEERING CALCULATIONS

Title: SETPOINT AND SCALING CALCULATIONS FOR FEED WATER HEATER LEVEL TRANSMITTERS			PLANT/ UNIT BFNP / 2
Preparing Organization NE/EE/I&C	Key Nouns: I&C, INSTR, CALIBRATION, SETPOINT, ACCURACY		
Project Identifiers ED-N2006-920370	RIMS Accession Number RIMS'Use	RIMS accession number	
Applicable Design Document: EEB TI 28 R1	R0		
	R1		
SAR SECTIONS: FSAR REVIEW SET	UNID SYSTEMS: 006		
Revision 0	R1	SAFETY RELATED YES ( ) NO(X)	
ECN No. DCN W17327 A		STATEMENT OF PROBLEM Determine the accuracy of the subject instrument loops and demonstrate that the accuracy is adequate for the intended purpose. Primary elements are located in a MILD environment. Subject devices ( ) are (x) are not part of PAM.	
Prepared			
Checked			
Reviewed			
Approved			
Date			
Pages added			
Pages deleted			
Pages changed			

ABSTRACT These calculations contain an unverified assumption(s) that must be verified later. Yes ( ) No (x)
Calculations were performed to determine the accuracy of the subject instrument loops. The determined accuracies are compared to the required accuracies, setpoints, safety limits and/or operational limits and the accuracy of the loops listed below are demonstrated to be acceptable for the intended function of the instrument loops listed on sheets 12 through 19

FSAR Compliance Review ______________________
Lead Electrical Engineer

QUALITY RELATED CALCULATION AND DIRECT DESIGN INPUT
Calculation contains special requirements or limiting conditions.
Yes ( ) No (X)
Rev 0 of this calculation consists of ________ sheets and ______ Attachments for a total of ________ sheets.

Microfilm and return calculations to Engineering Records Processing

Appendix H

Example Calculation

Title: SETPOINT AND SCALING CALCULATION FOR FEEDWATER HEATER LEVEL TRANSMITTERS		REVISION LOG ED-N2006-920370
REV #	DESCRIPTION OF REVISION	DATE APPROVED
0	Initial issue	

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

CALCULATION DESIGN VERIFICATION (INDEPENDENT REVIEW) FORM
(PER NEP-3.1)

Calculation Revision No 0

Method of design verification (independent review) used (check method used):

1. Design Review ______________
2. Alternate Calculation ______________
3. Qualification Test ______________

Justification (explain below):

Method 1:In the design review method, justify the technical adequacy of the calculation and explain how the adequacy was verified (calculation is similar to another, based on accepted handbook methods, appropriate sensitivity studies included for confidence, etc.).

Method 2:In the alternate calculation method, identify the pages where the alternate calculation has been included in the calculation package and explain why this method is adequate.

Method 3: In the qualification test method, identify the QA documented source(s) where testing adequately demonstrates the adequacy of this calculation and explain.

Design Verifier (Independent Reviewer) Date

Setpoint Calculations
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Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

FSAR COMPLIANCE REVIEW

CALCULATION REVISION 0

This review has been performed to comply with NEP 3.1 regarding FSAR Compliance. Below are listed the FSAR sections reviewed to satisfy the requirements of NEP 3.1:

11.3	11.5	11.6	11.7	11.8
11.9	14.5.2			

RESULTS OF REVIEW:

The following sections are not affected:

11.3	11.5	11.6	11.7	11.8
11.9	14.5.2			

The following sections are affected with their associated impact:

N/A

PREP ____________ DATE ____________

Setpoint Calculations
EEB-TI-28

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Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

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SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-H2006-920370

T A B L E O F C O N T E N T S (CONTINUED)

ATTACHMENTS

Setpoint Calculations
EEB-TI-28

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

1) PURPOSE:

The purpose of this calculation is a) to determine the accuracy of the instrumentation covered by this calculation, and b) to demonstrate that the instrumentation is sufficiently accurate to perform its intended function without safety or operational limits being exceeded. The instruments in this calculation are not safety related, but it is quality related and accident accuracies will not be demonstrated.

2) ASSUMPTIONS:

_x_ This calculation contains no assumptions.

2.a) REQUIREMENTS:

1. The Foxboro Model transmitter 823DP-D is installed in the plant in accordance with DCN W17327 A.
2. The output requirements of this calculation are listed in Summary of Results.

2.b) DEFINITIONS AND ABBREVIATIONS:

DEFINITIONS AND ABBREVIATIONS USED IN THIS CALCULATION ARE CONSISTENT WITH EEB-TI-28 (REFERENCE 1). SPECIAL DEFINITIONS/ABBREVIATIONS NOT COVERED IN EEB-TI-28 ARE LISTED BELOW:

DDI - Direct Design Input
FS - Full Scale
IAD - Integrated Accident Dose
INWC - Inches Water Column
MCR - Main Control Room
M&TE - Measuring and Test Equipment
N/A - Not Applicable
N/R - Not Required
OL - Operational Limits
SHP - Static Head Pressure
TID - Total Integrated Dose
URL - Upper Range Limit

REV___PREP__________DATE________CHECK__________DATE_________SHT 8 C/O___

Setpoint Calculations
EEB-TI-28

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

3) SOURCE OF DESIGN INPUT INFORMATION (REFERENCES)

REF#	ATT#	DDI (Y/N)	REFERENCE (RIMS NO)
1		N	BRANCH INSTRUCTION EEB-TI-28, REVISION 1, "SETPOINT CALCULATIONS" (RIMS NO. B43 88 1024 902)
2		N	TECHNICAL SPECIFICATIONS, UNIT 2, THRU AMENDMENT 202.
3		N	UPDATED FINAL SAFETY ANALYSIS REPORT FSAR THRU AMENDMENT 9.
4		Y	CALCULATION ED-Q2999-890038, REVISION 2, "IR EFFECTS" (RIMS NO. B22 90 0703 108)
5		Y	CALCULATION 72186RDM, REVISION 0, "A REVIEW OF ELECTRONIC COMPONENTS IN A RADIATION ENVIRONMENT OF $\leq$ 5 X 10^4 RADS"
6		Y	"INSTRUMENT ENGINEERS' HANDBOOK, PROCESS MEASUREMENT," REVISED EDITION, BELA G. LIPTAK, CHILTON BOOK COMPANY
7		Y	SITE STANDARD PRACTICE SSP 6.8 R0 "INSTRUMENTATION SETPOINTS, SCALING AND CALIBRATION PROGRAM".
8		Y	DRAWING, 47W225-1, R0, "HARSH ENVIRONMENTAL DATA DRAWING SERIES INDEX, NOTES AND REFERENCES"
9		Y	DRAWING, 2-47W600-25, R0, "MECHANICAL INSTRUMENTS AND CONTROLS"
10		Y	DRAWING, 2-47W600-26, R0, "MECHANICAL INSTRUMENTS AND CONTROLS"
11		Y	DRAWING, 2-47W600-32, R0, "MECHANICAL INSTRUMENTS AND CONTROLS"
12		Y	DRAWING, 2-47W600-33, R0, "MECHANICAL INSTRUMENTS AND CONTROLS"
13		Y	DRAWING, 2-47W600-45G, R0, "MECHANICAL INSTRUMENTS AND CONTROLS"
14 - 21			NOT USED
22		Y	DRAWING, 47W600-37, R000, "MECHANICAL INSTRUMENTS AND CONTROLS"
23		Y	DRAWING, 47W600-38, R000, "MECHANICAL INSTRUMENTS AND CONTROLS"
24		Y	DRAWING, 47W600-39, R000, "MECHANICAL INSTRUMENTS AND CONTROLS"
25		Y	DRAWING, 47B601-6-0 RX0E, "INSTRUMENT TABULATION, HEATER DRAINS AND VENT SYSTEM"
26	1	Y	FOXBORO PRODUCT SPECIFICATIONS PSS 2A-1A3 E ON 823DP INTELLIGENT d/p CELL TRANSMITTERS."
27		Y	SYSTEM DESIGN CRITERIA, BFN-50-7002, R6, "CONDENSATE AND DEMINERALIZED WATER SYSTEM - UNITS 2 & 3 (RIMS # B22 920411 303), DIM BFN 50-7002-3 (B22 920323 301).
28		Y	DESIGN CRITERIA, BFN-50-7003, R7, "REACTOR FEEDWATER SYSTEM - UNITS 2 & 3" (RIMS # B22 920422 302)
29		Y	SYSTEM DESIGN CRITERIA, BFN-50-7005, R2, "EXTRACTION STEAM SYSTEM - UNITS 2 & 3 " (RIMS # B22 920410 301)

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Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

3) SOURCE OF DESIGN INPUT INFORMATION (REFERENCES) (CONTINUED)

REF#	ATT#	DDI (Y/N)	REFERENCE (RIMS NO)
30		Y	DRAWING, 2-47E610-06-1, R6, "MECHANICAL CONTROL DIAGRAM, HEATER DRAINS AND VENT SYSTEM"
31		Y	DRAWING, 2-47E610-06-4, R6, "MECHANICAL CONTROL DIAGRAM, HEATER DRAINS AND VENT SYSTEM"
32	-37		NOT USED
38		Y	DRAWING 2-47E802-1 R005, FLOW DIAGRAM, EXTRACTION STEAM
39		Y	DRAWING 2-47E803-1 R010, MECHANICAL FLOW DIAGRAM, REACTOR FEEDWATER
40		Y	DRAWING 2-47E803-2 R004, MECHANICAL FLOW DIAGRAM, REACTOR FEEDWATER, BOILER FD PMP DRIVE TURBINE A.
41		Y	DRAWING 2-47E805-1 R004, MECHANICAL FLOW DIAGRAM, HEATER DRAINS AND VENTS & MISC. PIPING
42		Y	DRAWING 47W425-20 RB, UNIT 2, "MECHANICAL HEATERS DRAINS AND VENTS , TURBINE CONNECTIONS AND MISCELLANEOUS PIPING".
43	2	Y	FOXBORO INSTRUCTION MI 018-430 JANUARY 1985, E69F CURRENT TO PNEUMATIC CONVERTER.
44	3	Y	FOXBORO INSTRUCTION MI 012-340 SEPTEMBER 1968, TYPE C VERNIER VALVACTOR YOKE MOUNTED.
45	6	Y	FOXBORO PRODUCT SPECIFICATION FOR "INTELLIGENT AUTOMATION SERIES MODEL HHT HAND HELD TERMINAL" PSS 2A-1Z3 A.
46		Y	SSP 6.7 R01, SITE STANDARD PRACTICE "CONTROL OF MEASURING AND TEST EQUIPMENT".
47		Y	TVA CONTRACT 82127 D
48	4	Y	FOXBORO PRODUCT SPECIFICATION FOR E69F FIELD MOUNTED CURRENT TO PNEUMATIC SIGNAL CONVERTER PSS 4-8B1 A.
49	5	Y	FOXBORO PRODUCT SPECIFICATION FOR E69P, CURRENT TO PNEUMATIC VALVE POSITIONER PSS 4-10A2 A.
50		Y	FOXBORO PRODUCT SPECIFICATION FOR I/A SERIES INTELLIGENT TRANSMITTER INTERFACE MODULE (FBM 18) PSS 21H-2D5 B4.
51		Y	FOXBORO PRODUCT SPECIFICATION FOR E69F FIELD MOUNTED CURRENT TO PNEUMATIC SIGNAL CONVERTER PSS 4-8B1 A.
52		Y	DRAWING 47K1110-13, UNIT 2, GUARANTEE THROTTLE FLOW 3RFP- 2.00 "HG
53		Y	DRAWING 47K1110-15, UNIT 2, 75% VWO THROTTLE FLOW 3 RFP'S -2.00" HG
54		Y	DRAWING 47K1110-14, UNIT 2, VALVES WIDE OPEN FLOW 3 RFP'S
55		Y	DRAWING 47K1110-16, UNIT 2, 50 % VWO THROTTLE FLOW 3RFP'S- 2.00 "HG
53		Y	DRAWING 47K1110-17, UNIT 2, 25% VWO THROTTLE FLOW 3 RFP'S -2.00" HG

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER A1 LOOP IDENTIFIER: 2-L-06-1

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-1A	25-113A	9	588′	9	k-t8	9
2-LT-06-1B	25-113A	9	588′	9	k-t8	9
2-LM-06-1A	25-113A	9	590′	9	k-t8	9
2-LM-06-1B	LOCAL	9				
2-LCV-06-1	LOCAL	9				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 597′ 6" WLHP 601′ 2"
INSTRUMENT ELEVATION: 588′ REFERENCE: 9

FEEDWATER HEATER B1 LOOP IDENTIFIER: 2-L-06-19

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-19A	25-113A	9	588′	9	k-t8	9
2-LT-06-19B	25-113A	9	588′	9	k-t8	9
2-LM-06-19A	25-113A	9	590′	9	k-t8	9
2-LM-06-19B	LOCAL	9				
2-LCV-06-19	LOCAL	9				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 597′ 6" WLHP 601′ 2"
INSTRUMENT ELEVATION: 588′ REFERENCE: 9

FEEDWATER HEATER C1 LOOP IDENTIFIER: 2-L-06-37

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-37A	25-113B	10	588′	10	k-t8	10
2-LT-06-37B	25-113B	10	588′	10	k-t8	10
2-LM-06-37A	25-113B	10	590′	10	k-t8	10
2-LM-06-37B	LOCAL	10				
2-LCV-06-37	LOCAL	10				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 597′ 6" WLHP 601′ 2"
INSTRUMENT ELEVATION: 588′ REFERENCE: 10

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER A2 LOOP IDENTIFIER: 2-L-06-4

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-4A	25-113A	9	588'	9	k-t8	9
2-LT-06-4B	25-113A	9	588'	9	k-t8	9
2-LM-06-4AA	25-113A	9	590'	9	k-t8	9
2-LM-06-4BA	25-113A	9	590'	9	k-t8	9
2-LM-06-4AB	LOCAL	9				
2-LM-06-4BB	LOCAL	9				
2-LCV-06-4A	LOCAL	9				
2-LCV-06-4B	LOCAL	9				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 601' 10" WLHP 604'10"

INSTRUMENT ELEVATION: 588' REFERENCE: 9

FEEDWATER HEATER B2 LOOP IDENTIFIER: 2-L-06-22

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-22A	25-113B	10	588'	10	k-t8	10
2-LT-06-22B	25-113B	10	588'	10	k-t8	10
2-LM-06-22AA	25-113B	10	590'	10	k-t8	10
2-LM-06-22BA	25-113B	10	590'	10	k-t8	10
2-LM-06-22AB	LOCAL	10				
2-LM-06-22BB	LOCAL	10				
2-LCV-06-22A	LOCAL	10				
2-LCV-06-22B	LOCAL	10				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 601' 10" WLHP 604'10"

INSTRUMENT ELEVATION: 588' REFERENCE: 10

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER C2 LOOP IDENTIFIER: 2-L-06-40

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-40A	25-113B	10	588'	10	k-t8	10
2-LT-06-40B	25-113B	10	588'	10	k-t8	10
2-LM-06-40AA	25-113B	10	590'	10	k-t8	10
2-LM-06-40BA	25-113B	10	590'	10	k-t8	10
2-LM-06-40AB	LOCAL	10				
2-LM-06-40BB	LOCAL	10				
2-LCV-06-40A	LOCAL	10				
2-LCV-06-40B	LOCAL	10				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 601' 10" WLHP 604'10"

INSTRUMENT ELEVATION: 588' REFERENCE: 10

FEEDWATER HEATER B3 LOOP IDENTIFIER: 2-L-06-25

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-25A	25-108	12	588'	12	f-t7	12
2-LT-06-25B	25-108	12	588'	12	f-t7	12
2-LM-06-25A	25-108	12	590'	12	f-t7	12
2-LM-06-25B	LOCAL	12				
2-LCV-06-25	LOCAL	12				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 609' 10.5" WLHP 612'10.5"

INSTRUMENT ELEVATION: 588' REFERENCE: 12

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER C3 LOOP IDENTIFIER: 2-L-06-43

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-43A	25-109	11	588'	11	e-t7	11
2-LT-06-43B	25-109	11	588'	11	e-t7	11
2-LM-06-43A	25-109	11	590'	11	e-t7	11
2-LM-06-43B	LOCAL	11				
2-LCV-06-43	LOCAL	11				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 609' 10.5" WLHP 612'10.5"
INSTRUMENT ELEVATION: 588' REFERENCE: 11

FEEDWATER HEATER A3 LOOP IDENTIFIER: 2-L-06-7

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-7A	25-107	11	588'	11	g-t7	11
2-LT-06-7B	25-107	11	588'	11	g-t7	11
2-LM-06-7A	25-107	11	590'	11	g-t7	11
2-LM-06-7B	LOCAL	11				
2-LCV-06-7	LOCAL	11				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 609' 10.5" WLHP 612'10.5"
INSTRUMENT ELEVATION: 588' REFERENCE: 11

FEEDWATER HEATER A4 LOOP IDENTIFIER: 2-L-06-11

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-11A	25-115A	22	559'	22	d-t10	22
2-LT-06-11B	25-115A	22	559'	22	d-t10	22
2-LM-06-11AA	25-115A	22	561'	22	d-t10	22
2-LM-06-11BA	25-115A	22	561'	22	d-t10	22
2-LM-06-11AB	LOCAL	22				
2-LM-06-11BB	LOCAL	22				
2-LCV-06-11A	LOCAL	22				
2-LCV-06-11B	LOCAL	22				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 595' 11" WLHP 599'8"
INSTRUMENT ELEVATION: 559' REFERENCE: 22

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Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER B4 LOOP IDENTIFIER: 2-L-06-29

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-29A	25-115B	23	559′	23	d-t11	23
2-LT-06-29B	25-115B	23	559′	23	d-t11	23
2-LM-06-29AA	25-115B	23	561′	23	d-t11	23
2-LM-06-29BA	25-115B	23	561′	23	d-t11	23
2-LM-06-29AB	LOCAL	23				
2-LM-06-29BB	LOCAL	23				
2-LCV-06-29A	LOCAL	23				
2-LCV-06-29B	LOCAL	23				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 595′ 11" WLHP 599′8"

INSTRUMENT ELEVATION: 559′ REFERENCE: 23

FEEDWATER HEATER C4 LOOP IDENTIFIER: 2-L-06-47

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-47A	25-115C	24	559′	24	d-t11	24
2-LT-06-47B	25-115C	24	559′	24	d-t11	24
2-LM-06-47AA	25-115C	24	561′	24	d-t11	24
2-LM-06-47BA	25-115C	24	561′	24	d-t11	24
2-LM-06-47AB	LOCAL	24				
2-LM-06-47BB	LOCAL	24				
2-LCV-06-47A	LOCAL	24				
2-LCV-06-47B	LOCAL	24				

INSTRUMENT TAP INFORMATION:

TAP ELEVATION: WLLP 595′ 11" WLHP 599′ 8"

INSTRUMENT ELEVATION: 599′ REFERENCE: 23

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER A5 LOOP IDENTIFIER: 2-L-06-14

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-14A	25-115A	22	559'	22	d-t10	22
2-LT-06-14B	25-115A	22	559'	22	d-t10	22
2-LM-06-14AA	25-115A	22	561'	22	d-t10	22
2-LM-06-14BA	25-115A	22	561'	22	d-t10	22
2-LM-06-14AB	LOCAL	22				
2-LM-06-14BB	LOCAL	22				
2-LCV-06-14A	LOCAL	22				
2-LCV-06-14B	LOCAL	22				

INSTRUMENT TAP INFORMATION:

HEATER TOP 598' 3" HEATER BOTTOM 595' 9"

TAP ELEVATION: WLLP 595' 2" WLHP 599'0"

INSTRUMENT ELEVATION: 559' REFERENCE: 22

FEEDWATER HEATER B5 LOOP IDENTIFIER: 2-L-06-32

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-32A	25-115B	23	559'	23	d-t11	23
2-LT-06-32B	25-115B	23	559'	23	d-t11	23
2-LM-06-32AA	25-115B	23	561'	23	d-t11	23
2-LM-06-32BA	25-115B	23	561'	23	d-t11	23
2-LM-06-32AB	LOCAL	23				
2-LM-06-32BB	LOCAL	23				
2-LCV-06-32A	LOCAL	23				
2-LCV-06-32B	LOCAL	23				

INSTRUMENT TAP INFORMATION:

HEATER TOP 598' 3" HEATER BOTTOM 595' 9"

TAP ELEVATION: WLLP 595' 2" WLHP 599'0"

INSTRUMENT ELEVATION: 559' REFERENCE: 23

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.1) LOOP COMPONENT LIST

FEEDWATER HEATER C5 LOOP IDENTIFIER: 2-L-06-50

DEVICE ID#	PANEL	REF.	EL.	REF.	COORD.	REF.
2-LT-06-50A	25-115C	24	559′	24	d-t11	24
2-LT-06-50B	25-115C	24	559′	24	d-t11	24
2-LM-06-50AA	25-115C	24	561′	24	d-t11	24
2-LM-06-50BA	25-115C	24	561′	24	d-t11	24
2-LM-06-50AB	LOCAL	24				
2-LM-06-50BB	LOCAL	24				
2-LCV-06-50A	LOCAL	24				
2-LCV-06-50B	LOCAL	24				

INSTRUMENT TAP INFORMATION:

HEATER TOP 598′ 3″ HEATER BOTTOM 595′ 9″ TAP ELEVATION: WLLP 595′ 2″

WLHP 599′ 0″

INSTRUMENT ELEVATION: 559′ REFERENCE: 24

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.2) LOOP FUNCTION AND REQUIREMENTS

4.2a) LOOP FUNCTION

THE REACTOR FEEDWATER HEATER LEVEL TRANSMITTER CONTROLS THE HEATER DRAIN FLOW BY CONTROLLING THE VALVE, TO MAINTAIN THE REQUIRED WATER LEVEL IN THE HEATER. THIS LEVEL IS MAINTAINED SO THAT THE HEAT TRANSFER TO REACTOR FEEDWATER IS KEPT AT THE OPTIMUM. MAINTAINING LEVEL PREVENTS WATER FROM GETTING BACK TO THE TURBINE.

4.2b) RESPONSE TIME

THE RESPONSE TIME OF THE FEEDWATER HEATER LEVEL CONTROL LOOPS HAS BEEN ADEQUATE IN THE PAST WITH THE EXISTING PNEUMATIC DIFFERENTIAL PRESSURE TRANSMITTERS AND CONTROLLERS. THE FOXBORO 823DP TRANSMITTERS HAVE A FASTER RESPONSE TIME THAN THE EXISTING TRANSMITTERS. MODERN DISTRIBUTIVE CONTROL SYSTEMS ARE USED AS CONTROLLERS WHICH ARE MUCH FASTER THAN THE PNEUMATIC CONTROLLER SYSTEMS. THEREFORE THE RESPONSE TIME OF THE NEW CONTROL SYSTEM IS ACCEPTABLE.

4.2c) CALIBRATED SPAN AND SETPOINTS

FEEDWATER HEATER SETPOINTS GIVEN BELOW ARE FOR CALIBRATION. CONTROL POINTS MAY BE TAKEN ANY WHERE IN BETWEEN LOW AND HIGH LEVEL ALARM SETPOINTS IN ORDER TO ACHIEVE THE MAXIMUM HEATER EFFICIENCY AND ARE SET AT RESTART TESTING.

HEATER #	CALIBRATED SPAN INWC	SPAN IN INCHES	LOCAL LOW LVL ALARM INCHES	MCR HIGH LVL ALARM INCHES
1	43.5-5.4	0-44	4	26
2	35.7-3.4	0-36	3.5	28
3	35.8-2.8	0-36	3.5	28
4	44.8-2.2	0-45	12.5	34
5	38.8-9.8	0-30	3	23

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.2) LOOP FUNCTION AND REQUIREMENTS

4.2d) CALIBRATED SPAN OF LEVEL TRANSMITTERS

NOTE: STEAM PROPERTIES ARE TAKEN FROM CRANE TECHNICAL PAPER NO.410, "FLOW OF FLUIDS". DENSITY OF WATER AT STANDARD CONDITION (60°F) IS 62.371 POUNDS PER CUBIC FEET.

GUARANTEE THROTTLE FLOW, 3 REACTOR FEED PUMPS RUNNING - 100 % POWER. SEE RFERENCE 52. THESE VALUES ARE USED TO SPAN THE TRANSMITTERS

HEATER #	SPAN ACTUAL	PRESSURE PSIA	TEMP. °F		SPECIFIC VOLUME v	DENSITY lb/C FT	SPECIFC GRAVITY
1	44	195	380	WATER	0.01836	54.47	0.873
				STEAM	2.3438		
2	36	106	332	WATER	0.01779	56.21	0.9012
				STEAM	4.1931		
3	36	65	298	WATER	0.017433	57.36	0.9197
				STEAM	6.6533		
4	45	25	239	WATER	0.016927	59.08	0.947
				STEAM	16.301		
5	30	8	184	WATER	0.016527	60.51	0.970
				STEAM	47.345		

REFERENCE LEG SPECIFIC VOLUME OF WATER AT 90°F IS 0.016099 CU.FT/lbm AND SPECIFIC GRAVITY 0.996

FEEDWATER HEATER #1

PRESSURE AT REFERENCE LEG = 44 · 0.996 = 43.824 INWC

PRESSURE AT FULL HEATER LEVEL = 44 · 0.873 = 38.412 INWC

PRESSURE AT ZERO HEATER LEVEL = 44 · 1/2.3438 · 1/1728 · 1728/62.371
= 0.301 INWC

ΔP AT FULL LEVEL = PRESSURE AT REF.LEG - PRESSURE AT FULL LEVEL
= 43.824 - 38.412 = 5.412
= 5.4 INWC

ΔP AT LEVEL EMPTY = PRESSURE AT REF. LEG - PRESSURE AT ZERO LEVEL
= 43.824 - 0.301 = 43.523
= 43.5 INWC

THEREFORE HEATER LEVEL 0 TO 44 INCHES CORRESPONDS TO 43.5 TO 5.4 INWC AT THE TRANSMITTER INPUT.

4) DESIGN INPUT DATA

4.2) LOOP FUNCTION AND REQUIREMENTS (CONTINUED)

4.2d) CALIBRATED SPAN OF LEVEL TRANSMITTERS (CONTINUED)

FEEDWATER HEATER #2

PRESSURE AT REFERENCE LEG = 36 · 0.996 = 35.856 INWC

PRESSURE AT FULL HEATER LEVEL = 36 · 0.9012 = 32.443 INWC

PRESSURE AT ZERO HEATER LEVEL = 36 · 1/4.1931 · 1/1728 · 1728/62.371
= 0.1377 INWC

ΔP AT FULL LEVEL = PRESSURE AT REF.LEG - PRESSURE AT FULL LEVEL
= 35.856 - 32.443 = 3.413
= 3.4 INWC

ΔP AT LEVEL EMPTY = PRESSURE AT REF. LEG - PRESSURE AT ZERO LEVEL
= 35.856 - 0.1377 = 35.718
= 35.7 INWC

THEREFORE HEATER LEVEL 0 TO 36 INCHES CORRESPONDS TO 35.7 TO 3.4 INWC AT THE TRANSMITTER INPUT.

FEEDWATER HEATER #3

PRESSURE AT REFERENCE LEG = 36 · 0.996 = 35.856 INWC

PRESSURE AT FULL HEATER LEVEL = 36 · 0.9197 = 33.109 INWC

PRESSURE AT ZERO HEATER LEVEL = 36 · 1/6.6533 · 1/1728 · 1728/62.371
= 0.0868 INWC

ΔP AT FULL LEVEL = PRESSURE AT REF.LEG - PRESSURE AT FULL LEVEL
= 35.856 - 33.109 = 2.747
= 2.8 INWC

ΔP AT LEVEL EMPTY = PRESSURE AT REF. LEG - PRESSURE AT ZERO LEVEL
= 35.856 - 0.0868 = 35.769
= 35.8 INWC

THEREFORE HEATER LEVEL 0 TO 36 INCHES CORRESPONDS TO 35.8 TO 2.8 INWC AT THE TRANSMITTER INPUT.

4) DESIGN INPUT DATA

4.2) LOOP FUNCTION AND REQUIREMENTS (CONTINUED)

4.2d) CALIBRATED SPAN OF LEVEL TRANSMITTERS (CONTINUED)

FEEDWATER HEATER #4

PRESSURE AT REFERENCE LEG = 45 · 0.996 = 44.820 INWC

PRESSURE AT FULL HEATER LEVEL = 45 · 0.947 = 42.615 INWC

PRESSURE AT ZERO HEATER LEVEL = 45 · 1/16.301 · 1/1728 · 1728/62.371
= 0.0443 INWC

ΔP AT FULL LEVEL = PRESSURE AT REF.LEG - PRESSURE AT FULL LEVEL
= 44.820 - 42.615 = 2.205
= 2.2 INWC

ΔP AT LEVEL EMPTY = PRESSURE AT REF. LEG - PRESSURE AT ZERO LEVEL
= 44.820 - 0.0443 = 44.776
= 44.8 INWC

THEREFORE HEATER LEVEL 0 TO 45 INCHES CORRESPONDS TO 44.8 TO 2.2 INWC AT THE TRANSMITTER INPUT.

FEEDWATER HEATER #5

PRESSURE AT REFERENCE LEG = 39 · 0.996 = 38.844 INWC

PRESSURE AT FULL HEATER LEVEL = 30 · 0.970 = 29.100 INWC

PRESSURE AT ZERO HEATER LEVEL = 30 · 1/47.345 · 1/1728 · 1728/62.371
= 0.0102 INWC

ΔP AT FULL LEVEL = PRESSURE AT REF.LEG - PRESSURE AT FULL LEVEL
= 38.844 - 29.100 = 9.744
= 9.8 INWC

ΔP AT LEVEL EMPTY = PRESSURE AT REF. LEG - PRESSURE AT ZERO LEVEL
= 38.844 - 0.0102 = 38.8338
= 38.8 INWC

THEREFORE HEATER LEVEL 0 TO 30 INCHES CORRESPONDS TO 38.8 TO 9.8 INWC AT THE TRANSMITTER INPUT.

4) DESIGN INPUT DATA

4.2) LOOP FUNCTION AND REQUIREMENTS (CONTINUED)

4.2a) CORRECTION FACTOR FOR DIFFERENT REACTOR POWER LEVEL FOR EACH FEEDWATER HEATER

1. 75 % VWO THROTTLE FLOW, 3 REACTOR FEED PUMPS RUNNING
   – 75 % POWER, REFERENCE 53.

HEATER #	SPAN ACTUAL	PRESSURE PSIA	TEMP. °F	SPECIFIC VOLUME v	DENSITY lb/C FT	SPECIFC GRAVITY
1	44	154	360	0.01812	55.19	0.885
2	36	84	316	0.017608	56.79	0.910
3	36	52	284	0.017296	57.81	0.927
4	45	20	228	0.016834	59.40	0.952
5	30	7	175	0.016491	60.64	0.972

2. 50 % VWO THROTTLE FLOW, 3 REACTOR FEED PUMPS RUNNING
   – 50 % POWER, REFERENCE 55.

HEATER #	SPAN ACTUAL	PRESSURE PSIA	TEMP. °F	SPECIFIC VOLUME v	DENSITY lb/C FT	SPECIFC GRAVITY
1	44	104	331	0.01777	56.27	0.902
2	36	57	289	0.017351	57.63	0.924
3	36	36	260	0.017097	58.49	0.938
4	45	14	208	0.016702	59.87	0.960
5	30	5	159	0.016407	60.95	0.977

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.2) LOOP FUNCTION AND REQUIREMENTS (CONTINUED)

4.2e) CORRECTION FACTOR FOR DIFFERENT REACTOR POWER LEVEL FOR EACH FEEDWATER HEATER

3. 25 % VWO THROTTLE FLOW, 3 REACTOR FEED PUMPS RUNNING
- 25 % POWER, REFERENCE 53.

HEATER #	SPAN ACTUAL	PRESSURE PSIA	TEMP. °F	SPECIFIC VOLUME v	DENSITY lb/C FT	SPECIFC GRAVITY
1	44	52	283	0.017296	57.82	0.927
2	36	29	248	0.016993	58.85	0.944
3	36	18	223	0.016793	59.55	0.955
4	45	7	177	0.016491	60.64	0.972
5	40	3	134	0.01630	61.34	0.984

4.2f) TO OBTAIN LEVEL AT POWER OTHER THAN 100 % POWER, A CONVERSION FACTOR IS CALCULATED (SPECIFIC GRAVITY AT POWER LEVEL / SPECIFIC GRAVITY AT 100% POWER) AS SHOWN BELOW. FOR DIFFERENT LEVELS OF REACTOR POWER, ACTUAL LEVEL = INDICATOR READING MULTIPLIED BY (%/100)

HEATER #	SPAN ACTUAL INCHES	REACTOR POWER 75% %	REACTOR POWER 50% %	REACTOR POWER 25% %
1	44	101.4	103.3	106.2
2	36	101.0	102.5	104.7
3	36	100.8	102.0	103.8
4	45	100.5	101.4	102.6
5	30	100.2	100.7	101.4

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.3) COMPONENT DATA

VALID FOR: ALL TRANSMITTERS IDENTIFIED ON SHEETS: 12 THRU 19

CONTRACT #: 82127 D REF #: 47 NOTE(S): N/A

MANUFACTURER/MODEL: FOXBORO 823DP REF #: 47

INSTRUMENT RANGE: 0 TO 2 AND 150 INWC REF #: 26 NOTE(S): N/A

INPUT RANGE & UNITS: 0 TO 150 INWC OUTPUT RANGE & UNITS: DIGITAL

OVERRANGE LIMIT: 3000 PSIG REF #: 26 NOTE(S): N/A

MIN/MAX ABNORMAL TEMP: SEE NOTE 1 ACCIDENT TEMP: SAME

RADIATION TID (RAD): SEE NOTE 1 RADIATION IAD (RAD): N/A

40 YEAR NID (RAD): SEE NOTE 1 REF #: N/A NOTE(S): 1

FUNCTIONAL REQUIREMENTS PER MCEL: REF #: N/A NOTE(S): N/A

	EVENT	CAT.	OPER. TIME
LOCA	N/R		
HELB-IPC	N/R		
HPCI-OPC	N/R		
RCIC-OPC	N/R		
RWCU-OPC	N/R		
MS-OPC	N/R		

X MILD ENVIRONMENT, THEREFORE, NOT APPLICABLE.

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.3) COMPONENT DATA (CONTINUED)

VALID FOR: ALL LT IDENTIFIED ON SHEETS: 12 THRU 19

ACCURACY PARAMETERS:

TYPE	VALUE	NOTE	REFERENCES
Re	± 0.032 INWC	2	26
De	± 0.140 INWC	3	26
TNe	± 0.200 INWC	4	26
SPEe	± 0.032 INWC	5	26, 42
SECu	± 0.042 INWC	6	26, 42
PSEe	± 0.003 INWC	7	26, 50
RNDe	0	9	11, 5
ICTe	± 0.1 INWC	11	46
ICRe	± 0.1 INWC	12	46
OCTe	± 0.1 INWC	11	46
OCRe	0	13	N/A
Ab	± 0.1 INWC	10	1, 26
So	N/A	15	26
RADe	N/A	1	N/A
TAe	N/A	1	N/A
MTe	± 0.5 INWC	18	N/A
IRe	0	14	4
WLe	CORRECTION FACTOR USED	17	N/A
RFIe	± 0.045 INWC	8	26
SHP	N/A	17	N/A

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.4) COMPONENT DATA NOTES : COMPONENT ALL LTs

#	NOTES

1 TRANSMITTERS ARE LOCATED IN THE TURBINE BUILDING GENERAL FLOOR AREA ELEVATION 586'/ 557' OUTSIDE THE HEATER ROOMS. THE TEMPERATURE IN THE HEATER ROOM IS HIGH. THE GENERAL FLOOR AREA IS VENTILATED AND BY ENGINEERING JUDGEMENT THE WORST TEMPERATURE CAN NEVER EXCEED 120°F. THEREFORE THE WORST CASE TEMPERATURE THE TRANSMITTER WILL EVER SEE IS 120 °F. THIS IS ESSENTIALLY A MILD AREA AND HENCE THE RADIATION IN THIS AREA IS NEGLIGIBLE. THE TOTAL INTEGRATED DOSE NEVER EXCEEDS $\leq 5 \times 10^4$ RADS.

THUS,

RADe = N/A TAe = N/A

2 PER REFERENCE 26, THE TRANSMITTER REFERENCE ACCURACY FOR A DIGITAL LINEAR OUTPUT IS ± 0.07 % OF CALIBRATED SPAN, WHICH INCLUDES LINEARITY, HYSTERESIS AND REPEATABILITY. FOR A 45 IN SPAN (THE LARGEST SPAN IN ALL TRANSMITTER IS 45"), THE REPEATABILITY IS

$Re = \pm .0007 \cdot 45$ INWC

$Re = \pm 0.032$ INWC

3 PER REFERENCE 26, THE DRIFT OF THE TRANSMITTER OVER A PERIOD OF 6 MONTHS IS ± 0.07 % OF REFERENCE SPAN. A COMMONLY USED SPAN FOR EACH SENSOR HAS BEEN DEFINED AS THE REFERENCE SPAN, WHICH IS 100 INH_2O (25 kPa). THUS, FOR A 18 MONTH CALIBRATION INTERVAL INCLUDING TECH SPEC ALLOWANCE OF 25 % IS ADDED STATISTICALLY AS,

$De = \pm \sqrt{3 \cdot 1.25} \cdot 0.0007 \cdot 100$ INWC

$De = \pm 0.13555$ INWC

$De = \pm 0.14$ INWC

4 PER REFERENCE 26, THE TOTAL TEMPERATURE EFFECT FOR THIS TRANSMITTER IS ± 0.2 % OF REFERENCE SPAN FOR A TEMPERATURE RANGE -20°F TO +180° F. THE MAXIMUM CHANGE IN THE ABNORMAL TEMPERATURE RANGE IS LOW IN THE TURBINE BUILDING AND THE TRANSMITTER TEMPERATURE EFFECT IN THE TURBINE BUIDING IS,

$TNe = \pm (0.002 \cdot 100)$ INWC

$TNe = \pm 0.2$ INWC

5 PER REFERENCE 26, THE STATIC PRESSURE EFFECT FOR THIS 316 SS SENSOR DIAPHRAGM TRANSMITTER IS CATAGORIZED AS ZERO SHIFT AND TOTAL EFFECT FOR 1000 PSI. THE MAXIMUM DESIGN PRESSURE IN THE SHELL SIDE OF FEEDWATER HEATER IS 208 PSI (REFERENCE 42). PER REFERENCE THE ZERO SHIFT FOR 1000 PSI PRESSURE IS ± 0.15 % OF REFERENCE SPAN. HENCE

$SPEe = \pm(0.0015/1000\ PSI) \cdot 208\ PSI \cdot 100$ INWC

$SPEe = \pm 0.032$ INWC

part of BFN TS-447 RAI Enclosure 3

4) DESIGN INPUT DATA

4.4) COMPONENT DATA NOTES : COMPONENT ALL LTs

#	NOTES

6 THE SPAN ERROR CORRECTION UNCERTAINITY PER REFERENCE 26 IS ± 0.2 % OF REFERENCE SPAN FOR A 1000 PSI PRESSURE. HENCE

SECu = ±(0.002/1000 PSI) · 208 · 100 INWC

<u>SECu = ± 0.042 INWC</u>

SINCE THE STATIC PRESSURE SPAN EFFECT IS SYSTEMATIC, IT CAN BE CALIBRATED OUT. BUT THEY ARE NOT CALIBRATED OUT IN THESE LOOPS. HENCE, TO PROVIDE ADDITIONAL MARGIN FOR NOT CORRECTING THE SPAN, THE STATIC PRESSURE SPAN INACCURACY WILL BE CONSIDERED IN THIS CALCULATION.

7 PER REFERENCE 26, THE TRANSMITTER INACCURACY DUE TO POWER SUPPLY VARIATIONS IS LESS THAN ± 0.005% OF OUTPUT SPAN PER VOLT. THE OUTPUT SPAN CORRESPONDS TO 45 INWC. PER REFERENCE 50, THE POWER SUPPLY REGULATED OUTPUT IS 24 VDC +4%/-2%, A VARIATION OF ± 1.44 V. THE POWER SUPPLY IS LOCATED IN A MILD AREA AND THE INACCURACY GIVEN IS VALID FOR A TEMPERATURE OF 40°F TO 120 °F. HENCE,

PSEe = ± 0.00005/V · 1.44 V · 45 INWC

PSEe = ± 0.003 INWC

<u>PSEe = ± 0.003 INWC</u>

8 PER REFERENCE 26, THE RFI EFFECT OUTPUT ERROR IS 0.1 % OF CALIBRATED SPAN FOR A RADIO FREQUENCIES IN THE RANGE OF 27 TO 500 MHz AND FIELD INTENSITY OF 30V/M WHEN THE TRANSMITTER IS PROPERLY INSTALLED AND HOUSING COVER ARE IN PLACE. THUS

RFIe = ± 0.001 · 45 INWC

<u>RFIe = ± 0.045 INWC</u>

9 THE TRANSMITTER IS LOCATED IN THE TURBINE BUILDING. RADIATION ENVIRONMENT IS ≤ 5 X 10^4 RADS. PER REFERENCE 5, TRANSMITTER INACCURACY DUE TO A RADIATION ENVIRONMENT OF ≤ 5.4 X 10^4 RADS IS NEGLIGIBLE. THEREFORE,

<u>RNDe = 0</u>

10 PER REFERENCE 1, THE ACCEPTANCE BAND CAN BE SELECTED TO TWICE THE REFERENCE ACCURACY OF THE DEVICE. SINCE THERE ARE MARGIN IN THIS CALCULATION, BY ENGINEERING JUDGEMENT Ab IS TAKEN AS THREE TIMES THE REPEATABILITY. THUS,

Ab = 3 · Re

<u>Ab = ± 0.1 INWC</u>

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.4) COMPONENT DATA NOTES : COMPONENT ALL LTs

#	NOTES
11	FOXBORO INTELLIGENT AUTOMATION SERIES MODEL HHT HAND-HELD TERMINAL IS USED AS THE OUTPUT TEST INSTRUMENT. THE INACCURACY IS NOT GIVEN. PER REFERENCE 46, THE CONTROL OF MEASURING AND TEST EQUIPMENT SHALL IN NO CASE BE LESS ACCURATE THAN THE DEVICE BEING CALIBRATED. THEREFORE, ICTe = Ab AND OCTe = Ab ICTe = ± 0.1 INWC OCTe = ± 0.1 INWC
12	PER ENGINEERING JUDGEMENT, THE READING ERROR OF THE INPUT M&TE WILL NOT BE GREATER THAN THE ACCURACY OF THE M&TE. THEREFORE, ICRe = ICTe ICRe = ± 0.1 INWC
13	THERE IS NO READING ERROR ASSOCIATED WITH THE HHT HAND-HELD TERMINAL, WHICH IS USED TO MEASURE THE TRANSMITTER OUTPUT. OCRe = 0
14	REFERENCE 4 CONCLUDES THAT THERE IS NO INACCURACY DUE TO CABLE LEAKAGE CURRENT FOR INSTRUMENTATION LOOPS IN A HARSH ENVIRONMENT AT BROWNS FERRY. FURTHERMORE, THE TRANSMITTERS (AND THEIR ASSOCIATED CABLES) ARE NOT LOCATED IN A HARSH ENVIRONMENT IN TERMS OF UNIT 2. IRe = 0
15	SINCE THE LOOP IS NOT SAFETY RELATED, IT IS NOT REQUIRED TO FUNCTION AFTER A SEISMIC EVENT, THEREFORE Se IS N/A Se = N/A
16	THERE IS NO INDICATOR READING ERROR ASSOCIATED WITH A TRANSMITTER. INDRe = N/A
17	SINCE IT IS A LEVEL INSTRUMENT, THERE IS NO STATIC HEAD PRESSURE CORRECTION. THIS TRANSMITTER SENSES THE DIFFERENCE IN STATIC HEAD TO MEASURE THE LEVEL IN VESSEL. THE WATER LEG EFFECT VARIES WITH REACTOR POWER AND IS CALCULATED SEPERATELY IN PAGE 21 TO 23. WATERLEG EFFECT IS NOT TAKEN AS AN ERROR, BUT USED AS A CORRECTION FACTOR TO THE HEATER LEVEL INDICATION. THE OPERATOR IS PROVIDED WITH A TABLE OF INDICATION CORRECTION FACTOR AT DIFFERENT LEVELS REACTOR POWER (SEE PAGE 23). SHP = N/A WLe = CORRECTION FACTOR IS USED
18	SINCE THE LOCATION OF CONDENSATE POT IS NOT EXACT, A MOUNTING PROCESS ERROR IS CONSIDERED AND BY ENGINEERING JUDGEMENT, IT IS TAKEN AS ± 0.5 INWC MTe = ± 0.5 INWC

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.5) COMPONENT DATA FOR I/P SIGNAL CONVERTER

VALID FOR: I/P SIGNAL CONVERTERS IDENTIFIED ON SHEETS: 12-19

CONTRACT #: 82127 D REF #: N/A NOTE(S): N/A

MANUFACTURER/MODEL: FOXBORO/ E69F REF #: 48 NOTE(S): N/A

INSTRUMENT RANGE: 4 TO 20 MA REF #: 48 NOTE(S): N/A

INPUT RANGE & UNITS: 4 TO 20 mA OUTPUT RANGE & UNITS: 3 TO 15 PSI

OVERRANGE LIMIT: N/A REF #: 48 NOTE(S): ____

MIN/MAX ABNORMAL TEMP: SEE NOTE 1 ACCIDENT TEMP: N/A

RADIATION TID (RAD): ≤ 5E10⁴ RADIATION IAD (RAD): N/A

40 YEAR NID (RAD): < 5E10⁴ REF #: ____ NOTE(S): ____

FUNCTIONAL REQUIREMENTS PER MCEL: REF #: N/A NOTE(S): N/A

	EVENT	CAT.	OPER. TIME
LOCA	N/R		
HELB-IPC	N/R		
HPCI-OPC	N/R		
RCIC-OPC	N/R		
RWCU-OPC	N/R		
MS-OPC	N/R		

N/A MILD ENVIRONMENT, THEREFORE, NOT APPLICABLE.

REV____ PREP__________ DATE________ CHECK__________ DATE________ SHT 29 C/O____

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-H2006-920370

4) DESIGN INPUT DATA

4.5) COMPONENT DATA (CONTINUED)

VALID FOR: I/P SIGNAL CONVERTER IDENTIFIED ON SHEETS: 12-19

ACCURACY PARAMETERS:

TYPE	VALUE	NOTE	REFERENCES
Re	± 0.32 MA	3	48
De	± 0.32 MA	4	48
TNe	± 0.16 MA	5	48
SPEe	N/A	6	N/A
SECu	N/A	6	N/A
ASEe	± 0.08 MA	7	48
RNDe	N/A	8	--
ICTe	± 0.32 MA	10	36
ICRe	0	11	N/A
OCTe	± 0.32 MA	10	36
OCRe	± 0.32 MA	10	N/A
Ab	± 0.32 MA	9	1
Se	N/A	13	N/A
RADe	0	2	N/A
TAe	0	2	N/A
INDRe	N/A	14	N/A
SHP	N/A	15	N/A
IRe	0	12	4

4) DESIGN INPUT DATA

4.6) COMPONENT DATA NOTES : COMPONENT ALL I/P SIGNAL CONVERTERS

#	NOTES
1	THE I/P SIGNAL CONVERTER OUTPUT RANGE OF 3 TO 15 PSI CORRESPONDS TO AN INPUT OF 4 TO 20 MA. ACCURACIES IN THIS SECTION WILL BE DETERMINED IN UNITS OF MA.

2 ALL I/P SIGNAL CONVERTERS ARE LOCATED IN THE TURBINE BUILDING GENERAL FLOOR AREA ELEVATION 586'/ 557'OUTSIDE THE HEATER ROOMS. THE TEMPERATURE IN THE HEATER ROOM IS SUBSTANTIALLY HIGH. THE GENERAL FLOOR AREA IS VENTED AND BY ENGINEERING JUDGEMENT THE WORST TEMPERATURE CAN NEVER EXCEED 120°F. THEREFORE THE WORST CASE TEMPERATURE THE I/P CONVERTER WILL EVER SEE IS 120 °F. THIS IS ESSENTIALLY A MILD AREA AND HENCE THE RADIATION IN THIS AREA IS NEGLIGIBLE. THE TOTAL INTEGRATED DOSE NEVER EXCEEDS $\leq 5 \times 10^4$ RADS. THUS:

RADe = N/A   TAe = N/A

3 PER REFERENCE 48, THE I/P CONVERTER WORSE CASE REFERENCE ACCURACY FOR AN OUTPUT SIGNAL CODE OF 7 IS ± 2.0 % OF CALIBRATED SPAN, WHICH INCLUDES LINEARITY, HYSTERESIS AND REPEATABILITY. FOR A 16 MA SPAN, THE REPEATABILITY IS

$Re = \pm .02 \cdot 16$ MA

$Re = \pm 0.32$ MA

4 THE DRIFT OF THE I/P CONVERTER IS NOT GIVEN IN REFERENCE 48. HENCE IT IS CONSERVATIVE TO USE THE REPEATABILITY AS THE DRIFT FOR A CALIBRATION CYCLE OF 18+25% MONTHS. THUS, FOR A 18 MONTH CALIBRATION INTERVAL INCLUDING TECH SPEC ALLOWANCE OF 25 % IS:

$De = \pm 0.02 \cdot 16$ MA

$De = \pm 0.32$ MA

$De = \pm 0.32$ MA

5 PER REFERENCE 48, THE AMBIENT TEMPERATURE CHANGE OF 50 °F, BASED ON A 100 °F CYCLE WITHIN THE OPERATIVE LIMITS, WILL CAUSE ZERO AND SPAN SHIFTS OF ± 1.0 % OF SPAN OR LESS. THE MAXIMUM CHANGE IN THE ABNORMAL TEMPERATURE RANGE IS LOW IN THE TURBINE BUILDING AND THE I/P CONVERTER TEMPERATURE EFFECT IN THE TURBINE BUIDING IS,

$TNe = \pm (0.01 \cdot 16)$ MA

$TNe = \pm 0.16$ MA

6 THE STATIC PRESSURE EFFECT (SPEe) AND SPAN ERROR CORRECTION UNCERTAINITY (SECu) FOR THE I/P CONVERTER IS NOT APPLICABLE:

SPEe = N/A   SECu = N/A

7 THE I/P CONVERTER INACCURACY DUE TO AIR SUPPLY VARIATIONS IS LESS THAN ± 0.25 % OF SPAN PER PSI (REFERENCE 48). THE AIR SUPPLY IS REGULATED TO 20 PSI BY A REGULATOR, WHICH HAS AN ACCURACY OF 2 PSI BY ENGINEERING JUDGEMENT. THEREFORE THE AIR SUPPLY EFFECT IS

$ASEe = \pm 0.0025 \cdot 2 \cdot (15-3)$ PSI $\cdot 16/12$ MA
$ASEe = \pm 0.08$ MA
$ASEe = \pm 0.08$ MA

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.6) COMPONENT DATA NOTES : COMPONENT ALL I/P SIGNAL CONVERTERS

#	NOTES
8	THE TRANSMITTER IS LOCATED IN THE TURBINE BUILDING. RADIATION ENVIRONMENT IS ≤ 5 X 10⁴ RADS. PER REFERENCE 5, TRANSMITTER INACCURACY DUE TO A RADIATION ENVIRONMENT OF ≤ 5.4 X 10⁴ RADS IS NEGLIGIBLE. THEREFORE, RNDe = 0
9	PER ENGINEERING JUDGEMENT AND REFERENCE 1, THE ACCEPTANCE BAND IS SELECTED TO EQUAL THE REFERENCE ACCURACY OF THE DEVICE. THUS, Ab = Re Ab = ± 0.32 MA
10	PER REFERENCE 46, THE CONTROL OF MEASURING AND TEST EQUIPMENT SHALL IN NO CASE BE LESS ACCURATE THAN THE DEVICE BEING CALIBRATED. THEREFORE, ICTe = Ab AND OCTe = Ab OCRe = Ab ICTe = ± 0.32 MA OCTe = ± 0.32 MA OCRe = ± 0.32 MA
11	THERE IS NO READING ERROR ASSOCIATED WITH A DMM, WHICH IS USED TO MEASURE THE I/P CONVERTER INPUT CURRENT. ICRe = 0
12	REFERENCE 4 CONCLUDES THAT THERE IS NO INACCURACY DUE TO CABLE LEAKAGE CURRENT FOR INSTRUMENTATION LOOPS IN A HARSH ENVIRONMENT AT BROWNS FERRY. FURTHERMORE, THE TRANSMITTERS (AND THEIR ASSOCIATED CABLES) ARE NOT LOCATED IN A HARSH ENVIRONMENT IN TERMS OF UNIT 2. IRe = 0
13	SINCE THE LOOP IS NOT SAFETY RELATED, IT IS NOT REQUIRED TO FUNCTION AFTER A SEISMIC EVENT, THEREFORE Se IS N/A Se = N/A
14	THERE IS NO INDICATOR READING ERROR ASSOCIATED WITH AN I/P CONVERTER. INDRe = N/A
15	STATIC HEAD PRESSURE AND WATERLEG ERROR ARE NOT APPLICABLE IN THIS APPLICATION SHP = N/A WLe = N/A

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.7) COMPONENT DATA FOR POSITIONER

VALID FOR: POSITIONERS IDENTIFIED ON SHEETS: 12-19

CONTRACT #: 82127 D REF #: ____ NOTE(S): N/A

MANUFACTURER/MODEL: FOXBORO/ TYPE C REF #: ____ NOTE(S): N/A

INSTRUMENT RANGE: 3 TO 15 PSI REF #: ______ NOTE(S): N/A

INPUT RANGE & UNITS: 3 TO 15 PSI OUTPUT RANGE & UNITS: 0 TO 100 %

OVERRANGE LIMIT: N/A REF #: ______ NOTE(S): _____

MIN/MAX ABNORMAL TEMP: SEE NOTE 1 ACCIDENT TEMP: N/A

RADIATION TID (RAD): SEE NOTE 1 RADIATION IAD (RAD): N/A

40 YEAR NID (RAD): SEE NOTE 1 REF #: _____ NOTE(S): _____

FUNCTIONAL REQUIREMENTS PER MCEL: REF #: N/A NOTE(S): N/A

	EVENT	CAT.	OPER. TIME
LOCA	N/R		
HELB-IPC	N/R		
HPCI-OPC	N/R		
RCIC-OPC	N/R		
RWCU-OPC	N/R		
MS-OPC	N/R		

N/A MILD ENVIRONMENT, THEREFORE, NOT APPLICABLE.

NOTE 1: THE POSITIONER IS LOCATED ON THE VALVE IN THE TURBINE BUILDING HEATER ROOM. THE ENVIRONMENTAL CONDITION IN THESE ROOMS ARE NOT AVAILABLE.

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.8) COMPONENT DATA

VALID FOR: DISTRIBUTIVE CONTROL SYSTEM IDENTIFIED ON SHEETS: 12

CONTRACT #: 82127 D REF #: ________ NOTE(S): N/A

MANUFACTURER/MODEL: FOXBORO / DCS REF #: ______ NOTE(S): N/A

INPUT RANGE & UNITS: DIGITAL OUTPUT RANGE & UNITS: 4 TO 20 MA

MIN/MAX ABNORMAL TEMP: NOTE 1 ACCIDENT TEMP: N/A

RADIATION TID (RAD): NOTE 1 RADIATION IAD (RAD): NOTE 1

40 YEAR NID (RAD): NOTE 1 REF #: ________ NOTE(S): N/A

FUNCTIONAL REQUIREMENTS PER MCEL FOR SYSTEM 071: NOTE(S): N/A

	EVENT	CAT.	OPER. TIME
LOCA	N/A		
HELB-IPC	N/A		
HPCI-OPC	N/A		
RCIC-OPC	N/A		
RWCU-OPC	N/A		
MS-OPC	N/A		

_X_ MILD ENVIRONMENT, THEREFORE, NOT APPLICABLE.

NOTE 1: THE POSITIONER IS LOCATED ON THE VALVE IN THE TURBINE BUILDING HEATER ROOM. THE ENVIRONMENTAL CONDITION IN THESE ROOMS ARE NOT AVAILABLE.

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

4) DESIGN INPUT DATA

4.9) COMPONENT DATA NOTES AND VALUES

THE TWO WIRE INTELLIGENT TRANSMITTER MEASURES DIFFERENTIAL PRESSURE AND TRANSMITS A DIGITAL OUTPUT SIGNAL. THE FOLLOWING FOXBORO PRODUCTS ARE USED USED BEFORE THE SIGNAL IS CONVERTED TO PNEUMATIC AT THE I/P CONVERTER.

1) INTELLIGENT AUTOMATION SERIES MODEL HHT HAND HELD TERMINAL.

2) INTELLIGENT AUTOMATION SERIES PANEL DISPLAY STATION.

3) INTELLIGNT AUTOMATION SERIES AUTO/MANUAL STATION.

4) I/A SERIES INTELLIGENT TRANSMITTER INTERFACE MODULE

A REVIEW OF THE PRODUCT SPECIFICATION SHOWS THAT THE WORSE CASE INACCURACY IS FOR THE AUTO/ MANUAL STATION, WHICH IS 0.5 %. THEREFORE AS A CONSERVATIVE APPROACH THE TOTAL DISTRIBUTIVE CONTROL SYSTEM IS 1 % OF SPAN.

THUS NORMAL MEASURABLE/ UNMEASURABLE ACCURACY IS

$An_0 = \pm 1$ % OF SPAN

$\underline{An_0 = \pm .01 \cdot 45 = \pm 0.45 \text{ INWC}}$

THE ACCEPTABLE AS LEFT VALUE IS

$\underline{Ab_0 = \pm 0.45 \text{ INWC}}$

5. DOCUMENTATION OF ASSUMPTIONS:

SEE SECTION 2

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Example Calculation

SETPOINT AND SCALING CALCULATIONS
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6) ACCURACY CALCULATIONS / ANALYSES

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6.3 TRANSMITTER ACCURACY

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NORMAL ACCURACY	An_T
ACCEPTANCE BAND	Ab_T

6.4 I/P SIGNAL CONVERTER

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NORMAL ACCURACY	An_M
NORMAL ACCURACY IN INWC	An_{M_INWC}
ACCEPTANCE BAND	Ab_M
ACCEPTANCE BAND IN INWC	Ab_{M_INWC}

6.5 DISTRIBUTIVE CONTROLLER ACCURACY

NORMAL MEASURABLE ACCURACY	Anf_D
ACCEPTANCE BAND	Ab_D

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
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6) ACCURACY CALCULATIONS / ANALYSES

I N D E X (CONTINUED)

6.6	DISTRIBUTIVE CONTROL LOOP ACCURACY	
	LOOP NORMAL MEASURABLE ACCURACY	$LAnf_D$
	LOOP NORMAL ACCURACY	LAn_D
	LOOP ACCIDENT ACCURACY	LAa_D
	LOOP POST SEISMIC ACCURACY	LAs_D
	LOOP COMBINED ACCIDENT AND POST SEISMIC ACCURACY	$LAas_D$
	LOOP DESIGN BASIS EVENT ACCURACY	$LAdbe_D$
	LOOP ACCEPTANCE BAND	LAb_D
6.8	PLANT OPERATIONS PARAMETERS	
	ANALYTICAL LIMIT	AL
	CONTROLLER OPERATIONAL LIMIT	
	ALLOWABLE VALUE	AV
	MARGIN	
	CONTROLLER LOOP ACCEPTABLE AS FOUND	Alf_D
	CONTROLLER LOOP ACCEPTABLE AS LEFT	All_D

SETPOINT AND SCALING CALCULATIONS
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6) ACCURACY CALCULATIONS / ANALYSES

6.1) ACCURACY DISCUSSION

THE ACCURACY OF THESE INSTRUMENTS FOR NORMAL CONDITIONS WILL BE DETERMINED BY CONSIDERING THE PARAMETERS TABULATED IN THE DESIGN INPUT SECTION OF THIS CALCULATION.

THE SQUARE ROOT OF THE SUM OF THE SQUARES METHOD SHALL BE USED IN THIS CALCULATION FOR CALCULATING ACCURACY SINCE THE FACTORS AFFECTING ACCURACY ARE INDEPENDENT VARIABLES.

BIDIRECTIONAL ERRORS AND UNIDIRECTIONAL ERRORS, IF ANY, WILL BE COMBINED IN A MANNER SUCH THAT THE SUM OF THE POSITIVE UNIDIRECTIONAL ERRORS WILL BE ADDED TO THE POSITIVE PORTION OF THE BIDIRECTIONAL ERROR (OBTAINED FROM THE SQUARE ROOT OF THE SUM OF THE SQUARES METHOD), AND THE SUM OF THE NEGATIVE UNIDIRECTIONAL ERRORS WILL BE ADDED TO THE NEGATIVE PORTION OF THE BIDIRECTIONAL ERROR. THIS METHOD IS CONSERVATIVE AND WILL THEREFORE BE USED IN THIS CALCULATION.

LOOP ACCURACY INCLUDES THE TRANSMITTER AND DISTRIBUTED CONTROL SYSTEM ONLY. THE POSITIONER AND I/P SIGNAL CONVERTOR ARE NOT INCLUDED. THE DISTRIBUTED CONTROL OUTPUT IS A DEMAND SIGNAL BASED ON THE FEEDBACK SIGNAL AND SPANED BASED ON THE DISTRIBUTED CONTROL PROPORTIONAL BAND SET VALUES.

6.2) NUMERICAL CALCULATION METHODOLOGY

NUMERICAL CALCULATIONS IN THE FOLLOWING SECTIONS ARE PERFORMED USING MATHCAD SOFTWARE PACKAGE AND ARE VERIFIED BY HAND CALCULATIONS. LISTED BELOW ARE THE APPLICABLE ACCURACY PARAMETERS FROM SECTION 4 USED IN THESE CALCULATIONS AS DEFINED IN MATHCAD. UNLESS NOTED OTHERWISE, THE ACCURACY PARAMETERS LISTED BELOW AND THE VALUES CALCULATED IN THESE SECTIONS ARE BIDIRECTIONAL (+/-).

TRANSMITTER ACCURACY PARAMETERS

(VALUES IN INWC)

$Re_T = \pm 0.032$

$De_T = \pm 0.140$

$TNe_T = \pm 0.200$

$SPEe_T = \pm 0.032$,

$SECu_T = \pm 0.042$

$PSEe_T = \pm 0.003$

$ICTe_T = \pm 0.100$

$ICRe_T = \pm 0.100$

$OCTe_T = \pm 0.100$

$Ab_T = \pm 0.100$

$MTe_T = \pm 0.500$

$RFIe_T = \pm 0.045$

DISTRIBUTIVE CONTROL SYSTEM PARAMETER

(VALUES IN INCHES)

$Anf_D = \pm 0.45$

$Ab_D = \pm 0.45$

I/P SIGNAL CONVERTER PARAMETERS

(VALUES IN MA)

$Re_M = \pm 0.32$

$De_M = \pm 0.32$

$TNe_M = \pm 0.16$

$ASEe_M = \pm 0.08$

$ICTe_M = \pm 0.32$

$OCTe_M = \pm 0.32$

$OCRe_M = \pm 0.32$

$Ab_M = \pm 0.32$

SETPOINT AND SCALING CALCULATIONS
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6.3) TRANSMITTER NORMAL MEASURABLE ACCURACY

$$Anf_T = \sqrt{Re_T^2+De_T^2+TNe_T^2+RFI_T^2+SPEe_T^2+SECu_T^2+ICTe_T^2+ICRe_T^2+OCTe_T^2+Ab_T^2+PSEe_T^2}$$

$\underline{Anf_T = \pm\ 0.32\ INWC}$

TRANSMITTER NORMAL ACCURACY

$$An_T = \sqrt{Anf_T^2 + MTe_T^2}$$

$\underline{An_T = \pm\ 0.6\ INWC}$

TRANSMITTER ACCEPTANCE BAND

$\underline{Ab_T = \pm\ 0.1\ INWC}$

6.4) I/P SIGNAL CONVERTER ACCURACY

I/P NORMAL MEASURABLE ACCURACY

$$Anf_M = \sqrt{Re_M^2+De_M^2+TNe_M^2+ASEe_M^2+ICTe_M^2+OCTe_M^2+OCRe_M+Ab_M^2}$$

$\underline{Anf_M = \pm\ 0.8\ MA}$

$$Anf_{M\ INWC} = Anf_M * \frac{12}{16}$$

$\underline{Anf_{M\ INWC} = \pm\ 0.6\ PSI}$

I/P NORMAL ACCURACY

$An_M = Anf_M$

$\underline{An_M = \pm\ 0.8\ MA}$

I/P ACCEPTANCE BAND

$\underline{Ab_M = \pm\ 0.32\ MA}$

$$Ab_{M\ INWC} = Ab_M * \frac{12}{16}$$

$\underline{Ab_{M\ INWC} = \pm\ 0.24\ PSI}$

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6.5) DISTRIBUTIVE CONTROLLER ACCURACY

CONTROLLER NORMAL MEASURABLE ACCURACY

$Anf_D = \pm 0.45$ INCHES

$Ab_D = \pm 0.45$ INCHES

6.6) DISTRIBUTIVE CONTROL LOOP ACCURACY

CONTROLLER LOOP NORMAL MEASURABLE ACCURACY

$$LAnf_D = \sqrt{Anf_T^2 + Anf_D^2}$$

$LAnf_D = \pm 0.55$ INWC

CONTROLLER LOOP NORMAL ACCURACY

$$LAn_D = \sqrt{An_T^2 + Anf_D^2}$$

$LAnf_D = \pm 0.75$ INWC

CONTROL LOOP ACCIDENT AND POST SEISMIC ACCURACIES

SINCE THE CONTROLLER FUNCTTION IS NOT SAFETY RELATED, THE ACCIDENT AND POST SEISMIC ACCURACIES ARE NOT REQUIRED.

LAa_D = N/A

LAs_D = N/A

$LAas_D$ = N/A

$LAdbe_D$ = N/A

CONTROLLER LOOP ACCEPTANCE BAND

$$LAb_D = \sqrt{Ab_T^2 + Ab_D^2}$$

$LAb_D = \pm 0.46$ INWC

6) ACCURACY CALCULATIONS / ANALYSES

6.7) PLANT OPERATIONS PARAMETERS

ANALYTICAL LIMIT (AL)

SINCE THE CONTROLLER FUNCTION IS NOT SAFETY RELATED, THERE IS NO ANALYTICAL LIMIT ASSOCIATED WITH THE CONTROLLER.

AL = N/A

CONTROLLER OPERATIONAL LIMIT

SINCE THE LOOPS ARE NOT SAFETY RELATED, THERE IS NO SPECIFIC REQUIREMENTS FOR CONTROLLER LOOP ACCURACY. THE REQUIRED ACCURACY OF THE LOOP IS SELECTED TO EQUAL THE CONTROLLER LOOP NORMAL ACCURACY.

REQUIRED ACCURACY = LA_{R_2}

REQUIRED ACCURACY = ± 0.75 INWC

ALLOWABLE VALUE (AV)

SINCE THE LOOPS ARE NOT SAFETY RELATED, THEN THERE IS NO ALLOWABLE VALUE ASSOCIATED WITH THE SWITCH.

AV = N/A

MARGIN (M)

SINCE THERE IS NO ANALYTICAL LIMIT, THEN THERE IS NO MARGIN.

M = N/A

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SETPOINT AND SCALING CALCULATIONS
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6) ACCURACY CALCULATIONS / ANALYSES

6.7) PLANT OPERATIONS PARAMETERS (CONTINUED)

HEATER NUMBER 1, 2, 3, 4, AND 5

CONTROLLER LOOP ACCEPTABLE AS FOUND (Alf_n)

PER REFERENCE 1,

$Alf_n = LAnf_n$

$Alf_n = \pm 0.55$ INWC

CONTROLLER LOOP ACCEPTABLE AS LEFT (All_n)

PER REFERENCE 1,

$All_n = LAb_n$

$All_n = \pm 0.46$ INWC

$Ab_n = \pm 0.46$ INWC

7) SUMMARY OF RESULTS

FOR HIGH AND LOW LEVEL ALARM LOOPS, AND
FOR DISTRIBUTED CONTROLLER LOOPS

CALCULATED ACCURACY IS:

Anf = ± 0.55 INWC

An = ± 0.75 INWC

Ab = ± 0.46 INWC

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SETPOINT AND SCALING CALCULATIONS
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7) SUMMARY OF RESULTS (Continued)

LOOP NUMBER: 2-L-06-1 | CSSC? NO

LOOP FUNCTION: MONITOR THE REACTOR FEEDWATER HEATER LEVEL AND MAINTAIN THE REQUIRED WATER LEVEL BY CONTROLLING THE DISCHARGE FLOW.

LOOP ACCURACY:

FUNCTION	ALLOWABLE VALUE	ACCEPTABLE AS FOUND	ACCEPTABLE AS LEFT
REACTOR FEEDWATER HEATER 2A1	N/A	± 0.55 INWC	± 0.46 INWC

LOOP COMPONENTS:

NO.	UNID NO.	PROCESS RANGE/SETPOINT	CALIBRATION VALUE INPUT	CALIBRATION VALUE OUTPUT	ACCEPTABLE AS FOUND	ACCEPTABLE AS LEFT
1	2-LT-06-01A	0 - 44"	43.5 TO 5.4 INWC	0 - 44"	±0.32 INWC	± 0.1 INWC
2	2-LT-06-01B	0 - 44"	43.5 TO 5.4 INWC	0 - 44"	±0.32 INWC	± 0.1 INWC
3	HIGH ALARM	0 - 44"/ 26"	0-44"	CONTACT	±0.45 INCH	±0.45 INCH
4	CONTROL	0 - 44"	0-44"	NOTE 3	N/A	N/A
5	LOW ALARM	0 - 44"/ 4"	0-44"	CONTACT	±0.45 INCH	±0.45 INCH
6	2-LM-06-01A	4 - 20 MA	4-20 mA	3-15 PSI	± 0.60 PSI	±0.24 PSI
7	2-LM-06-01B	3 - 15 PSI	3-15PSI	OPEN/CLOSE	N/A	N/A
8	2-LCV-06-01	OPEN / CLOSE	3-15PSI	OPEN/CLOSE	N/A	N/A

COMPONENT DESCRIPTION:

NO.	MANUFACTURER / MODEL NUMBER	ORIGINAL CONTRACT NO.	LOCATION
1-2	FOXBORO / 823DP	82127 D	25-113A
3-5	FOXBORO DISTRIBUTIVE SYSTEM	82127 D	25-113A
6	FOXBORO / E69F I/P CONVERTER	82127 D	25-113A
7	POSITIONER	82127 D	LOCAL
8	VALVE		LOCAL

ADDITIONAL CALIBRATION REQUIREMENTS: SEE FOXBORO INSTRUCTION MI 020-467
CALIBRATION FREQUENCY REQUIREMENTS: ONCE EVERY 18 MONTHS

CALIBRATION EQUIPMENT ACCURACY REQUIREMENTS: FOR TRANSMITTER ICTe = ICRe = OCTe = ± 0.1 INWC; OCTe = N/A; FOR I/P CONVERTER, ICTe= OCTe= OCRe=±.24 PSI; ICRe= N/A; FOR CONTROLLER ICTe= OCTe= N/A OCTe = OCRe = N/A

STATIC HEAD CORRECTION: N/A

TECHNICAL SPECIFICATIONS: N/A

Note: There will be a set of SSD's for each loop covered by this calculation.

REV__ PREP____ DATE____ CHECK____ DATE____ SHT 43 C/O__

SETPOINT AND SCALING CALCULATIONS
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7) SUMMARY OF RESULTS (Continued)

TRANSFER FUNCTIONS
COMPONENT NO. 1 OUTPUT IN INCHES (DIGITAL) = INPUT IN INWC
COMPONENT NO. 2 OUTPUT IN INCHES (DIGITAL) = INPUT IN INWC
COMPONENT NO. 3, 4, 5 SETPOINT = CONTROLLER FUNCTION
COMPONENT NO. 6 OUTPUT (PSI) = $\frac{\text{INPUT (mA)} - 4\text{ mA}}{16\text{ mA}} \cdot 12\text{ PSI}$

REV___ PREP______ DATE______ CHECK______ DATE______ SHT 44 C/O___

SETPOINT AND SCALING CALCULATIONS
BRANCH/PROJECT IDENTIFIER ED-N2006-920370

7) **SUMMARY OF RESULTS (Continued)**

COMMENTS AND NOTES

1. THIS INSTRUMENT LOOP IS CALIBRATED TO GIVE CORRECTED LEVEL INDICATION FOR FULL REACTOR POWER OPERATION. AT OTHER POWER LEVELS, THE INDICATED LEVEL READING SHOULD BE DIVIDED BY THE FOLLOWING FACTORS:

REACTOR AT 100% POWER	= IND READING · 1.000
REACTOR AT 75% POWER	= IND READING · 1.014
READING AT 50% POWER	= IND READING · 1.033
READING AT 25% POWER	= IND READING · 1.062

2 CONFIGURATION FOR THE CONTROLLER IS DONE IN THE DISTRIBUTIVE CONTROL SYSTEM BY SOFTWARE. THE CONTROLLER SET POINT, THE HIGH LEVEL ALARM AND LOW LEVEL ALARM ARE CONFIGURED BY SOFTWARE.

3 CONTROLLER HAS REVERSED 4 TO 20 MA OUTPUT SIGNAL CORRESPONDING TO 0 TO 100 % DEMAND SIGNAL. CONTROLLER SETPOINT IS SELECTED FOR MAXIMUM HEATER EFFIEIENCY.

4 THE TRANSMITTER COMMUNICATES BI-DIRECTIONALLY OVER THE FIELD WIRING TO THE HHT INSTALLED ANYWHERE ALONG THE LOOP AND THE I/A SERIES SYSTEM. THE FOLLOWING INFORMATION CAN BE REMOTELY DISPLAYED AND CONFIGURED. FOR ADDITIONAL CALIBRATION INFORMATION SEE CONTRACT NO.82127 D (FOXBORO INSTRUCTION MI 020-467):

OUTPUT	ENGINEERING UNITS
ZERO AND SPAN	0-44 INCHES
ELEVATION OR SUPPRESSION	5.4 INWC
OUTPUT	LINEAR SIGNAL
PRIMARY ENGINEERING UNITS	INCHES OF WATER
STATIC PRESSURE ENGINEERING UNITS	NA
DAMPING	NONE
FAILSAFE FAIL	UPSCALE
TAG NAME	HTR 2A1 LEVEL
TEMPERATURE FAILURE STRATEGY	CONTINUE TO OPERATE
TRANSMITTER ACTION	REVERSE

Appendix H

Example Calculation

SETPOINT AND SCALING CALCULATIONS
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9) CONCLUSIONS

THE RESULTS OF THIS CALCULATION ARE VALID ONLY FOR LOOPS WITH FOXBORO MODEL 823 DP DIFFERENTIAL PRESSURE TRANSMITTERS AS THE PRIMARY ELEMENT.

THE INSTRUMENTATION ADDRESSED IN THIS CALCULATION WILL PERFORM ITS INTENDED FUNCTION FOR ALL ENVIRONMENTAL CONDITIONS AS REQUIRED FOR THE RESTART OF UNIT 2.

Appendix I

Insulation Resistance Effects

The components of the instrument signal transmission system (cable, splices, connectors, penetrations, terminal blocks, etc.) are all constructed of insulating materials between electrical conductors. These insulators normally are characterized by a low conductivity due to a low concentration and low mobility of ions. However, under elevated temperature and humidity conditions, the ionic mobility increases, which leads to increased leakage current. The relationship (Reference 3.20, page 89) between conductivity and temperature for the insulator is given as:

$$C = CO * e^{\frac{B}{T}} \qquad \textbf{Eqn. (I-1)}$$

where:

C	= ionic conductivity in Khos
T	= temperature in degrees Kelvin (K)
CO and B	= constants

It is observed in the equation above that the conductivity increases exponentially with increasing temperature. As insulation resistance (IR) is the reciprocal of conductivity, IR decreases with increasing temperature. The rise in moisture also increases the surface conductivity effects, particularly with respect to exposed conductor surfaces such as in terminal blocks.

There are also instrument channels where lead wire resistance may be a contributor to the total channel uncertainty, such as thermocouple or RTD instrument channels. However, this appendix only addresses IR effects.

<u>Sources of IR Data</u>

Insulation resistance measurements are normally taken before, during, and after the High Energy Line Break (HELB) simulation phase of a qualification test. Normally the IR data during the HELB simulation is the data of interest. Therefore, the IR data will usually be published within the qualification test report. HELB simulation tests may report cable IR based on IR or leakage current tests conducted on various cable types (e.g., shielded, unshielded, 2 conductor, 4 conductor, etc.) and measurement configurations (e.g., conductor-to-conductor, conductor-to-shield, multiple conductor-to conductor/shield, etc.). The cable IR values extracted from the simulation tests for use in channel uncertainty calculations should bound those expected for the particular channel's application. If necessary, calculations can be performed, using the test configuration measured IR values, to obtain IR values for the channel cable configuration.

Usually the qualification test gives data for cable samples longer than 1 foot. This is because practical considerations normally require lengths longer than 1 foot for qualification testing due to the size of environmental chamber. When calculating Current Leakage Effect (IR_e), it is necessary to determine an "ohms-foot" value for IR such that total resistance (R_T) for actual installed cable lengths that vary in length can be easily calculated. As an example, assume a cable test sample 25 feet in length exhibited a tested conductor-to-conductor resistance of 1.0 x 10^6 ohms. The 25 foot sample may be considered to be the lumped parallel resistance combination of 25 one-foot samples or

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_{25}}} \qquad \textbf{Eqn. (I-2)}$$

where R1 = R2 = ... R25, each resistance equal to the resistance (R) of a 1 foot sample. Thus, the equation becomes:

$$R_T = \frac{R}{25} \qquad \text{Eqn. (I-3)}$$

$$R = 25 * R_T \qquad \text{Eqn. (I-4)}$$

Thus, the individual 1 foot resistance is equal to:

$$R = 25 * 1.0E6 = 2.5E7 \; ohms\text{-}ft \qquad \text{Eqn. (I-5)}$$

Typically, qualification tests use a bounding temperature profile so that the report will be applicable to as many plants as possible, each with different peak accident temperatures. It is conservative but not always practical to use the IR values measured at the peak tested temperature. It is acceptable to extrapolate by defining the Equation I-1 constants by using test data and solving for "C" or using actual tested IR values at lower temperatures that more closely bound or equal the user's peak temperature. When the testing was performed at the maximum current rating of the cable and the application is a low current application, the self heating effect due to the high current can be backed out of the peak temperature to obtain a lower tested peak temperature. However, caution must be applied and a technical analysis must be performed when extrapolating test data and backing out the self heating effect.

IR Effect Example: Current Source Channel

A great majority of pressure, flow, level, etc., sensors used in the nuclear industry act essentially like ideal or constant current sources. That is, for a given process input, their output remains at a constant current value, insensitive to loop resistance variations within a specified range. Figures I-l(a) and I-l(b) show a typical pressure transmitter (PT) and signal transmission system (blocks 1-5) to an indicator. The signal transmission components are in a harsh environment and, therefore, are subject to IR degradation during an accident. The system is shielded up to component 2. However, the shield drain wire is included but not terminated to anything in the splice. The shield is single-point grounded outside containment. The connector and penetration cases are grounded.

An equivalent circuit schematic, showing the IR leakage paths and currents, is shown in Figure I-1(c). Note that R_{11}, R_{21}, R_{31}, etc., are the conductor-to-conductor IR values. Also, R_{12}, R_{13}, R_{22}, R_{23}, R_{32}, R_{33}, etc., are the conductor-to-shield values. The pressure transmitter is represented by current source (I_S). The Power supply is equivalent to a voltage source (V_S), and the indicator is equivalent to the load resistor (R_L). Note that although the loop shown in Figure I-l(b) is ungrounded, an air leakage path, (R_{AIR}), is shown to provide a return path for leakage currents I_{12}, I_{13}, I_{22}, I_{23}, I_{32}, I_{33}, etc.

Appendix I

Insulation Resistance Effects

Referring to Figure I-1(c) and I-1(d), the following equalities can be written:

$$R_{EQ}1 = \frac{1}{\frac{1}{R_{11}} + \frac{1}{R_{21}} + \frac{1}{R_{31}} + \frac{1}{R_{41}} + \frac{1}{R_{51}}}$$ Eqn. (I-6)

$$R_{EQ}2 = \frac{1}{\frac{1}{R_{12}} + \frac{1}{R_{22}} + \frac{1}{R_{32}} + \frac{1}{R_{42}} + \frac{1}{R_{52}}}$$ Eqn. (I-7)

$$R_{EQ}3 = \frac{1}{\frac{1}{R_{13}} + \frac{1}{R_{23}} + \frac{1}{R_{33}} + \frac{1}{R_{43}} + \frac{1}{R_{53}}}$$ Eqn. (I-8)

These equations can be solved for R_{EQ1}, R_{EQ2}, and R_{EQ3} and substituted into Figure I-l(d) for analysis. If we assume R_{AIR} is several orders of magnitude larger than R_{EQ2} and R_{EQ3}, the circuit further simplifies to that shown in Figure I-l(e). This means,

$$R_E = \frac{1}{\frac{1}{R_{EQ}}1 + \frac{1}{R_{EQ}2 + R_{EQ}3}}$$ Eqn. (I-9)

Thus this equation can be solved for R_E. This leakage path gives rise to leakage current (I_E), which is also the error current. Under ideal conditions with no leakage due to IR degradation, the transmitter current (I_S) and load current (I_L) would be equivalent. As shown in Figure I-l(e), however, I_L and I_S differ by the error current, I_E.

Summing voltages in a clockwise fashion around the right-hand loop of the circuit, the following equality can be written:

$$V_S = (I_E * R_E) + (I_L * R_L)$$ Eqn. (I-10)

Solving for I_E,

$$I_E = \frac{V_S - I_L * R_L}{R_E}$$ Eqn. (I-11)

At node 1 of Figure I-1(e),

$$I_L = I_E + I_S$$ Eqn. (I-12)

Substituting Equation (I-12) into Equation (I-11) yields

$$I_E = \frac{V_S - (I_E + I_S) * R_L}{R_E} \quad \text{Eqn. (I-13)}$$

Rearranging Equation (I-13),

$$I_E * R_E = V_S - I_E * R_L - I_S * R_L \quad \text{Eqn. (I-14)}$$

$$I_E * (R_E + R_L) = V_S - I_S * R_L \quad \text{Eqn. (I-15)}$$

$$I_E = \frac{V_S - I_S * R_L}{R_E + R_L} \quad \text{Eqn. (I-16)}$$

Using Equations (I-6), (I-7), (I-8), (I-9), and (I-16), the error current I_E can be determined for a given transmitter output current (Equation I-16). Examination of Equation (I-16) reveals the following facts:

1) The IR_e for a current loop is a positive bias with respect to current
2) The larger the V_s, the larger IR_e
3) The smaller the I_S, the larger IR_e
4) The smaller the R_L, the larger IR_e
5) The smaller the R_E, the larger IR_e

The error in % span can be determined by:

$$I_E(\%) = \frac{I_E}{I_S(\text{MAX}) - I_S(\text{MIN})} * 100\% \quad \text{Eqn. (I-17)}$$

Note that the resistance paths shown apply to a typical configuration. More or less leakage paths may be present in a particular situation (e.g., 4 wire RTD).

As an example, assume the circuit shown in Figure I-I(b) and I-I(c) has the following values:

$$R_{11} = R_{21} = R_{41} = 5.0E6 \text{ ohms} \quad \text{Eqn. (I-18)}$$

Cable length = 300 ft (sample tested was 25 ft in length with measured conductor-to-conductor resistance = 1.0E7 ohms and conductor-to-shield resistance = 0.5E7 ohms)

$$R_{S1} = R_{S2} = R_{S3} = 1.0E6 \text{ ohms} \quad \text{Eqn. (I-19)}$$

$$R_{12} = R_{13} = R_{22} = R_{23} = R_{42} = R_{43} = 2.5E6 \text{ ohms} \quad \text{Eqn. (I-20)}$$

Appendix I

Insulation Resistance Effects

For this example, assume that the area of interest or the setpoint is 50% of span or

$$I_S = 12.0\ mA \qquad \text{Eqn. (I-21)}$$

Note: To obtain a worst case or bounding analysis, the corresponding current at 0% of span (4 mA) should have been used.

$$I_S(\text{Max}) = 20.0\ mA \qquad \text{Eqn. (I-22)}$$

$$I_S(\text{Min}) = 4.0\ mA \qquad \text{Eqn. (I-23)}$$

$$V_S = 30\ VDC \qquad \text{Eqn. (I-24)}$$

For V_s, the maximum loop voltage (ie., power supply voltage plus the power supply's tolerance) shall be used for the calculation.

$$R_L = 250\ ohms \qquad \text{Eqn. (I-25)}$$

Using the measured conductor-to-conductor resistance 1.0E7 ohms for a 25 foot sample of cable, the"ohms-foot" value of R_{31} is determined by:

$$R = 25 * 1.0E7 = 2.5E8\ ohms-ft \qquad \text{Eqn. (I-26)}$$

Thus,

$$R_{31} = \frac{2.5E8\ ohms-ft}{300ft} \qquad \text{Eqn. (I-27)}$$

$$R_{31} = 8.33E5\ ohms \qquad \text{Eqn. (I-28)}$$

Similarly,

$$R_{32} = R_{33} = \frac{25ft * 0.5E7\ ohms}{300ft} \qquad \text{Eqn. (I-29)}$$

$$R_{32} = R_{33} = 4.17E5\ ohms \qquad \text{Eqn. (I-30)}$$

Appendix I

Insulation Resistance Effects

Using Equations (I-6), (I-7), (I-8), and (I-9),

$$R_{EQ1} = \frac{1}{\frac{1}{5.0E6} + \frac{1}{5.0E6} + \frac{1}{8.33E5} + \frac{1}{5.0E6} + \frac{1}{1.0E6}} \qquad \text{Eqn. (I-31)}$$

$$\overline{R_{EQ1} = 3.57E5\ ohms} \qquad \text{Eqn. (I-32)}$$

$$R_{EQ2} = \frac{1}{\frac{1}{2.5E6} + \frac{1}{2.5E6} + \frac{1}{4.17E5} + \frac{1}{2.5E6} + \frac{1}{1.0E6}} \qquad \text{Eqn. (I-33)}$$

$$R_{EQ2} = R_{EQ3} = 2.17E5\ ohms \qquad \text{Eqn. (I-34)}$$

$$R_E = \frac{1}{\frac{1}{3.57E5} + \frac{1}{2.17E5 + 2.17E5}} \qquad \text{Eqn. (I-35)}$$

$$R_E = 1.96E5\ ohms \qquad \text{Eqn. (I-36)}$$

Thus, substituting (I-21), (I-24), (I-25), and (I-31) into equation (I-16):

$$I_E = \frac{30 - 0.012 * 250}{1.96E5 + 250} \qquad \text{Eqn. (I-37)}$$

$$I_E = 0.138\ mA \qquad \text{Eqn. (I-38)}$$

$$I_E(\%) = \frac{0.138}{20.0 - 4.0} * 100\% \qquad \text{Eqn. (I-39)}$$

Based upon Equation I-12, the leakage current (I_E) increases the current flow through the load which causes the output to indicate a higher than actual value. Per this TI's sign convention, the uncertainty would be negative.

$$I_E(\%) = -\ 0.86\%\ span \qquad \text{Eqn. (I-40)}$$

Appendix I

Insulation Resistance Effects

IR Model For Current Loop

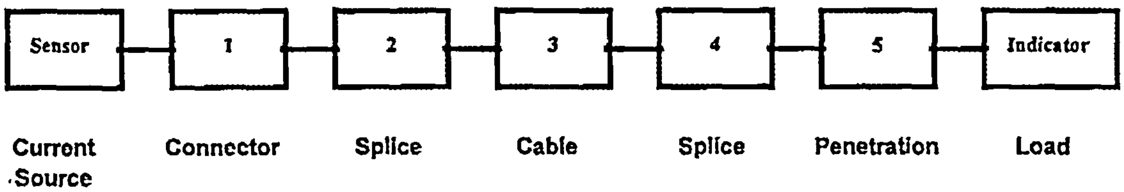


Figure I-1(a)

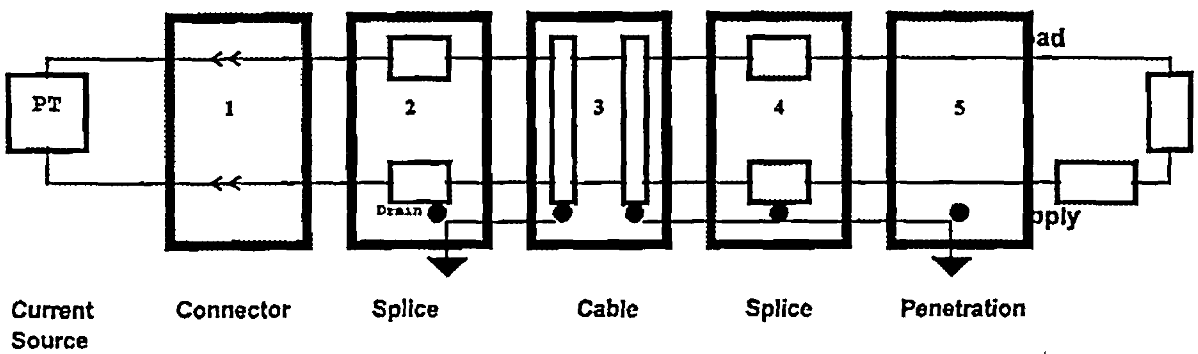


Figure I-1(b)

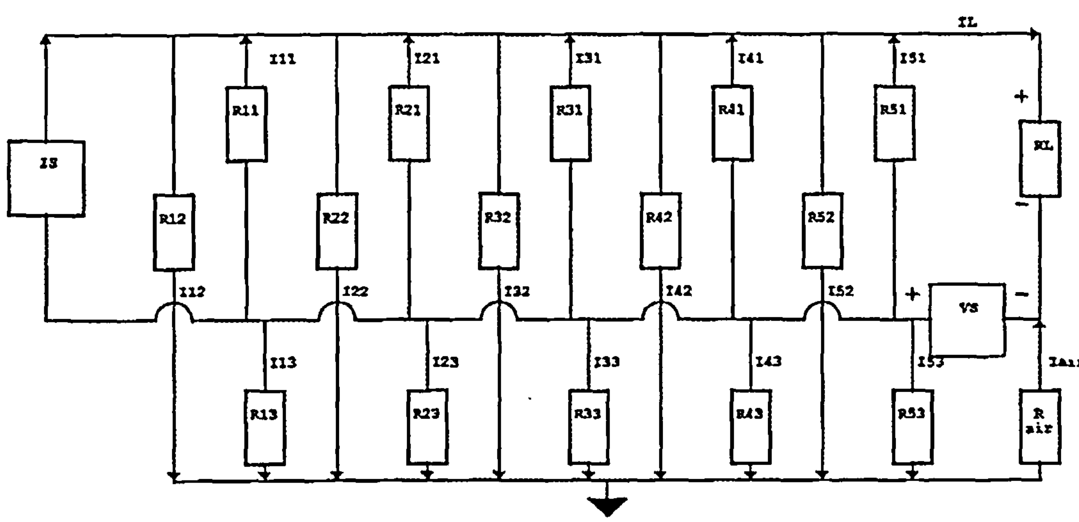


Figure I-1(c)

Designation R X Y means:
R = Resistance
X = Signal Transmission Component Number (See Figures 1(A), 1(B))
Y = 1 - Conductor-To-Conductor; 2 - Conductor-To-Shield/Case; and 3 -To-Shield/Case
For example, R12 is resistance of component 1 (connector) and Conductor-To-Shield/Case

Appendix I

Insulation Resistance Effects

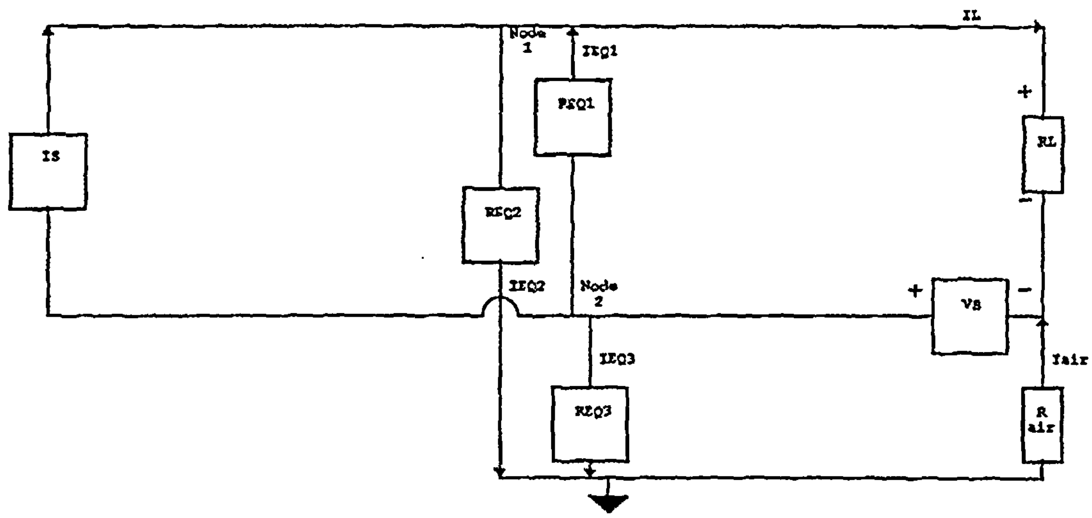


Figure I-1(d)

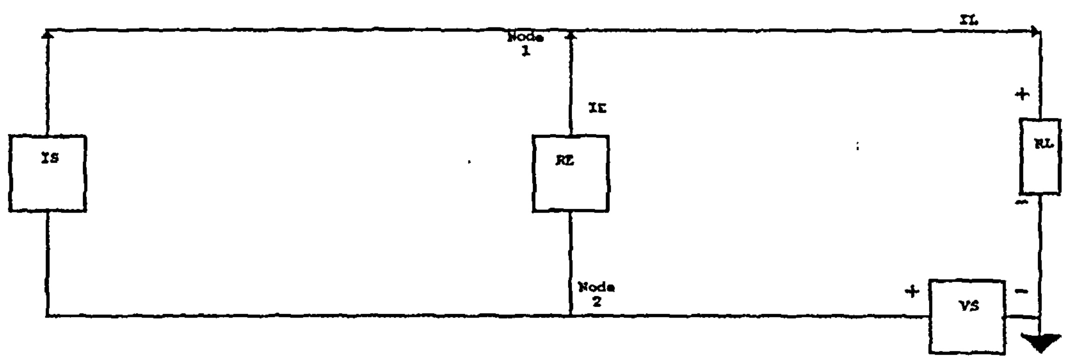


Figure I-1(e)

Appendix J

Statistical Evaluation of Interactions Between Setpoints

The following is a description of and the analysis of the Emergency Gas Treatment System EGTS auto transfer system. It shows the overlap of multiple setpoints. EGTS is utilized post accident to maintain a negative pressure in the Annulus of the Primary Containment structure to ensure that all outleakage of irradiated air is processed through filters. The system consists of two redundant paths. One starts automatically on the occurrence of an accident signal. The other is in standby and only starts if the first system fails to start and maintain the annulus within proper limits.

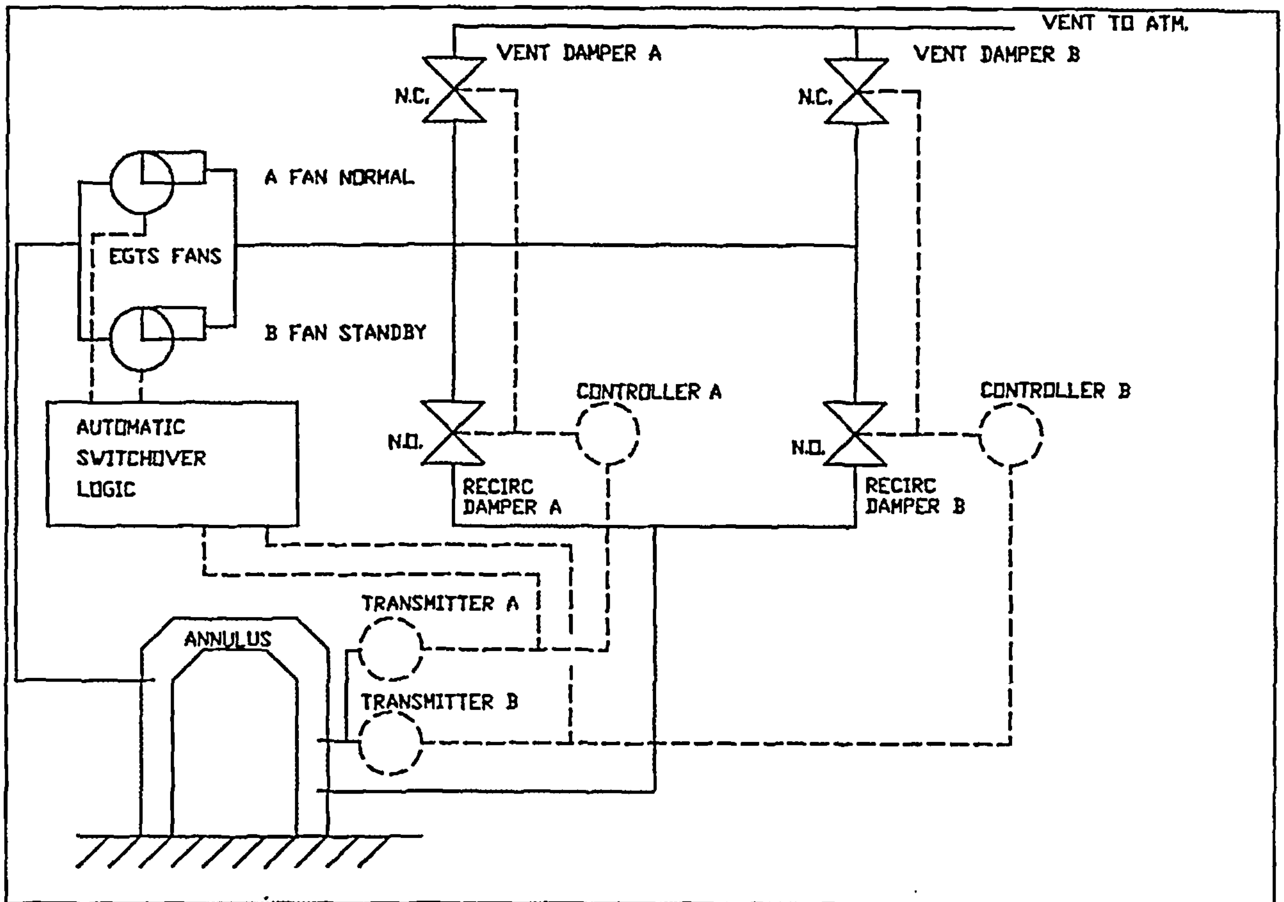


Figure J-1

The following page shows the system diagrammatically and shows the logic that initiates the transfer from the normal train to the standby train on detection of inadequate operation. It should be noted that the EGTS is required to maintain the annulus at a 0.5 inch water column (WC) vacuum while the normal vacuum system maintains the annulus at a 5 inch WC vacuum. As can be seen from the transfer logic, Figure J-2, there are four pressure switches that arm and initiate the transfer of failure detection. These switches are designated A, B, C, & D. Their functions are described as follows: The A switch detects the total loss of normal and standby vacuum control by detecting a 0.2 inch WC decreasing vacuum indicating that the EGTS controller cannot maintain the 0.5 inch WC vacuum required.. The D switch (4.0 inch WC increasing vacuum) is an arming function that indicates that the normal vacuum control system is functioning and the plant is running. The C switch (0.7 inch WC decreasing vacuum) works in conjunction with the D switch as an additional arming function. It indicates that the normal vacuum control system has been lost (normal control is at 5.0 inch WC vacuum) which indicates that the EGTS accident system is controlling the vacuum. The B switch (1.2 inch WC increasing vacuum) works in conjunction with the two arming

Appendix J

Statistical Evaluation of Interactions Between Setpoints

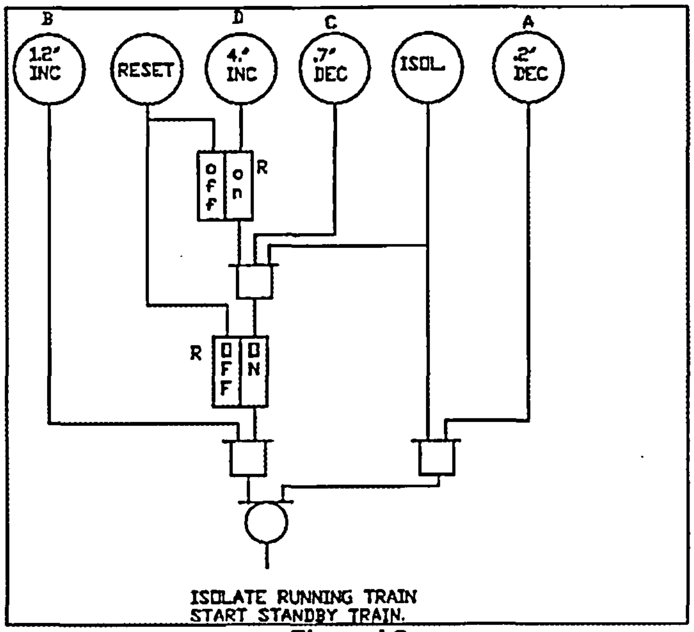


Figure J-2

switches (D and C) to indicate that the EGTS accident vacuum control system has failed and is pulling too much vacuum. The significance of too much vacuum is that there is too much exhaust going through the filtration system with too little holdup time for radiation filtration and absorption. The significance of too little vacuum is that the can be leakage directly to the environment without filtration. The interaction of the differing switch actuation points and the control ranges are shown on the Figure J-4. The figure shows that the small range of vacuum causes a congested layout of switch actuation points and control ranges. This type of

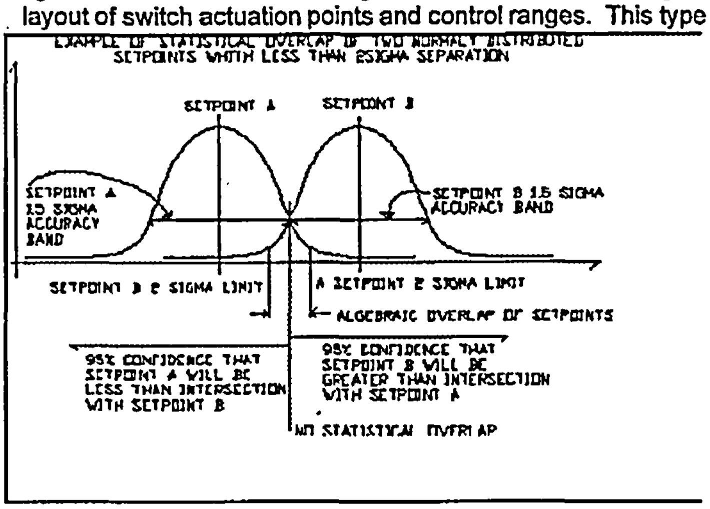


Figure J-3

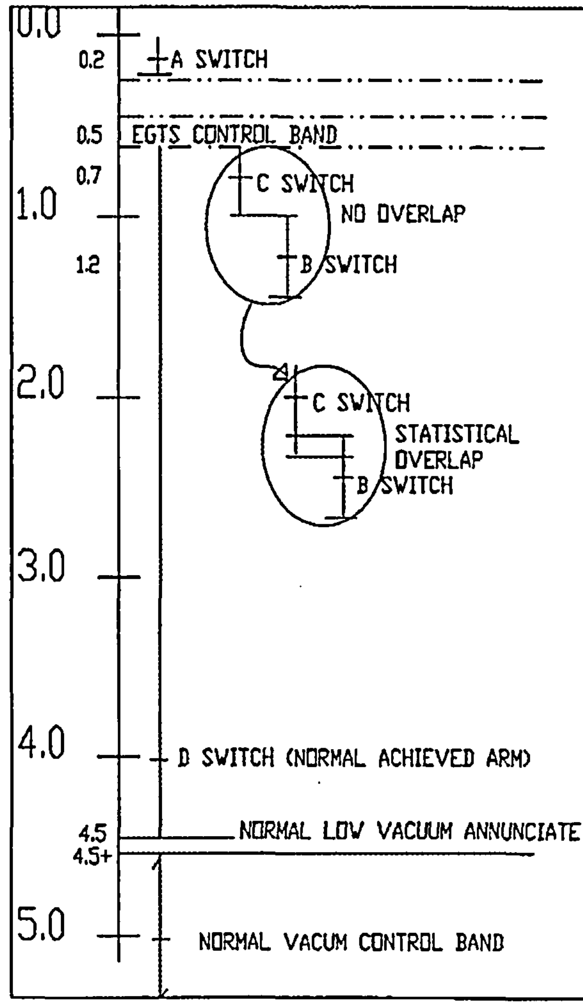


Figure J-4

layout of switch actuation is more representative of actual plant situations than the simple examples of the Ref. 3.4, with one setpoint and one limit. In this example it should be noted that biases effecting the different device setpoints cancel in the analysis of overlap. It also should be noted that for extremely congested setpoints statistical overlap can be considered to allow closer setpoint arrangement but still guaranty a 95% confidence that the setpoints do not overlap nor violate the safety and operating limits. This is possible by taking into consideration that the accuracies of each device is random and therefore can be statistically combined (SRSS) such that the overlap is in the tails of the normal distribution (See Figure J-3).

Appendix K

Calibration History as a Tool For Predicting Drift

Purpose

The purpose of this document is to provide guidance and direction in the collection and analysis of instrumentation calibration data. The following requirements will ensure a quality end product from the standpoint of 10CFR50 Appendix B, standardization of data from plant to plant, and provide a standard method of data analysis.

The analysis of calibration history can be a useful but dangerous tool for predicting future response of instrumentation. The usefulness is that time and seasonal trends can be quantified and projected into the future. The danger lies in not knowing what you are attempting to predict before analyzing the data. It should also be noted that the resulting predictions are different if making predictions about the analyzed instruments or about the general population of like instruments. The predictions are also different if using one or two sided statistics.

Data Collection Process

To ensure the collection of quality data that will meet 10CFR50, Appendix B Standards, plant procedures which fall under the plant's existing Appendix B program should be utilized. Additional procedures may be needed to supplement the data collection process. The plant's Surveillance Instructions (SI) utilized to implement the plant's Technical Specification surveillance requirements should be the main source of plant data since these SI and their results (data) already fall under the plant's Appendix B program.

When data for a specific device is needed, the person performing the analysis should start by identifying all the different applications of that specific device within the plant (A computerized instrument database, if one exist, is very valuable in doing this search). Once the different applications have been identified by a unique tag number or function, a search for the associated SI(s) can be performed. When the associated SI's are identified, the data documented from the periodic performance of these specific SI's can be retrieved (QA Record for Appendix B requirements) for review and analysis.

Required Data

The following information and data is needed to perform a thorough analysis and achieve a good understanding of the plant's raw calibration data.

1) Manufacturer and Model Number

2) Manufacturer's Lot Number or Revision level if applicable

3) Instrument's Range

4) Instrument's calibrated span for its specific application

5) In service conditions (Normally pressurized or not pressurized)

6) As Found/ As Left Values from the plant's SI's

7) Time Span between As Found/ As Left Data from the plant's SI's

8) Time Span between Calibrations (Can be different from the time span between As Found/ As Left data)

9) Temperature at the time of calibration (Some temperatures can be obtained from plant temperature monitoring programs), or a Statement that the temperature was the same during the As Found and the previous As Left data collection process, or a statement that the room temperature is limited to a small variation such as +/-10 °F (a small variation is normally insignificant).

10) Measurement and Test Equipment (M&TE) Accuracy or requirements (e.g., 4 to 1 Ratio of M&TE to Tested Device accuracy, 10 to 1, etc.). The plant SI should have recorded the serial numbers of the actual M&TE used during the performance of the SI.

11) M&TE Reading uncertainties (if MT&E has a digital readout, there would be no indicator uncertainties).

12) Instrument setting or calibration tolerance used during calibration process (A_b).

13) Document any Maintenance Reports or Work Orders on the instruments (i.e., Time, Problem Found, etc.)

Recommended Data

The following data is not necessary but could be useful during the data analysis process.

1) Time in Service

2) Power supply stability within 10%

Outline for the Analysis of Drift Data

The basic steps that must be performed to analyze the raw data obtained from the plant are as follows:

1) Quantify drift uncertainties through statistical methods (i.e., calculate deviation and it's mean and variance);

2) Determine if drift is a function of time by plotting deviation versus duration between calibrations (a trend would be indicated if the data drifted in a single direction or if the data becomes more spread with time). If there is no apparent relationship to time then the deviations are likely due to other factors such as repeatability.

3) Determine if there are any temperature effects by plotting deviation versus month of year or date of calibration; quantify the temperature effect (refer to example shown later in this report which uses multiple linear regression to quantify both time and temperature effects);

4) Separate these effects from the drift uncertainties if possible;

5) Determine if the drift's distribution is normal (plot histogram of deviation vs frequency and/or cumulative);

6) Determine if drift has a dependence with respects to setting, calibrated span, upper range limit or a combination thereof. This is accomplished by plotting the deviation versus setpoint, span, or upper range limit and looking for an apparent trend.

Data Analysis Methodology

The general data analysis compares the as-found data of one calibration to the as-left data from the previous instrument's adjustment which may or may not be it's last calibration. The results of the calibration must be noted to determine if a device has been recalibrated or only checked, replaced due to damage, or any other unusual circumstance that could bias the results. The other part of the data analysis is to note the duration from the previous calibration and the date of the calibration. Plots of the deviation versus duration and the deviation versus date are used to determine if there is a time relationship or a seasonal fluctuation indicative of a temperature effect. Trends in the drift data with relation to time or temperature must be quantified first, then the uncertainty about the trend statistically evaluated. After qualitatively determining that there is or is not a time/seasonal variation, the data is statistically reduced by calculating the mean, standard deviation, and distribution. The distribution is used to evaluate how close the data is to a normal distribution. As long as the data approximates a normal distribution the reduced data's mean and standard deviation can be used to predict future behavior utilizing the tolerance and confidence tables of this paper.

There are two types of predictions that can be made about future device accuracy utilizing the results of the statistical analysis. These are:

1) Predicting the future response of the devices analyzed (e.g., making a prediction about the samples from there past experience),

2) Predicting the future response of all like devices (e.g., making predictions about the general population based on a sample from the population).

Appendix K

Calibration History as a Tool For Predicting Drift

The difference between the two types of predictions is based upon the uncertainty of extrapolating the data from the sample set to the general population. When the mean (m) and standard deviation (s) of the general population are unknown, the tolerance limits do not equal 100 percent. In general, the price that must be paid for not knowing the population parameters is a wider band of uncertainty about the predicted values. The typical tolerance limits used for accuracy calculations for the sample set is based upon a 95% probability limit for the number of degrees of freedom of the sample. The inference to the general population requires the addition of a confidence limit as well. These two limits yield multiplying factors that when applied to the standard deviation in combination with the mean for the sample data yield the predicted tolerance bands. The general equation for the predicted response band based upon the mean (μ) and the standard deviation (σ) of the population are:

$\mu \pm \sigma \cdot$ tolerance multiplier

$\mu \pm \sigma \cdot$ tolerance multiplier $\cdot$ confidence multiplier

It should be noted that in most practical situations the true values of the mean (μ) and standard deviation (σ) of the general population are not known, and tolerance limits must be based on the mean (x) and standard deviation (s) of a random sample from the general population. Whereas, m $\pm$ 1.96s are limits enveloping 95% of a normal population, the same cannot be said for the limits x $\pm$ 1.96s. These limits are values of random variables and they may not include a given proportion of the population. Nevertheless, it is possible to determine a constant K so that one can assert with a degree of confidence 1-α that the proportion of the population contained between x $\pm$ Ks is at least P (i.e., 95%). Such values of K for random samples from approximately normal populations are given in table 14 of reference 1 for proportions P = .9, .95, .99 and for degrees of freedom n-1 (n is the number of samples) from 2 to 1000. The table provides values for both single sided and two sided statistics. In order to determine that the tables are applicable to your data you must verify that the distribution of the deviations is bell shaped and thus approximately normal. This is accomplished by developing a histogram or frequency graph that plots the number of data points that occur in a range of deviations. As long as the curve appears to be a single bell shaped distribution, the tables are applicable. If the distribution is other than a bell shaped such as a uniform equal probability distribution then you should refer to a more detailed statistical text book for the appropriate tables of probabilities. The example shown later in this report shows how to utilize a spreadsheet program to develop a histogram of a data distribution.

To avoid confusion, note that there is an essential difference between confidence limits and tolerance limits. Whereas confidence limits are used to estimate a parameter of a population, tolerance limits are used to bound a certain proportion of a population. This distinction is emphasized by the fact that when n becomes large the length of the confidence interval approaches zero while the tolerance limits approach the values for the population (e.g., for large n of approximately 30, K approaches 1.96 for P=.95).

The purpose of the statistical analysis is to develop a realistic prediction of accuracy for a device based upon past operating experience. Since the statistical analysis yields a prediction of accuracy that approximates a normal distribution, the resulting number ($\mu \pm K\sigma$) can be used directly in the Square Root of the Sum of the Squares (SRSS) combinational technique.

The prediction of the accuracy consists of two parts which are the equation for the trend as a function of time or temperature and the uncertainty about this trend. The analysis of the uncertainty has been discussed in the preceding sections and consists of a combination of a multiplier and the standard deviation of the deviations. The quantification of the trend will be discussed in the following sections.

Before proceeding with quantifying the trends a method of determining if any data points are statistically insignificant outlier or invalid data points should be discussed. The analysis discussed so far assumed that all the data taken is valid and should be included in the analysis. This assumption is not always legitimate since it is always possible to incorrectly copy a number, or miss-calibrate a test instrument, or any of a thousand other reasons for obtaining invalid data points. Reference 3 of this Appendix and Appendix B of this TI provide methods of evaluating the apparently extreme observations to determine if they are statistically valid data points. The method used here is based upon evaluation of the **Maximum Normal Residual** (MNR). The attached MNR table provides the criterion to evaluate for various sample sizes (n) for 95% and 99% confidence levels. The method of evaluating the suspect data point in order to determine if it is an extreme observation that can be thrown out is to first calculate the criterion based on the sample size, and then compare it to the value in the appropriate significance column. If the calculated criterion value is larger than the significance factor then it can be concluded that the data point is extreme and can be dropped from further evaluations. The test of a second suspect data point can now be performed based upon the reduced number of samples.

Quantification of Trends in Time and Temperature

The following is an example of a typical data analysis. This evaluation is an analysis of the data provided by a transmitter manufacturer (which will not be mentioned due to the proprietary nature of the test results). This particular manufacturer has had a long running test setup to analyze drift. The test includes 12 transmitters that have been powered and pressurized. The data taken on these transmitters has been the as-found values for specific calibration points. The data including calibration temperature was recorded monthly for 63 months.

The analysis was performed to analyze the deviation data as a function of independent variables (months since calibration and temperature deviation from calibration temperature). The analysis of the data is an application of a linear regression least squares curve fit of the dependent variable (deviation) from the two independent variables (time and temperature). Linear regression is described in reference 4 (NUMERICAL METHODS FOR ENGINEERS). The linear regression analysis performs a statistical reduction of the data and yields the coefficients of the equation for the trend and the standard deviation of the data about this trend equation. There are several software packages available to perform the multiple variable linear regression (i.e., Excel or MathCad) with most being very similar in use. These packages require the user to define certain portions of information defined as follows:

<u>Dependent variable</u> is the raw data being analyzed. It is being analyzed as a function of the independent variable(s).

<u>Independent variable(s)</u> are the inputs to the regression analysis that you suspect are the causes of the variation of the raw data. As an example the **duration since last calibration** and the **temperature deviation from the calibration temperature** are independent variables.

For the purpose of this example, spreadsheet software was used to perform the multiple variable linear regression. The raw data provided by the manufacturer is shown in the table that follows and consists of the duration since the previous calibration (column 1), difference in temperature at recalibration relative to temperature at initial calibration (column 2), and the as-found minus as-left instrument setting (column 3):

Time (Months)	ΔTemp (°F)	Deviation (% of span)
0	0	0.030
1	2	0.080
2	16	0.035
3	21	0.000
4	20	0.000
5	-1	0.080
6	12	0.010
7	-38	0.150

Time (Months)	ΔTemp (°F)	Deviation (% of span)
8	-41	0.210
12	-14	0.090
15	20	0.040
18	-18	0.115
21	-56	0.200
25	-13	0.090
27	28	0.010
30	-2	0.090
34	-30	0.200
36	-16	0.160
38	18	0.010
40	14	0.090
42	6	0.140
44	20	0.310
45	-26	0.330
48	2	0.260
50	22	0.060
53	-18	0.290
55	-28	0.310
57	-22	0.250
62	4	0.150
63	8	0.140

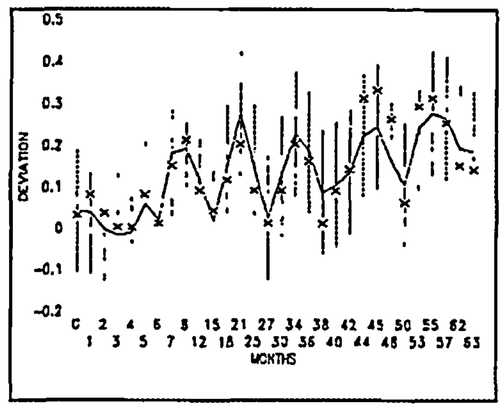
The regression was performed by defining the first two columns (duration and Δ temperature) as **Independent Variables** and defining the third column (deviation) as the **Dependent variable** then telling the software to perform the analysis. The results of the linear regression are printed in the following spreadsheet format.

Regression Output:		
Constant	**0.03975271**	
Std Err of Y Est	**0.04725163**	
R Squared	**0.79933641**	
No. of Observations	**30**	
Degrees of Freedom	**27**	
	duration	**Δ temp**
X Coefficient(s)	**0.002661**	**-0.0031532**
Std Err of Coef.	**0.000426**	**0.0004068**

These analysis results form the basis for an equation that best fits the data with a quantified error band noted (Std Err of Y Est or s). Before examination of these results, the format of the tables must be discussed. There are several pertinent pieces of results that are to be examined. Since the curve fit is a fit of the dependent variable to two independent variables, there are four parts to the equation that represents it. These are:

dev = constant + time*timeslope + Δtemp*tempslope ± std_y_error * K

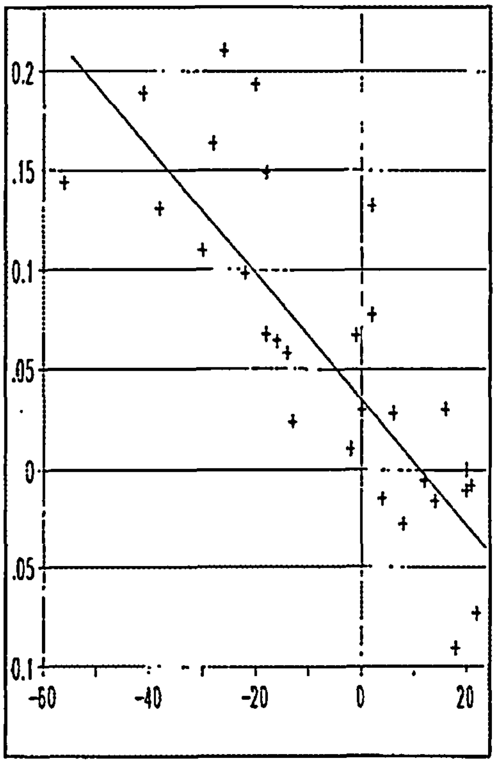
The slope constants are shown in the table (X Coefficients). As can be seen from the goodness of fit indicator (R squared), the linear regression is good (79.93%) but not great (100% is perfect).



The time and temperature curve fit indicate that there is a high degree of correlation of the deviation to both time and temperature. The figure shows the raw data as X's, the time and temperature curve fit (horizontal line) and the repeatability band consisting of the standard error of y estimate (or repeatability) times the tolerance multiplier for 27 degrees of freedom as vertical lines. For this example we are predicting future operation of these S/N devices only. In order to generalize to the population of like devices, the n (number of samples) would be the number of transmitters in the test (12). The multiplier is a tolerance limit based on two sided statistics, 27 degrees of freedom, and a desired 95% confidence level and 95% tolerance limit. It is assumed that the data is roughly normally distributed.

As can be seen in the figure, the raw data is always enveloped by the predicted deviation limits represented by the vertical bars. Here the horizontal curve is the temperature and time (drift) effects and the vertical bars are the repeatability or uncertainty of the devices.

If the analysis is to quantify only the drift effect of the device, then the temperature effect should be removed. A plot of the raw data deviation versus temperature along with the straight line predicted by the slope of the temperature regression coefficient shows a high correlation.

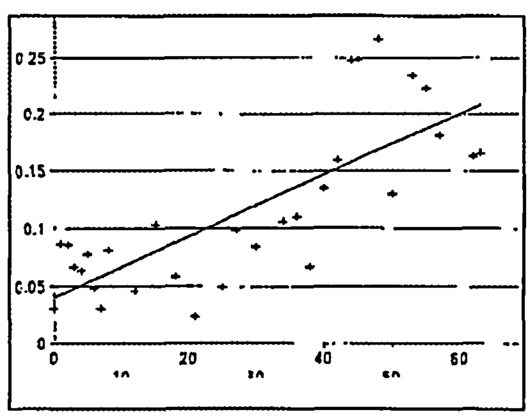


The raw data can have the temperature effect removed by subtracting the value of the temperature coefficient times the calibration temperature deviation from the raw data. This is shown in the following table.

Duration since calib	Temp change from calib	As found minus as left	Time & temp trend	Raw data minus temp eff	Drift only trend
0	0	0.0300	0.0398	0.0300	0.0000
1	2	0.0800	0.0361	0.0863	0.0027
2	16	0.0350	-0.0054	0.0855	0.0053
3	21	0.0000	-0.0185	0.0662	0.0080
4	20	0.0000	-0.0127	0.0631	0.0106
5	-1	0.0800	0.0562	0.0768	0.0133
6	12	0.0100	0.0179	0.0478	0.0160
7	-38	0.1500	0.1782	0.0302	0.0186
8	-41	0.2100	0.1903	0.0807	0.0213
12	-14	0.0900	0.1158	0.0459	0.0319
15	20	0.0400	0.0166	0.1031	0.0399
18	-18	0.1150	0.1444	0.0582	0.0479
21	-56	0.2000	0.2722	0.0234	0.0559
25	-13	0.0900	0.1473	0.0490	0.0665
27	28	0.0100	0.0233	0.0983	0.0718
30	-2	0.0900	0.1259	0.0837	0.0798
34	-30	0.2000	0.2248	0.1054	0.0905
36	-16	0.1600	0.1860	0.1095	0.0958
38	18	0.0100	0.0841	0.0668	0.1011
40	14	0.0900	0.1020	0.1341	0.1064
42	6	0.1400	0.1326	0.1589	0.1118
44	-20	0.3100	0.2199	0.2469	0.1171
45	-26	0.3300	0.2415	0.2480	0.1197
48	2	0.2600	0.1612	0.2663	0.1277
50	22	0.0600	0.1034	0.1294	0.1330
53	-18	0.2900	0.2375	0.2332	0.1410
55	-28	0.3100	0.2744	0.2217	0.1463
57	-22	0.2500	0.2608	0.1806	0.1517
62	4	0.1500	0.1921	0.1626	0.1650
63	8	0.1400	0.1822	0.1652	0.1676

By plotting the raw data minus the temperature effect the drift trend predicted by the regression analysis the trend is apparent.

The temperature corrected raw deviation data should now be analyzed to determine the statistical variation from the trend. This is performed by subtracting the temperature corrected data from the trend equation and then statistically evaluating the deviations (mean and standard deviation).



Appendix K

Calibration History as a Tool For Predicting Drift

Raw data minus Temp effect	Drift time Trend trend	Deviation from Time
0.0300	0.0398	-0.0098
0.0863	0.0424	0.0439
0.0855	0.0451	0.0404
0.0662	0.0477	0.0185
0.0631	0.0504	0.0127
0.0768	0.0531	0.0238
0.0478	0.0557	-0.0079
0.0302	0.0584	-0.0282
0.0807	0.0610	0.0197
0.0459	0.0717	-0.0258
0.1031	0.0797	0.0234
0.0582	0.0876	-0.0294
0.0234	0.0956	-0.0722
0.0490	0.1063	-0.0573
0.0983	0.1116	-0.0133
0.0837	0.1196	-0.0359
0.1054	0.1302	-0.0248
0.1095	0.1355	-0.0260
0.0668	0.1409	-0.0741
0.1341	0.1462	-0.0120
0.1589	0.1515	0.0074
0.2469	0.1568	0.0901
0.2480	0.1595	0.0885
0.2663	0.1675	0.0988
0.1294	0.1728	-0.0434
0.2332	0.1808	0.0525
0.2217	0.1861	0.0356
0.1806	0.1914	-0.0108
0.1626	0.2047	-0.0421
0.1652	0.2074	-0.0422

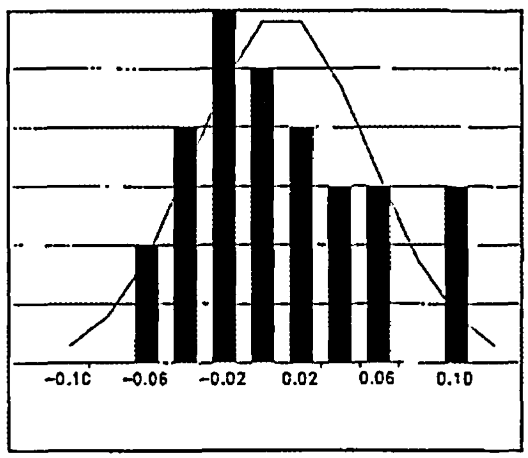
avg	**-0.0000**
std	**0.0448**
min	**-0.0741**
max	**0.0988**

30 Samples (or 12 samples for predicating future operation of the general population)

In order to properly extrapolate the above results to either the future operation of these devices or to the general population, the distribution of the deviations should be verified to be approximately normal. This is performed by partitioning the deviations into deviation magnitudes from the most negative to the most positive and then counting the number of deviations that fall into each partition. The table below shows such an analysis.

Deviation from the trend

Deviation bands	**Count**
-0.10 to -.08	0
-0.08 to -.06	0
-0.06 to -.04	2
-0.04 to -.02	4
-0.02 to .00	6
-0.00 to .02	5
0.02 to .04	4
0.04 to .06	3
0.06 to .08	3
0.08 to .10	0
0.10 to .12	3

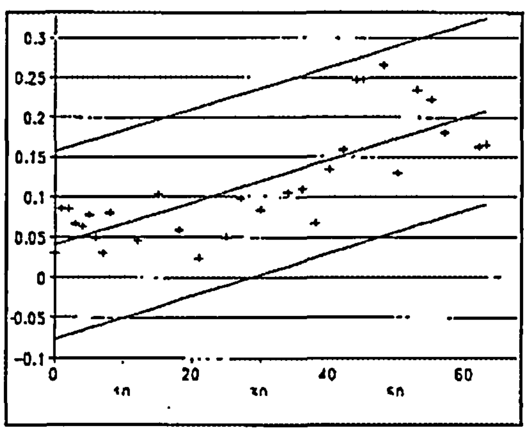


The frequency distribution of the data as calculated in the above table appears as.

The figure appears to show that the deviations have an approximately normal distribution (mound shaped) and therefore the results can be extrapolated to the general population based on the standard deviation and the number of degrees of freedom utilizing the 95%/95% confidence multipliers discussed earlier. A cumulative graph (See Section 4.3.3.5) can also be used for easier visualization.

For predicting future operation of these specific devices use 29 degrees of freedom and two sided statistics, the tolerance & confidence multiplier from the K-tables is 2.549 which when combined with the standard deviation of the deviations from the trend (0.0448) yields an accuracy band of 0.114 about the time trend. The time trend is the equation based on the linear regression utilizing the constant and time slope X-coefficient as follows:

$$deviation(time) = Constant + time * timeslope \pm K\sigma$$



To generalize to the population of like devices, use the K values for n = 12 samples.

Appendix K

Calibration History as a Tool For Predicting Drift

--- K Table ---

95% confidence 95% of population enveloped (and 95% student-t)

n	95%/95% 1 side	95%/95% 2 side	95% student-t
3	7.655	9.916	4.303
4	5.145	6.370	3.182
5	4.202	5.079	2.776
6	3.707	4.414	2.571
7	3.399	4.007	2.447
8	3.188	3.732	2.365
9	3.031	3.532	2.306
10	2.911	3.379	2.262
15	2.566	2.954	2.145
20	2.396	2.752	2.093
30	2.220	2.549	2.045

n = number of samples

Normal Distribution Probability Density

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

$$-\infty < x < +\infty$$

Maximum Normal Residual Significance (See Appendix B of this TI)

Criterion	n	5%	1%
$\frac{X_n - X_{n-1}}{X_n - X_1}$	3	.941	.988
	4	.765	.889
	5	.642	.780
	6	.560	.698
	7	.507	.637
$\frac{X_n - X_{n-1}}{X_n - X_2}$	8	.554	.683
	9	.512	.635
	10	.477	.597
$\frac{X_n - X_{n-2}}{X_n - X_2}$	11	.576	.679
	12	.546	.642
	13	.521	.615
$\frac{X_n - X_{n-2}}{X_n - X_1}$	14	.546	.641
	15	.525	.616
	17	.490	.577
	20	.450	.535
	25	.406	.489

REFERENCES:

1 PROBABILITY & STATISTICS FOR ENGINEERS, 2nd, Irwin Miller and John Freund, Prentice-Hall Inc., 1977

2 STATISTICAL METHODS FOR ENGINEERS, McCuen, Prentice-Hall Inc., 1985

3 STATISTICAL METHODS, 8TH, Snedecor and Cochran, Iowa State University Press.

4 NUMERICAL METHODS FOR ENGINEERS, Chapra & Canale, McGraw Hill 1985.

Appendix L

Process and Reference Leg Uncertainties for Differential Pressure Transmitters

When differential pressure transmitters are used to measure liquid level in vessels, changes in density of the reference leg fluid, the vessel fluid, or both, can cause uncertainties unless the level measurement system automatically compensated for density changes. This occurs because differential pressure transmitters respond to hydrostatic (head) pressures, which are directly proportional to the height of the liquid column multiplied by the liquid density. Therefore, measurement uncertainty may be induced because, while the actual level in the vessel or reference leg remains constant, the liquid density changes as a function of pressure and temperature. This changes the pressure delivered to the differential pressure transmitter, which makes the indicated level appear different for the actual level. The transmitter cannot distinguish that the difference in pressure is caused by the density effect.

In most applications, two (2) situations are frequently encountered. Although other situations are common, it is not practical to cover the details of each. Instead the situations described herein encompass the basic theory and methodology that can be applied to the other situations. These are:

1) Type A: The level measuring system is calibrated for assumed normal operating conditions. No automatic vessel or reference leg density compensation is provided.

2) Type B: The level measuring system is automatically compensated for density variations of the fluid in the vessel, but no reference leg compensation is provided.

It is further assumed that the vessels are closed (non-vented) and contain a saturated mixture of steam and water, the reference leg is water-filled and saturated, and no temperature gradient exists along the length of the reference leg. Often the reference leg fluid is a compressed liquid, but for the purpose of this discussion, it is assumed to be saturated. Use densities and specific volumes as appropriate (e.g. subcooled, superheated). For simplicity vessel growth is not considered in this example.

Before deriving the uncertainty equations for the situations described above, a review of level measurement theory is presented. Figure L-1 shows a closed vessel containing a saturated steam/water mixture along with explanations of the symbols used. From Figure L-1 the differential pressure supplied to the transmitter is obtained as follows:

$$dP = Pressure\ (HI) - Pressure\ (LO) \qquad \text{Eqn. (L-1)}$$

Now,

$$Pressure\ (HI) = HR * SGR + Static\ Pressure \qquad \text{Eqn. (L-2)}$$

$$Pressure\ (LO) = HW * SGW + HS * SGS + Static\ Pressure \qquad \text{Eqn. (L-3)}$$

Substituting Equations (L-2) and (L-3) into (L-1),

$$dP = HR * SGR - HW * SGW - HS * SGS \qquad \text{Eqn. (L-4)}$$

Appendix L

Process and Reference Leg Uncertainties for Differential Pressure Transmitters

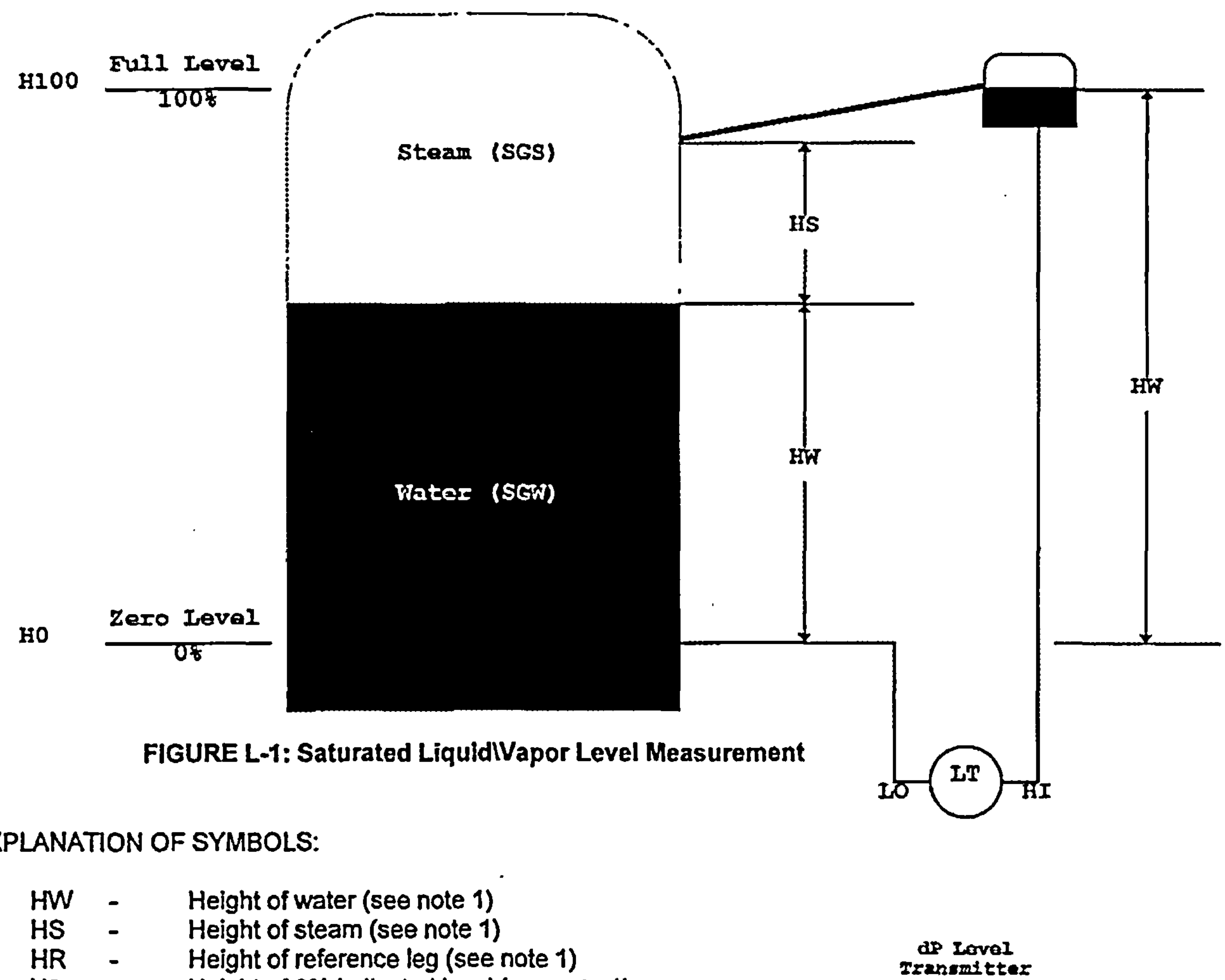


FIGURE L-1: Saturated Liquid\Vapor Level Measurement

EXPLANATION OF SYMBOLS:

HW	-	Height of water (see note 1)
HS	-	Height of steam (see note 1)
HR	-	Height of reference leg (see note 1)
H0	-	Height of 0% indicated level (see note 1)
H100	-	Height of 100% indicated level (see note 1)
SVW	-	Specific volume of water at saturation temperature
SVS	-	Specific volume of steam at saturation temperature
SVR	-	Specific volume of reference leg fluid
SGW	-	Specific gravity of water at saturation temperature (see note 2)
SGS	-	Specific gravity of steam at saturation temperature (see note 2)
SGR	-	Specific gravity of reference leg fluid (see note 2)
dP	-	Differential pressure in inches of H_2O,

Where:

$$dP = HR * (SGR - SGS) + HW * (SGS - SGW)$$

Notes: 1. All heights (except HS) are referenced above centerline of lower level sensing nozzle (recommended units are vessel inches)

2. Equation for Specific Gravity calculation:

$$SGN = \frac{SVW\,(@68^{\circ F})}{SVN} \qquad N = W, S, R$$

Substituting (HR - HW) for HS in Equation (L-4) yields

$$dP = HR * SGR - HW * SGW - (HR - HW) * SGS \qquad \text{Eqn.(L-5)}$$

or

$$dP = HR * (SGR - SGS) + HW * (SGS - SGW) \qquad \text{Eqn.(L-6)}$$

Using Equation (L-6) and substituting in for HW the height of the water when at 0% of indicated scale (HO) and at 100% of indicated scale (H100), the differential pressures at 0% (dP0) and at 100% (dP100), respectively, can be determined.

Note that HR, HW, H0, and H100 are normally stated in inches above the lower level sensing tap centerline. If the senselines below the lower tap are routed together, it is good engineering judgment that the fluid in these senselines are at the same density if they contain the same fluid and are at equal temperature. Because SGW, SGR, and SGS are unitless quantities, dP, dP0, and dPI00 are normally stated in "inches of water" (in H_2O) based on 68°F water. To calibrate the transmitter to read correctly, it is necessary to establish a base set of operating conditions in the vessel and reference leg from which SGW, SGR, and SGS can be determined using ASME steam tables. After the specific gravity terms are defined, they can be plugged into Equation (L-6) along with HR, H0, and H100 and the equation solved for dP0 and dPI00 These values of dP are then used to calibrate the transmitter (assuming in an ideal situation that the transmitter static head correction is neglected).

As long as the actual vessel and reference leg conditions (SGWA, SGSA, etc.) remain the same as the base conditions for the Type A System, the indicated level is a linear function of the measured differential pressure and no vessel/reference leg density effects are created. Therefore, the following proportionality can be written:

$$\frac{HW - H0}{H100 - H0} = \frac{dP - dP0}{dP100 - dP0} \qquad \text{Eqn. (L-7)}$$

Solving for HW yields:

$$HW = \frac{(H100 - H0) * (dP - dP0)}{dP100 - dP0} + H0 \qquad \text{Eqn. (L-8)}$$

To assess the effects of varying vessel/reference leg conditions, assume an erroneous differential pressure, dP_e, and erroneous water level, H_e are generated due to an off-base operating condition. Equation (L-8) can then be rewritten as:

$$HW \pm H_e = \frac{(H100 - H0) * (dP \pm dP_e - dP0)}{dP100 - dP0} + H0 \qquad \text{Eqn. (L-9)}$$

Substituting Equation (L-8) into Equation (L-9) and solving for H_e yields

$$H_e = \frac{(H100 - H0) * dP_e}{dP100 - dP0} \qquad \text{Eqn. (L-10)}$$

The denominator of Equation (L-10) can be rewritten using Equation (L-6) as

$$dP100 - dP0 = [HR * (SGR - SGS) + H100 * (SGS - SGW)] -$$

$$...[HR * (SGR - SGS) + H0 * (SGS - SGW)]$$

$$dP100 - dP0 = (H100 - H0) * (SGS - SGW) \qquad \text{Eqn. (L-11)}$$

Equation (L-11) can be substituted into Equation (L-10) yielding

$$H_e = \frac{dP_e}{SGS - SGW} \qquad \text{Eqn. (L-12)}$$

The numerator of Equation (L-12) is simply the difference in the differential pressure measured at the actual conditions, dPA, less the differential pressure measured at the base condition, dPB, or

$$dP_e = dPB - dPA \quad \text{(TVA Sign Convention)} \qquad \text{Eqn. (L-13)}$$

Using Equation (L-6) and assuming HR and HW are constant, we can substitute

$$dPA = HR * (SGRA - SGSA) + HW * (SGSA - SGWA) \qquad \text{Eqn. (L-14)}$$

and

$$dPB = HR * (SGRB - SGSB) + HW * (SGSB - SGWB) \qquad \text{Eqn. (L-15)}$$

into Equation (L-13), yielding

$$dP_e = HR * (SGRB - SGSB - SGRA + SGSA) + HW * (SGSB - SGWB - SGSA + SGWA) \qquad \text{Eqn. (L-16))}$$

The denominator in Equation (L-12) is equivalent to (SGSB-SGWB). Substituting this and Equation (L-16) into Equation (L-12) yields

$$H_e = \frac{HR * (SGRB - SGSB - SGRA + SGSA) + HW * (SGSB - SGWB - SGSA + SGWA)}{(SGSB - SGWB)} \qquad \text{Eqn. (L-17)}$$

Equation (L-17) defines the uncertainty induced by changes in liquid density in the vessel, reference leg, or both for Type A situations. For Type B situations, SGSA = SGSB and SGWA = SGWB as the vessel conditions are automatically compensated. In other words, a Type B system measures the temperature of the vessel fluid and effectively modifies the base calibration point of the transmitter to be equivalent to the measured or actual temperature. Therefore, reference leg density effects must be determined, but the vessel density effects are eliminated. Typically, the signal compensation is done with a network of function generators and signal multipliers programmed with correction factors, based on density, that multiply the correction factor times the dP input from the level transmitter to get the true level. As equipment uncertainties may be present in the compensation circuitry, which may effectively multiply the dP as well, it is necessary to calculate the reference leg heatup effect in terms of dP, using Equation (L-16), and plug dP_e in the channel uncertainty equation in a similar fashion as a dP equipment uncertainty. Therefore, for the Type B situation, Equation (L-16) reduces to:

$$dP_e = HR * (SGRB - SGRA) \qquad \textbf{Eqn. (L-18)}$$

Equation (L-18) shows that dP uncertainty becomes increasingly positive as the actual temperature increases above the base temperature. This is expected due to the way dP_e is defined and the fact that the hydrostatic pressure contributed by the reference leg decreases with increasing temperature. dP magnitude decreases as vessel level rises. It is also worth noting that the equipment errors associated with the compensation circuits normally are very small. Therefore, the approximate magnitude of the reference leg density effect can be estimated by:

$$H_e = \frac{HR * (SGRB - SGRA)}{SGSB - SGWB} \qquad \textbf{Eqn. (L-19)}$$

This equation was developed from Equation (L-17) letting SGSA = SGSB and SGWA = SGWB.

As previously discussed, the Type B system compensation equipment effectively "adjusts" the base calibration conditions to match the actual vessel conditions. Therefore, when using Equation (L-19) the level error, H_e, is determined at the vessel condition of interest by plugging in the specific gravity steam and specific gravity water values for that condition, not the base condition for which the transmitter is calibrated.

If the high pressure (HI) side of the transmitter had been connected to the lower nozzle and the low pressure (LO) side had been connected to the upper nozzle, it can be shown by similar derivation that Equations (L-17) and (L-19) still apply. Equation (L-18) becomes:

$$dP_e = HR * (SGRA - SGRB) \qquad \textbf{Eqn. (L-20)}$$

Because the denominator term in Equations (L-17) and (L-19) decreases with increasing temperature, it is evident that the effect increases with rising vessel temperature. Furthermore, examination of the numerator of Equation (L-17) reveals that the effect is maximized when HW is equal to H100. Examination of Equation (L-19) reveals that an increasing reference leg temperature above the base conditions results in an increasing negative effect assuming vessel conditions remain constant.

The equations above calculate uncertainties in actual engineering units. If it is desired to work in percent span, the quantities H_e and dP_e can be converted to percent span by dividing each by (H100-H0) or (dP100-dP0), respectively, and multiplying the results by 100%. As previously discussed, the sign of dP_e must be considered based on which way the high and low pressure sides of the dP transmitter are connected to the vessel.

Appendix L

Process and Reference Leg Uncertainties for Differential Pressure Transmitters

Assume for example that a Type A system configured as shown in Figure L-1 has the following conditions:

1) HR	= 150 inches
2) H0	= 50 inches
3) H100	= 150 inches
4) HW	= 100 inches
5) Base Conditions:	Vessel Fluid Temperature = 532°F (saturated water @ 681 psia) Reference Leg Temperature = 68°F (subcooled water @ 681 psia)
6) Actual Conditions:	Vessel Fluid Temperature = 500°F (saturated water @ 900 psia) Reference Leg Temperature = 300°F (subcooled water @ 900 psia)

It is desired to determine H_e using Equation (L-17). First, the specific gravity terms are found using the specific volumes of water (SVW) and specific volumes of steam (SVS) from the thermodynamic steam tables. The following values are determined:

$$SGWA = \frac{SVW(68^\circ F)}{SVW(500^\circ F)} = \frac{0.01605\ ft^3/lbm}{0.02043\ ft^3/lbm} = 0.79$$ **Eqn. (L-21)**

$$SGSA = \frac{SVW(68^\circ F)}{SVS(500^\circ F)} = \frac{0.01605\ ft^3/lbm}{0.67492\ ft^3/lbm} = 0.0238$$ **Eqn. (L-22)**

$$SGRA = \frac{SVW(68^\circ F)}{SVW(300^\circ F)} = \frac{0.01605\ ft^3/lbm}{0.01741\ ft^3/lbm} = 0.92$$ **Eqn. (L-23)**

$$SGWB = \frac{SVW(68^\circ F)}{SVW(532^\circ F)} = \frac{0.01605\ ft^3/lbm}{0.02123\ ft^3/lbm} = 0.76$$ **Eqn. (L-24)**

$$SGSB = \frac{SVW(68^\circ F)}{SVS(532^\circ F)} = \frac{0.01605\ ft^3/lbm}{0.50070\ ft^3/lbm} = 0.0321$$ **Eqn. (L-25)**

$$SGRB = \frac{SVW(68^\circ F)}{SVW(68^\circ F @ 900psia)} = \frac{0.01605\ ft^3/lbm}{0.01600\ ft^3/lbm} = 1.0$$ **Eqn. (L-26)**

Next we substitute HW = 100 inches, HR 150 inches, and quantities from Equations (L-21) through (L-26) above into Equation (L-17) and solve for H_e; thus,

$$H_e = \frac{HR * (SGRB - SGSB - SGRA + SGSA) + HW * (SGSB - SGWB - SGSA + SGWA)}{(SGSB - SGWB)} \qquad \text{Eqn. (L-27)}$$

$$= \frac{150 * (1.0 - 0.0321 - 0.92 + 0.0238) + 100 * (0.0321 - 0.76 - 0.0238 + 0.79)}{(0.0321 - 0.76)} = -20.04 \text{ inches}$$

In percent of indicated span,

$$H_e(\%) = \frac{H_e}{H100 - H0} * 100\% \qquad \text{Eqn. (L-28)}$$

$$= \frac{-20.04}{150 - 50} * 100\%$$

$$= \underline{-20.04\% \text{ of span}}$$