Entergy

Entergy Nuclear Northeast
Entergy Nuclear Operations, Inc.
Vermont Yankee
322 Governor Hunt Rd.
P.O. Box 157
Vernon, VT 05354
Tel 802-257-7711

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U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Subject: **Vermont Yankee Nuclear Power Station**
License No. DPR-28 (Docket No. 50-271)
Technical Specification Proposed Change No. 257
Implementation of ARTS/MELLLA at VYNPS
Supplemental Information and Proposed Allowable Value

By letter dated March 20, 2003[1] Vermont Yankee[2] (VY) proposed to amend Facility Operating License DPR-28 for the Vermont Yankee Nuclear Power Station (VYNPS) by incorporating the Average Power Range Monitor, Rod Block Monitor Technical Specifications/Maximum Extended Load Line Limit Analysis (ARTS/MELLLA) operating strategy into the facility's licensing basis.

Based on communications with the NRC staff, VY agreed to change the methodology used in establishing the limiting safety system setting for the safety-related instrumentation affected by the March 20, 2003 license amendment request (LAR). VY is proposing herein revised Technical Specifications (TS) for the APRM High Flux (flow bias) trip function by establishing an Allowable Value which was based on ISA-S67.04[3] Part II Method 1. VY plans to limit application of this methodology to LARs associated with extended power uprate and only in situations where the current TS instrument limiting safety system setting value is proposed to be changed.

The application of Allowable Values in TS represents a change in licensing basis for VYNPS and introduces new terminology into the custom TS. The Allowable Value is the limiting value that the instrument trip setpoint may have when tested periodically, beyond which appropriate action will be taken. To ensure proper application of this terminology, this definition and others are defined in the VYNPS Instrument Uncertainty and Setpoint Design Guide, which is provided as Attachment 1. This design guide only establishes the setpoint program applicable to TS instrument settings instituted or revised in support of this LAR and the LAR for extended power uprate[4] and replaces the version provided by VY letter of July 21, 2003[5] for this purpose.

[1] Vermont Yankee letter to U.S. Nuclear Regulatory Commission, "Technical Specification Proposed Change No. 257, Implementation of ARTS/MELLLA at Vermont Yankee," BVY 03-23, March 20, 2003.

[2] Entergy Nuclear Vermont Yankee, LLC and Entergy Nuclear Operations, Inc. are the licensees of the Vermont Yankee Nuclear Power Station.

[3] Instrument Society of America, "Setpoints for Nuclear Safety-Related Instrumentation," standard ISA-S67.04-1994.

[4] Vermont Yankee letter to U.S. Nuclear Regulatory Commission, "Technical Specification Proposed Change No. 263, Extended Power Uprate," BVY 03-80, September 10, 2003.

[5] Vermont Yankee letter to U.S. Nuclear Regulatory Commission, "Technical Specification Proposed Change No. 257, ARTS/MELLLA – Additional Information in Response to RAI No. 9," BVY 03-64, July 21, 2003.

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Attachment 2 is a copy of recently revised VY calculation VYC-0693A, "APRM Neutron Monitoring Trip Loops," which provides the TS Allowable Values proposed in Proposed Change No. 257. In the performance of safety analyses to support the VYNPS ARTS/MELLLA license amendment request, previously-established analytical limits were used as inputs. If an analytical limit changed as a result of a safety analysis (as was the case for the APRM flow-biased high flux limit), an instrument Allowable Value is proposed. Because there are no other changes in analytical limits from which Technical Specification limits derive in the adoption of ARTS/MELLLA at VYNPS, no other instrument allowable values are being proposed.

The calculation provided as Attachment 2 to this letter is current as of the date of this submittal. However, it is not VY's intent to maintain the docket current with regard to future changes to this calculation.

Attachment 3 provides a discussion of changes to the revised Technical Specifications. Attachment 4 provides replacement mark-ups of current TS pages, and Attachment 5 provides the re-typed TS pages. TS pages 6, 11, 14, 21, and 24 that were provided by letter of March 20, 2003, should be replaced with the attached. In addition, due to the added text, there is now a TS page 14a included with the re-typed pages. The bases for the changes remain as stated in the March 20, 2003 application and are supplemented by Attachments 1 and 2 hereto. An additional change is the proposed deletion of TS Figure 2.1.1, "APRM Flow Reference Scram Setting." VY has determined that Figure 2.1.1 provides no additional requirements beyond those specified elsewhere in TS and is therefore redundant and should be eliminated from TS. Also, a typographical error (now moot) was identified in the March 20, 2003 submittal: On page 3 of Attachment 1, Item 7 incorrectly specified a Single Loop Operation trip setting as "$S \leq 1.28W + 26.0\%$ for $39.1\% < W \leq 61.9\%$." The correct trip setting (as specified a number of times in the submittal) should have been: "$S \leq 1.28W + 26.8\%$ for $39.1\% < W \leq 61.9\%$."

The changes provided herewith do not expand the scope or change the conclusions of the original application for a license amendment, and the prior determination of no significant hazards consideration is unchanged. If you have any questions in this regard, please contact Mr. Len Gucwa at (802) 258-4225.

Sincerely,

Jay K. Thayer

Jay K. Thayer
Site Vice President

STATE OF VERMONT)
)ss
WINDHAM COUNTY)

Then personally appeared before me, Jay K. Thayer, who, being duly sworn, did state that he is Site Vice President of the Vermont Yankee Nuclear Power Station, that he is duly authorized to execute and file the foregoing document, and that the statements therein are true to the best of his knowledge and belief.

Sally A. Sandstrum

Sally A. Sandstrum, Notary Public
My Commission Expires February 10, 2007

SALLY A. SANDSTRUM NOTARY PUBLIC WINDHAM COUNTY, VERMONT

Attachments

cc:

USNRC Region 1 Administrator (cover letter only)
USNRC Resident Inspector – VYNPS (cover letter only)
USNRC Project Manager – VYNPS (with attachments)
Vermont Department of Public Service (with attachments)

Attachment 1

Vermont Yankee Nuclear Power Station

Technical Specification Proposed Change No. 257

Instrument Uncertainty and Setpoint Design Guide

ENTERGY VERMONT YANKEE

NUCLEAR POWER STATION

INSTRUMENT UNCERTAINTY AND SETPOINT DESIGN GUIDE

APPENDIX D To Setpoint Program Manual

REVISION 3

Approvals: JOSEPH GAROZZO Joseph Garozzo 11/24/03
Prepared By (Print/Sign) Date

James W. Allen James W. Allen 11/24/03
Reviewed By (Print/Sign) Date

R-T-VIBERT R-T-Vibert 11/24/03
Approved By (Print/Sign) Date

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Effective Date 12/1/03

PREFACE

This document is intended to support the overall Setpoint Program at the Vermont Yankee Nuclear Power Station by providing guidance for the preparation of instrument uncertainty and setpoint calculations. Historical background, implementation, and responsibilities will be contained in the Setpoint Program Manual.

This design guide is written for a diverse group of potential users, which include:

(1) Preparers or reviewers of both nuclear safety-related and non-safety related setpoint calculations,
(2) Potential auditors of the Setpoint Program,
(3) Preparers of instrument calibration and testing procedures.

Since not all information in this guide will be of interest to all users, the following "road map" is provided to help the user quickly find the information he or she may require.

- Specialized terms are defined in section 5., "Definitions and Abbreviations."

- Cross-references to documents listed in section 6., "General References," are shown as [Ref. x.xx], where x.xx is the paragraph number. References to other sections of this guide are shown as [Sec. x.xx] or "see Appendix X."

- This guide employs a "graded" approach to the evaluation of uncertainty and the development of setpoints or operator decision points. The degree of rigor and the conservatism of the calculation are based upon the safety significance of the instrument function. The classification scheme is introduced in section 2., "Scope", the effect on uncertainty calculations discussed in section , "Module Uncertainty," as well as under each uncertainty element, guidance for classifying particular functions is provided in section , "Setpoint Classification," and the specifics of setpoint calculations for each classification are covered in section , "Setpoint Determination."

- Section 3., "Uncertainty Evaluation," begins with a general discussion of how uncertainty is calculated, covers evaluation of specific elements of uncertainty from vendor and testing data, then shows how these elements may be combined, first for individual modules, and then entire loops.

- Section 4., "Setpoints and Decision Points," begins with the different bases for each type of setpoint, shows how loop uncertainty is used to find the nominal setpoint and Allowable Value as appropriate, includes the evaluation of the calculated setpoint against the estimated operating limitations and concludes with a discussion of the content of a setpoint calculation and general design considerations.

- Topics which apply to only a few calculations have been placed in the appendices. Related information in an appendix will be noted in the text. Appendix A, "Graded Approach to the Determination of Instrument Channel Accuracy," defines the graded approach used for calculations and Appendix B, "Recommended Calculation Format," shows a recommended shell for a setpoint calculation.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. SCOPE 2

2.1 Setpoint Classes 2
2.1.1 Class 1: Nuclear Safety Related 3
2.1.2 Class 2: Parameter Monitoring Important to Safety 4
2.1.3 Class 3: NNS Functions Requiring Detailed Analysis 4
2.1.4 Class 4: NNS Functions Not Requiring Detailed Analysis 5
2.2 Site-Specific Criteria 5
2.3 Regulatory and Standards Commitments 6
2.3.1 Vermont Yankee Commitment Tracking System 7
2.3.2 Surveillance Extension 7
2.3.3 Regulatory Guide 1.97 7
2.3.4 Custom Technical Specifications (CTS) 7

3. UNCERTAINTY EVALUATION 8

3.1 Types of Uncertainties - Random and Bias 8
3.2 Evaluation of Randomness 10
3.3 Dependency 11
3.4 Methods of Combining Uncertainties 11
3.5 Combining Uncertainties with Different Confidence Levels 12
3.6 Uncertainty Elements 13
3.6.1 General Considerations 13
3.6.2 Reference Accuracy (A) 14
3.6.3 Calibration Effect (CE) and Calibration Tolerance (CT) 15
3.6.4 Readability Uncertainty (RD) 18
3.6.5 M&TE Uncertainty (MTE) 18
3.6.6 Analyzed Drift (DA) 20
3.6.7 Drift (DR) 23
3.6.8 Temperature Effect (TE) 24
3.6.9 Barometric Pressure Effect (PB) 27
3.6.10 Humidity Effect (HE) 28
3.6.11 Radiation Effect (RE) 28
3.6.12 Seismic/Vibratory Effect (SE) 30
3.6.13 Process Static Pressure (SP) Effects 31
3.6.14 Power Supply Voltage Effect (VE) 33
3.7 Environmental Influences 33
3.8 Module Uncertainty (e) 34
3.8.1 Testing Conditions 35
3.8.2 Normal Conditions 36
3.8.3 Accident and Seismic Conditions 36

3.9 Process Corrections and Measurement Uncertainties (PM) 40
3.9.1 Level Measurements 40
3.9.2 Flow Measurements 40
3.9.3 Pressure Measurements 41
3.10 Insulation Resistance (IR) Leakage Effects 41
3.11 Total Loop Uncertainty 42
3.12 Difference Uncertainties for Sequential Setpoints 43

4. SETPOINTS AND DECISION POINTS 46

4.1 Setpoint Basis 50
4.2 Setpoint Classification 51
4.2.1 Class 1 Setpoints and Decision Points 51
4.2.2 Class 2 Decision Points 51
4.2.3 Class 3 Setpoints and Decision Points 52
4.2.4 Class 4 Setpoints and Decision Points 52
4.3 Limits for Class 1 Setpoints 52
4.4 Class 2 and Class 3 Setpoints/Uncertainties 55
4.5 Class 4 Setpoints/Uncertainties 55
4.6 Setpoint Determination 55
4.6.1 Limiting Setpoint (LSp) 56
4.6.2 Allowable Value (AV) 57
4.6.3 Setpoints and Administrative Limits 59
4.6.4 As-Found and As-Left Tolerances 59
4.6.5 Sequential (Stacked) Setpoint Determination 60
4.7 Design Considerations 62
4.7.1 Scaling 62
4.7.2 Installation 62

5. DEFINITIONS AND ABBREVIATIONS 64

5.1 Definitions 64
5.2 Abbreviations 72

6. GENERAL REFERENCES 76

<u>Attachments</u>
Attachment A: Graded Approach to the Determination of Instrument Channel Accuracy
Attachment B: Recommended Calculation Format
Attachment C: Process Corrections and Measurement Uncertainty
Attachment D: Flow Loop Scaling and Uncertainty
Attachment E: Special Considerations for Radiation Monitors
Attachment F: Statistical Considerations

Attachment G:	Abnormal and Uniform Uncertainty Distributions
Attachment H:	IST Accuracy Calculation and Calibration Requirements
Attachment I:	Instrument Cross Comparison Averaging Methodology
Attachment J:	Instrument Uncertainty and Performance Monitoring
Attachment K:	Maximum Allowable Deviation Limit

LIST OF TABLES

Table 1: Standard Calibration Tolerances 16
Table 2: Normal Temperature Ranges 25
Table 3: Uncertainty Sign for LSp and AV Evaluation 54

LIST OF FIGURES

Figure 1: Bias and Normally Distributed Random Uncertainties 8
Figure 2: Deleted 37
Figure 3: Stacked Setpoint Loop 43
Figure 4: Typical Safety-Related Setpoint Allowances (ITS) 46
Figure 5: Typical Safety-Related Setpoint Allowances (CTS) 47
Figure 6: Uncertainty Relationships for Class 1 Setpoints 52
Figure 7: Setpoint and Administrative Limits 56
Figure 8: Sequential (Stacked) Setpoints 58
Figure 9: Accuracy 60
Figure 10: Repeatability 61
Figure 11: Hysteresis and Dead Band 63

REVISION HISTORY

Revision	Date	Description of Change
Original	5/7/97	Original Issue
1	2/5/2000	Numerous changes have been incorporated such that this revision is viewed as a **Major Change**. As such, revision bars will not be applied. A summary of key changes follows: 1. Converted text from Word Perfect to Microsoft Word 2. Added Attachment H, I, J & K 3. Revised the discussion on Graded Approach. 4. Improve the description of statistical analysis and the applicability of Confidence Interval, Tolerance Interval, Proportion, and Probability. 5. Attachment A – Replaced 'Standard Criteria and Assumptions' with 'Graded Approach to the Determination of Instrument Channel Accuracy' 6. Attachment B – Revised the 'Recommended Calculation Format' and included a setpoint check-off list. 7. Attachment D – Updated the method of propagating flow uncertainty.
2	7/15/03	Revised the following pages as described: 1. Pages 6 and 7 – Removed references to FSAR Tables, which are no longer applicable. Removed reference to accuracy for RG 1.97. 2. Page 39 – Removed Figure which is no longer applicable. 3. Page 54 - Revised Figure to remove erroneous references. 4. Page 56 – Editorial corrections made to uncertainty terms, removed AL/PL check that are not necessary. 5. Page 57 – Editorial corrections made to uncertainty terms. 6. Page 58 – Removed AL/PL check that are not necessary. 7. Page 60 – Removed TSL check that is not necessary. 8. Page 68 – Removed unecessary wording from LSSS definition.
3		Revised Appendix D to revise Methodology to Determine AV and LSp to ISA 67.04, Part 2, Method 1.

1. INTRODUCTION

This design guide establishes a methodology for the preparation of instrument loop uncertainty and setpoint calculations. A systematic method of identifying and combining instrument uncertainties is necessary to ensure that adequate margin has been provided to protection limits as well as normal operations. The methodology is based on the industry standard ANSI/ISA S67.04 Part I-1994, "Setpoints for Nuclear Safety-Related Instrumentation" [Ref. 6.4].

Instrument setpoints associated with nuclear safety-related (NSR) functions are generally based on established safety or analytical limits, while setpoints associated with a non-nuclear safety-related (NNS) function will frequently be based upon estimated operating limits. NSR and NNS are categories used in this design guide to denote the classification of the function that a particular channel or loop performs. This guide complies with the intent of ISA RP67.04 Part II-1994 [Ref. 6.5] with respect to NSR setpoints. Where appropriate, clarifications of the standard as it applies to Vermont Yankee will be provided; however it is not the intent of this guide to replicate the material in the recommended practice. Anyone using this guide to prepare NSR calculations should also be familiar with ISA S67.04 Part I and ISA-RP67.04 Part II.

This design guide provides an appropriate degree of rigor in the method by which a setpoint is determined. The intent is to provide a format for combining uncertainties caused by process variations with those due to the instrumentation to ensure that there is adequate margin for the given plant parameter. This provides a consistent criterion for assessing the magnitude of uncertainties associated with each component, thereby ensuring plant safety and adequate operating margin.

Instrument uncertainty is of interest for purposes other than setpoint determination. Operators use parameter indications (e.g. indicators and recorders) to monitor plant performance. This monitoring function supports surveillance activities as well as supporting the operators in the use of the emergency operating procedures (EOPs). Specific monitoring systems are relied upon post-accident and must be evaluated for uncertainty under those conditions.

This design guide will be applied to the determination of setpoints applicable to both Vermont Yankee's existing Technical Specifications and the yet to be implemented Improved Technical Specifications.

It is expected that as the Setpoint Program evolves this guide will be revised.

2. SCOPE

This design guide applies to the determination of instrument uncertainties and setpoints, as well as the evaluation of EOP decision points. These include any of the instrumentation used in NSR channels, other TS required loops, post-accident monitoring channels, and NNS/BOP setpoints and indication loops at Vermont Yankee, for example:

- Temperature, flow, conductivity, and radiation detector elements;
- Temperature, pressure, flow, level, and conductivity transmitters and switches;
- Signal conditioners, discriminators, converters, and analog isolators;
- Alarm switches, bistables, and trip units;
- Display meters, panel indicators, and recorders;
- Time delay relays, counters, rate meters, totalizers, summers, characterizers, and function modules;
- Analog to Digital Converter (ADC) and Digital to Analog Converter (DAC) devices.

This design guide does not currently apply to setpoints for control loop controllers, motor-operated valve (MOV) torque switches, snubbers, transformer tap settings, mechanical limit switches, or mechanical relief valves. MOV requirements are addressed in the Vermont Yankee Motor Operated Valve Program Manual [Ref. 6.23]. Response times associated with setpoint initiation and actuation of nuclear safety-related devices are separately addressed in VYC-264, "Safety Class Instrument Accuracy Review: Instrumentation and Logic Circuit Time Response" [Ref. 6.31].

2.1. Setpoint Classes

The methods described in this guide are intended to apply to the entire range of protective setpoints, and to a limited extent to control setpoints, applicable to Vermont Yankee. Differences in instrument functions are recognized and accounted for by the degree of rigor required in the methodology employed to arrive at the instrument uncertainty and final setpoint. The Vermont Yankee graded methodology classifies instrument setpoints into four levels. These correspond to a "level of confidence" that the setpoint will perform its function with respect to a limit or other limiting criteria. These levels range from Class 1, which provides the highest confidence, to Class 4, which may only document engineering judgment.

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

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

2.1.1. Class 1: Nuclear Safety Related

RG-1.105, ISA S67.04 Part I, and ISA-RP67.04 Part II are all concerned with setpoints for nuclear safety-related instrumentation, which are defined as follows:

"That which is essential to the following:

a) Provide emergency reactor shutdown
b) Provide containment isolation
c) Provide reactor core cooling
d) Provide for containment or reactor heat removal
e) 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."

The design guide is predicated on this definition which is taken from ISA-RP67.04 Part II [Ref. 6.5].

Nuclear safety related trips (e.g. Low Low Reactor Water Level) and initial process conditions assumed in the accident and transient analysis (e.g. Torus Water Temperature) are considered Class 1. Class 1 instrument functions are those that are required to fulfill the safety functions or support systems important to safety described in the Vermont Yankee Engineering Design Basis Manual [Ref. 6.26]. Those instrumentation functions and loops are generally found in the FSAR tables identified in Section 2.3 below, however the specific list of setpoints and functions for each class will be contained in the Setpoint Program Manual.

Attachment A provides the application of Rigor for Class 1 setpoints and uncertainty calculations.

2.1.2. Class 2: Parameter Monitoring Important to Safety

This level will include those setpoints that:

1) Ensure compliance with Technical Specification but are not Class 1 setpoints.

2) Provide setpoints or limits associated with RG 1.97, category 1 and 2 variables.

3) Provide essential setpoints or limits associated with station emergency operating procedure (EOP) requirements.

The RG 1.97 category 1 and 2 variables are included in Class 2 since they: 1) provide the primary information required to permit the control room operator to take specific manually controlled actions for which no automatic control is provided and that are required for safety systems to accomplish their safety functions for design basis accident events, and 2) provide the operator with information that is essential to ensuring safety related post-accident functions are occurring.

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

Setpoints or limits contained in station EOPs that are RG 1.97 category 1 and 2 variables, or setpoints that provide specific action values are included in Class 2. Other EOP setpoints may be either Class 2 or 3 depending on their function.

This class includes instruments qualified under the Vermont Yankee Environmental Qualification (EQ) Program [Ref. 6.21] for harsh environments, as well as NSR and NNS instruments which do not require qualification for harsh environments.

Attachment A provides the application of Rigor for Class 2 setpoints and uncertainty calculations.

2.1.3. Class 3: NNS Functions Requiring Detailed Analysis

This Class will include those setpoints that:

1) Provide setpoints or limits associated with RG 1.97, category 3 variables.

2) Provide setpoints or limits associated with other regulatory requirements or operating commitments, e.g. OSHA, EPA, etc.

3) Provide setpoints or limits that are clearly associated with personnel safety or equipment protection.

The RG 1.97, category 3 variables are associated with contingency actions and may be included in EOPs or other written procedures.

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

Attachment A provides the application of Rigor for Class 3 setpoints and uncertainty calculations.

2.1.4. Class 4: NNS Functions Not Requiring Detailed Analysis

This Class will include those setpoints that:

1) Provide setpoints or limits not identified with the requirements in Class 1, 2 or 3 above.

2) Require documentation of engineering judgment, industry or station experience, or other methods that have been used to set or identify an operating limit.

Class 4 shall provide documentation of all non-Vermont Yankee methodologies used to establish instrument loop accuracies or instrument setpoints.

2.2 Site-Specific Criteria

Safety-related calculations prepared in accordance with this guide shall satisfy the requirements of WE-103, "Engineering Calculations and Analyses" [Ref. 6.12], Project Procedure VYDEP-15, "Calculations," AP 0017, "Calculations and Analyses" [Ref. 6.13], and Vermont Yankee Procedure AP 0022, "Setpoint Change Requests" [Ref. 6.14]. Non-safety related calculations should also be prepared in accordance with WE-103 or approved Vermont Yankee plant procedures and VYDEP-15.

2.3 Regulatory and Standards Commitments

From the Vermont Yankee Final Safety Analysis Report (FSAR) Section 7.2.2, Safety Design Bases (7.c.):

> "The system shall be designed for a high probability that when any monitored variable exceeds the scram setpoint, the event shall result in an automatic scram and shall not impair the ability of the system to scram as other monitored variables exceed their scram setpoints."

From FSAR Section 7.2.4, Safety Evaluation:

> "Because the Reactor Protection System meets the precision requirements of Safety Design Bases 1, 2, and 3 using instruments with the characteristics described in Table 7.2.1, it is concluded that Safety Design Basis 5 is met."

2.3.1 Vermont Yankee Commitment Tracking System

(a) AUDITRPT9207EEC1: Develop VERMONT YANKEE position for SSCA 0878 defining setpoint methodology and setpoint design basis.

(b) INF96022_01: Revise setpoint program to specify M&TE acceptable for given surveillance calibration. Modify surveillance test and/or calibration procedures to incorporate M&TE specified by the calculations.

(c) INS941601: Reevaluation of the surveillance setpoint tracking program to ensure compliance with NRC bulletin 90-01, Supplement 1.

(d) MOOID9207MGT1: Develop setpoint philosophy document to ensure that setpoint issues are consistently addressed.

(e) OE7795: Humidity effects on setpoint drift in Barksdale B1T and B2T pressure switches at Duane Arnold.

These and parts of other commitments will be addressed by this design guide and other parts of the Improved Setpoint Program.

2.3.2 Surveillance Extension

As part of the Vermont Yankee effort to extend surveillance test intervals (i.e. from monthly to quarterly), a commitment was made to the NRC to document the plant specific drift and reliability of the affected instrumentation and submit an amendment to the Technical Specifications [Ref. 45]. This design guide will provide a methodology to evaluate and document the setpoint changes as a result of the required drift studies.

2.3.3 Regulatory Guide 1.97

The Vermont Yankee RG 1.97 commitments are summarized in "Guidance & Methodology Associated with Vermont Yankee's Regulatory Guide 1.97 Program Commitments [Ref. 6.22]. This document identifies those instruments, ranges and design features required to satisfy RG 1.97. The methodology discussed in the Instrument Uncertainty and Setpoint Design Guide addresses those requirements.

2.3.4 Custom Technical Specifications (CTS)

CTS criteria apply until Improved Technical Specifications (ITS) are implemented. CTS requirements need to be included, as well as any formal Technical Specification interpretations and clarifications provided in "VY Clarification Document".

3. UNCERTAINTY EVALUATION

All instrumentation exhibits some error from the true value of the measured parameter; however, that error may not be known exactly. The limits of that error may however be evaluated statistically. Uncertainty is the term used to describe the distribution of errors and the numerical limits of error which are "most likely" [Sec. 3]. See Attachment F: "Statistical Considerations", for further detail.

Instrument accuracy and uncertainty are terms that are often misunderstood and misused. Accuracy is the closeness of agreement between a recognized standard or ideal value and the result of a measurement [Sec. 3]. Often, this is quantitatively expressed as error or inaccuracy. Unfortunately, the value of error for any one measurement is not knowable, all that can be known is an estimate of the range of values of likely error [Ref. 6.8]. Accuracy will be used in this guide as synonymous with reference accuracy.

The principal application of uncertainty covered by this design guide applies to the evaluation of families of similar instruments to establish limits of error over an extended calibration cycle and a wide range of conditions, as is typical of the installed process instruments at Vermont Yankee. This view of uncertainty is central to the setpoint methodology described in this design guide. Rather than being dependent upon the behavior of a specific instrument or loop the resulting setpoints may be expected to be valid for any similar model of instrumentation, for similar conditions and test intervals.

An important feature of the setpoint program at Vermont Yankee is the collection and analysis of plant instrument drift data. This guide provides direction for interpreting the results of this type of analysis to develop appropriate uncertainties, testing limits, and setpoints for instrument loops likely to be found at Vermont Yankee.

3.1 Types of Uncertainties - Random and Bias

There are two basic categories of errors described by this guide-random (R) and bias (B). The total error (u) of a particular measurement (k) can be expressed as a sum of these two types of errors.

$$U_k = B_k + R_k$$

Bias errors and normally distributed random errors are illustrated in Figure 1, "Bias and Normally Distributed Random Uncertainties."

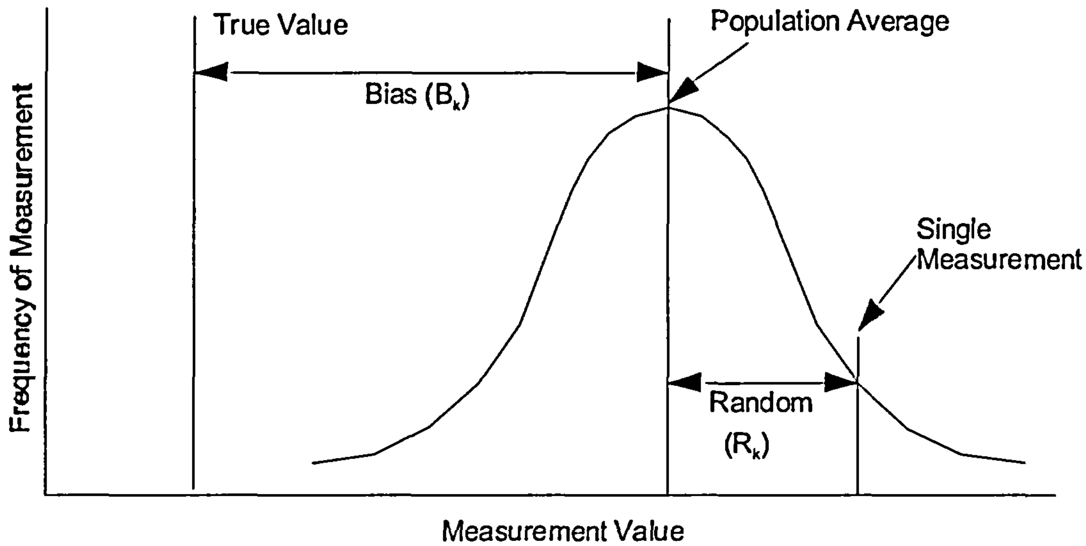


Figure 1: Bias and Normally Distributed Random Uncertainties

Bias errors (also called systematic errors) show a repeatable pattern to the errors [Sec. 3]. With only bias errors, the difference between the "true" value and the measured value is consistent and theoretically predictable. Also treated as biases are those effects that are not predictable, but are likely to assume values near known limits.

Random errors can vary both in sign and magnitude for each measurement [Sec. 3]. Random errors cannot be predicted exactly but can be estimated by a distribution function. As generally used in this design guide, random terms are those which have an equal possibility of deviating from the norm in a positive or negative direction (e.g., ±), and are approximately normally distributed; however, guidance is also provided in Attachment G: "Abnormal and Uniform Uncertainty Distributions," for those distributions which are not "covered" by the normal, bell shaped distribution.

Sign Convention: Throughout this guide a positive uncertainty implies that the "sensed" output is greater than the actual process condition, as is the case with a signal-developing instrument and associated loop. However, the signal convention for field devices (e.g. pressure switches) may be reversed where the uncertainty is a shift of setpoint rather than a shift of ideal signal output.

3.2 Evaluation of Randomness

The uncertainty behavior of an instrument for a given effect may be random or bias. If the effect is random, then the characteristics of a group of instruments will also be random. Commonly, an individual instrument may show a systematic or bias error for a given effect. Other similar instruments (e.g., same model number) may also individually exhibit bias behavior. However, as a group, the sign of the individual instrument errors is equally likely to be positive as negative and the possibility of a positive error of a given magnitude is as likely as a negative error of equal magnitude. This satisfies the concept of a symmetric random distribution. This kind of effect is considered as random independent, since the installation of any particular device is random. This allows us to use the Square-Root-Sum-of-Squares (SRSS) to evaluate overall uncertainty and to apply that uncertainty symmetrically to a particular point of interest (e.g., a process limit or setpoint). Obviously, if individual devices have random characteristics, then the characteristics of the group of instruments will also be random. However, even if individual devices have non-random characteristics, the characteristics of the group of instruments may also be random. Random in these discussions assumes a normal distribution.

Also, most devices (within a family of similar devices) will exhibit little error, with a few having larger errors. This in a general way implies a normal distribution. Use of a normal distribution allows relating two standard deviations to a 95% confidence interval.

In some cases, the likelihood that one member of the group may exhibit a large error is on the same order as the likelihood of a small error, although the distribution is still random, it does not have the same coverage as the normal distribution. In those cases, this guide will apply the mathematical rules of a uniform or rectangular distribution, which are based upon the fact that in such a distribution the possibility of all errors within the range of the distribution are equally likely [Attachment G].

For this design guide, determination of whether a given type of uncertainty or effect is random or biased is based upon the characteristics of a group of similar instruments (e.g., same model), rather than of a single installed instrument (which may be replaced some time later).

Care must be exercised in relying on vendor supplied test results to determine whether an uncertainty is random or bias. Although most vendors specify nearly all of their instrument performance specifications as "±", there is often insufficient data available to support classifying the uncertainty as random. In some cases, an examination of the actual test results will reveal that the "±" specification refers to an arbitrary limit of error rather than a statistical distribution.

Summary

If available, testing data should be evaluated statistically to determine randomness.

If no data are available, then try to obtain a statement from the vendor characterizing a specification as random or biased.

If neither testing data or vendor statements are available, follow the assumptions provided in this guide for specific uncertainty elements.

3.3 Dependency

Dependent errors can exist when there is an interaction between two or more effects. Those interactions could be intra device (multiple effects acting on one instrument) or inter-device (an effect causing an interaction between devices). Where errors are truly random, normally distributed or near normally distributed, there can be no dependency. Dependency can exist between different parts of the process (i.e. an increase in temperature can result in a decrease in density for a fluid in a tank and an increase in tank pressure). Since both the changes are directional and produced by the single temperature change event these results are dependent. Any analysis performed for density errors must also include dependent pressure errors. Where there is indication of a non-normal distribution, for a given error, dependency should be evaluated. Where errors are random and normally distributed, dependency may be ignored. Using site-specific analyzed drift would account for any intra device dependencies for testing conditions. For further information see Attachment F, "Statistical Considerations."

3.4 Methods of Combining Uncertainties

The method presented in this guide for combining uncertainties, while conservative in nature, is not unnecessarily restrictive with respect to plant operations. This method does not determine the maximum loop error; rather, it determines the uncertainty that can reasonably be expected for a given set of conditions. By using a "Square-Root-Sum-of-the-Squares" (SRSS) relationship, the method recognizes that the elements of uncertainty are free to vary in both direction and magnitude. This results in smaller total uncertainty, while maintaining the desired confidence level.

Determination of maximum loop uncertainty on the basis of a "Straight Sum" or algebraic method would imply that all component errors apply at the same time, at their maximum values, and all in the same direction (+/-). In other words, the uncertainties would all be biases. While this method provides almost 100% assurance that the derived uncertainty is conservative, it is likely that the resulting setpoints would be set too deep into the normal operating ranges of a parameter.

The final form of the uncertainty expression is determined by characterizing each element of uncertainty as one of the following:

(a) Random, Independent
(b) Random, Dependent
(c) Bias

The method presented here is a combination of the algebraic and SRSS methods. The random elements of uncertainty are combined under the SRSS method, and any bias uncertainties are added algebraically (straight-sum) to the SRSS result. Any random dependent elements are added to each other algebraically and then combined with random independent terms using the SRSS method.

In equation form, the combination of uncertainty elements for a particular module, might be expressed as follows:

$$u=\sqrt{w^2+(x+y)^2}+v$$

Where,
x and y are random, dependent elements
w and (x + y) are random, independent elements
v is a bias element
u is the total uncertainty for a particular module

The overall uncertainty (U) for a loop consisting of 3 modules (n = 1, 2, 3) would be found by separately combining the random uncertainties (u_{Rn}) of each module using SRSS and adding the bias terms (u_{Bn}) as follows:

$$u=\sqrt{u_{R1}^2+u_{R2}^2+u_{R3}^2}+u_{B1}+u_{B2}+u_{B3}$$

3.5 Combining Uncertainties with Different Confidence Interval Levels

This guide generally assumes that random errors are normally distributed. See Attachment G, "Abnormal and Uniform Uncertainty Distributions," for guidance in using abnormally distributed uncertainties. For conservatism, it shall be assumed that published vendor specifications are no better than 95% confidence with 95% proportion (2σ) values unless specific information is available to indicate otherwise.

If there is **very strong evidence** that a particular error specification represents a higher confidence level, the individual preparing an uncertainty calculation may adjust that specification in accordance with guidance provided in Attachment F or the drift analysis calculations if available. If there is strong evidence that a particular error specification represents a low confidence or proportion level, the individual preparing an uncertainty calculation must adjust that specification also.

3.6 Uncertainty Elements

The elements of instrument uncertainty discussed in this section are typical of effects which can alter the overall accuracy of an instrument. Other effects or uncertainties may exist for an instrument (e.g., radiation monitors) which are not covered by this general list.

The normal manner of handling environmental effects is to consider each effect separately and then combine the factors as appropriate for random and bias terms. The sections below deal with the effects of individual environmental factors.

Throughout this section, vendor performance specifications are shown in a form that applies to most cases. The reader is cautioned that this is not always a valid assumption. In actuality, the performance specification may take virtually any form (i.e., linear, exponential, or stepped functions).

Although the preparer of an uncertainty or setpoint calculation is expected to consider each category of uncertainty addressed in this section, not every uncertainty will be applicable to every instrument. The preparer shall provide a discussion sufficient to explain his/her rationale for any uncertainty category that is not included in the uncertainty calculation.

3.6.1 General Considerations

- All random, normally distributed elements of uncertainty are independent of each other. All other elements of device uncertainty should be evaluate for independence based on the error cause and effect relationship [see Attachment F section 4]

- Most instrument uncertainty elements are random. The vendor expressions are used as limits of error. An individual instrument can have an error smaller than the published value, and can vary in both sign and magnitude between instruments. The process measurement and static pressure terms are usually biases, though in some cases each could be random, abnormally distributed, and could be treated as a uniform distribution [Attachment G].

- Vendor expressions may or may not be linear. Some terms may be exponential, quadratic, constants, or step functions. Vendor expressions which are not linear may not be extrapolated up or down without additional justification. Contact the vendor when in doubt.

- For consistency between calculations, all elements of device uncertainty should be calculated in terms of percent calibrated span (% CS) of the device. If constant percent of calibrated span is not applicable, percent of input value (% IV) may be used. Once combined with other elements for a given module, the preparer may convert the resulting uncertainty to engineering units (inches level, psig, gpm). For loops containing more than one instrument it is strongly suggested that units of %CS or %IV be used.

- However, where the loop contains non-linear devices the error must be propagated through the non-linear device based on the specific input and output signal units at the point of interest. Error values associated with non-linear devices will not be converted to percent of calibrated span. In any case, the same units should be used throughout the calculation, converting to specific signal levels only when necessary (i.e., as found tolerance in mA for trip units).

- For any effect, for which vendor or plant data is not available, a value estimated by similarity with other instruments, or based upon other applicable experience should be used, rather than assuming a default of zero. This should be explained in the assumptions section. As noted in ISA-RP67.04 Part II, the absence of a rating does not necessarily mean the effect is negligible.

The guides provided below are the results of extensive experience and discussion; however, the individual performing the calculation must ensure the values used for device uncertainty and the manner in which the elements of device and loop uncertainty are combined are consistent with the instrumentation as installed.

3.6.2 Reference Accuracy (A)

Reference accuracy is a performance specification to which the instrument is tested during calibration [Sec. 3]. Instrument manufacturers often disagree on the terms used to describe an instrument's advertised accuracy. For the purpose of this method, accuracy shall include the combined effects of hysteresis, linearity, deadband, and repeatability.

Inclusion of any terms **missing** from the vendor's stated accuracy should be as follows:

$$A=\sqrt{(AX)^2+h^2+l^2+r^2+db^2}$$

where,

A	=	Reference accuracy of instrument
AX	=	vendor's stated basic accuracy expression
h	=	Hysteresis
l	=	linearity
r	=	repeatability
db	=	deadband

Determination of the accuracy of flow elements is discussed in Attachment D, "Flow Loop Scaling and Uncertainties."

3.6.3 Calibration Effect (CE) and Calibration Tolerance (CT)

Accuracy is not usually used alone but combined with other terms to determine the overall calibration effect (CE). Calibration effect is the overall inaccuracy introduced into the calibration process due to the procedural allowances given to the technician during instrument calibration, not including measurement and test equipment (M&TE) uncertainty. If the as-left calibration tolerance (CT) for an instrument is larger than the vendor stated accuracy of the device, then the vendor's stated accuracy cannot be verified by calibration. For this reason, the accuracy is effectively limited by the calibration tolerance since that is the limit on how well the instrument can be shown to perform. As part of calculations prepared using this guide, the appropriate calibration tolerance shall be determined. Preferably the calibration tolerance should be equal to the reference accuracy. Whether or not the existing calibration tolerance is appropriate, CT shall be stated in the calculation requirement section.

Per the ISA Recommended Practice (Ref. 6.5), various approaches may be taken to account for calibration effect, depending on the calibration techniques implemented in the field. For the purpose of this Design Guide:

A. Analog Loop Components

$CE = CT + A$,

Where: A is taken as a dependent term when, during calibration testing, less than a full traverse is performed.

B. Bistables/Switches

$CE = CT + A$,

Where: A is taken as a dependent term when, during calibration testing, actuation is only tested once.

C. **Full Traverse/Multiple Actuations**

CE = CT,

Where: analog loop component testing uses full traverses and bistables/switches are tested with multiple actuations.

D. **Exception**

CE = CT,

Where: for a single point device (i.e. bistables/switches/time delays relays) used in a single direction, where repeatability is the primary contributor to A, and where drift analysis has been performed, determine if the value for analyzed drift is within expected performance characteristics. To simplify verification within performance characteristics, combine (via SRSS) the vendors published accuracy (or the current calibration tolerance if larger), the vendors stated drift term, and the M&TE terms. This value will be compared to the plant specific drift. Plant specific drift must be less than the expected performance,

IF DA < $(A^2 + DR^2 + M\&TE^2)^{1/2}$ THEN CE = CT
IF DA ≥ $(A^2 + DR^2 + M\&TE^2)^{1/2}$ THEN CE = CT + A

For Class 2 and 3 setpoints the confidence interval may be reduced based on the nature of the function being analyzed. Since the effect of reducing the confidence interval is to reduce the value of the error used, the associated acceptance band for the instrument calibration or setting tolerance can not be also reduced. Reduction of the tolerances would in effect require a more precise calibration where the calculation justifies relaxing the calibration requirements. The following multipliers are used to define the confidence interval and can be used to convert from one confidence interval value to another.

Confidence Interval Factors for One and Two Sided Uncertainties		
Proportion	**Single-Sided**	**Two-Sided**
75%	0.68	1.15
90%	1.29	1.65
95%	1.65	1.96
99%	2.33	2.58

Example: Given a calibration tolerance value of 0.25% of span assumed to be three sigma (99 % confidence interval) convert to a 75% confidence interval value. Since three sigma is approximately a 99% value the following calculation is used:

0.25% * 1.15/2.58 = 0.1114% of span equivalent error.

However, using the reduced confidence interval values complicates the evaluation of analyzed drift discussed above. The confidence interval reduction factor is not used as a multiplier to determine the as left, as found or M&TE associated with the calibration. The same values used for the 99% confidence interval would be used. The reduction in confidence interval does not require smaller values for calibration tolerance or M&TE errors.

The M&TE, Calibration Tolerance, and Analyzed Drift comparisons discussed above should use the Reference Accuracy, Vendor Drift allowance (or applicable assumption) and the M&TE value determined for 95% confidence interval. The analyzed drift term for 95 % tolerance interval should be compared to these values to determine if performance is within expected limits. Since the reduction of drift and the reduction of the other terms is by a simple ratio, if the 95% confidence interval values indicate acceptable performance the 75% confidence interval values will also indicate acceptable performance.

Table 1: Standard Calibration Tolerances

Instrument Type	Input Tolerance	Output Tolerance	Calibration Units
Rosemount Pressure Transmitters (1151, 1152, 1153) 4-20 mA output	--	±0.25% CS	±0.04 mA (4-20mA span)
GEMAC Type 551, 552 Transmitters	--	±0.5% CS	±0.2 mA (10-50mA span)
GEMAC Type 555 Transmitters		±0.4% CS	±0.16 mA (10-50mA span)
Rosemount mA Master Trip Units (510, 710) RTD Master Trip Units (710)	±0.20% CS ±0.80% CS	--	±0.03 mA (4-20mA span) ±0.13 mA (4-20mA span)
Rosemount mA Slave Trip Units (510, 710) RTD Slave Trip Units (710)	±0.25% CS ±0.90% CS	--	±0.04 mA (4-20mA span) ±0.14 mA (4-20mA span)
GE/Westinghouse Type 180 Indicators	--	±2.0% CS	-
Sigma/International Type 1151 Indicators	--	±2.0% CS	-
Static-O-Ring Pressure Switches	±1.0% URL[1]	--	

[1] URL = upper range limit, which for switches refers to the maximum setting.

3.6.4 Readability Uncertainty (RD)

Readability is the ability of the user to determine the markings on a device. Readability is limited to the number of markings on a device and the operators ability to distinguish between the marks. Analog indicator or recorder readability is generally half of a minor division. Analog indicator or recorder readability uncertainty is generally one quarter of a minor division.

3.6.5 M&TE Uncertainty (MTE)

M&TE uncertainty is the inaccuracy introduced into the calibration process due to the limitations of the test instruments. M&TE uncertainty includes three principal components: (1) reference accuracy of the test equipment, (2) effect of temperature on the test equipment, and (3) accuracy of the test equipment calibration process. The first two components are included directly in M&TE uncertainty and the third is assumed to be included in the conservatism of the accuracy.

All (100%) of test equipment is certified to pass the calibration requirements, not just 95%, the common confidence interval used for uncertainty calculations. Discussions with vendors have shown that the actual accuracy of the test equipment is better than the vendor published values. Both of these provide conservatism in the accuracy of the M&TE. Further the standards used to calibrate the M&TE are generally rated 10:1 better than the equipment being calibrated [Ref. 6.15, Ref. 6.16]. The published accuracy of the M&TE should not be included with the accuracy of the test equipment calibration process since M&TE divided by 10 is negligible in relation to other uncertainties.

> Note: where the 10:1 ratio is not achievable for the calibration standards, the accuracy of the calibration standard should be included in the overall M&TE accuracy.

Since M&TE is certified before and after use at several data points (i.e. 100 % verification) M&TE error may be considered a 3 sigma value. This 3-sigma value may then be reduced to 2 sigma for the calculation. The uncertainty of the measurement and test equipment used for calibration affects the overall accuracy of an instrument loop. The uncertainty included should be representative of the way calibrations are performed by site personnel, or of an assumed method which is clearly stated as one of the requirements for the calculation to be valid.

If loop calibrations are not performed, then total loop uncertainty includes M&TE for each instrument. If loop calibrations are performed, the total loop uncertainty would include only the input and output M&TE for the loop test.

The M&TE uncertainty for a single test instrument is the SRSS combination of the accuracy, readability, and temperature effect. Usually more than one test instrument is involved in the calibration of a process transmitter or signal converter. The uncertainty of the test instrument should be applied to the process instrument to which it provides input, or from which it measures output. When multiple test instruments are used for a given process instrument, the accuracy and temperature effect of each test instrument should be combined using SRSS.

$$m = \sqrt{A^2_m + RD^2_m + TE^2_m}\,\frac{CS_m}{CS}$$

$$MTE_i = \sqrt{m_1^2 + m_2^2}$$

where,

A_m	=	accuracy of test instrument in percent of span of the test instrument (including hysteresis, linearity, repeatability and deadband).
RD_m	=	readability of test instrument in percent of span of the test instrument
TE_m	=	temperature effect on the test instrument in percent of span of the test instrument
CS_m	=	calibrated span of the test instrument
CS	=	calibrated span of process instrument being tested
m_1, m_2	=	uncertainty of 1st and 2nd test instrument in percent calibrated span of the process instrument
MTE	=	M&TE uncertainty in percent of calibrated span of the instrument being tested

The temperature effect on the test instrument may be calculated using: (1 the difference between the test temperature and the temperature at which the test instrument was calibrated or, (2 the difference between the temperature at which the M&TE will be used and the limits of a rating band within which the basic accuracy applies. Consult the M&TE specifications to see which applies.

Generally the MTE allowance is an **output** requirement of the uncertainty or setpoint calculation, which is to be imposed upon the testing procedure to ensure that a minimum accuracy is met. To avoid imposing requirements that can not be met, the calculation preparer shall verify that the specified uncertainty can be met by available equipment. VYC-1758 (Ref. 6.46) calculates the accuracy for most common M&TE available. This calculation should be used as the primary reference for M&TE accuracy. The values in VYC-1758 should be considered as 3 sigma.

Accuracies for other parameters, such as pressure, are typically based on requiring that the SRSS of all M&TE used to calibrate a process instrument be at least as accurate as that instrument.

For example, if a pressure transmitter has a rated accuracy of ±0.25% CS. The combined uncertainty of the input pressure gauge and the output current measurement (2 sigma values) should then be no greater than the same ±0.25% CS. The accuracy of the current measurement is ±0.127% CS (±0.0203 mA over a 4-20 mA span). The minimum accuracy of the pressure measurement can be determined by solving the following equation for x:

$$\pm 0.25 = \sqrt{0.127^2 + x^2}$$

$$x^2 = 0.25^2 - 0.127^2 = 0.046371$$

$$x = 0.2153$$

Solving for x results in a minimum accuracy for the pressure gauge of ±0.215% CS. This can then be converted into engineering units, for example for a transmitter with a 0 - 300 psi span, the minimum accuracy would be 0.64 psi.

3.6.6 Analyzed Drift (DA)

Analyzed drift (DA) is the term used here to describe uncertainty values derived in accordance with the Vermont Yankee Instrument Drift Analysis Design Guide [Ref. 6.17] to statistically represent the **change** in instrument uncertainty from one calibration to the next. Each data point, in addition to drift (DR), includes the influence from M&TE errors (MTE, Sec. 3.6.5), personnel errors, errors caused by misapplication of the instrument or other cumulative operating effects. True drift (DR, Sec. 3.6.7) is only that uncertainty which **cannot** be attributed to other influences beside the passage of time. Where plant specific drift has not been determined Section 3.6.7 provides guidance on using vendor or assumed drift values.

The overall analyzed drift tends to account for Reference Accuracy (A), M&TE, and for normal environmental effects, including temperature (TE_{cal}, Sec. 3.6.8), radiation (RE, Sec.3.6.11), power supply voltage variations, assuming that the power supply is not calibrated prior to device calibration (VE, Sec. 3.6.14), humidity (HE, Sec. 3.6.10), and barometric pressure (PB, Sec. 3.6.9). The calculation preparer **does** need to account for any difference between normal and applicable accident conditions.

Since both the as-found and as-left measurements include any M&TE error, any random error in these measurements will be reflected in the analyzed drift term.

Since the present testing method only involves increasing signal levels, dead band is not reflected in analyzed drift, however readability is generally included for indicators and recorders, since the technician must read off the output value from the instrument under test.

The analyzed drift does not include process effects that are not within the scope of the calibration procedure. Nor does it usually include effects of conditions that are not present during the calibration process such as equipment vibration, if the source of vibration is shut down. However for instruments in radiation zones, the normal effect of radiation is cumulative and is typically reflected in the calibration data.

Analyzed drift is reported as a 95/95 confidence and proportion, along with the sample mean, sample standard deviation and the number of data samples analyzed. For Class 1 setpoints or decision points, the 95/95 confidence and proportion shall be used as the DA term. For Class 2 and 3 functions, the proportion may be reduced while maintaining the confidence. The proportion may be reduced to 90 percent for Class 2 functions (95/90). For Class 3 functions, the proportion may be reduced to 75 percent (95/75).

A detailed summary is provided in each drift calculation describing the results of the analysis. Included in the summary are discussions on time dependency, distribution (normal or not normal), etc. In addition, data is provided which specifies the statistical results of the drift analysis associated with Kurtosis, mean, standard deviation, and the TIF used. Analyzed drift values for various probabilities may be calculated based on the drift analysis.

The summary provided in the associated drift analysis should be included (all or in part) within the setpoint calculation as well as any other portion or the drift calculation which provides an input to the setpoint calculation. Guidance is provided in Attachment F. The determination of time dependence, in the drift analysis, will be used as the basis for extending the drift value for a longer time interval.

The drift analysis evaluates the change in instrument output for a given input over the normal instrument calibration cycle (based on the average time between calibrations). The drift analysis may indicate that there is no relationship between the magnitude of drift and time, some relationship between magnitude and time or a strong relationship between magnitude and time. If the desired calibration cycle does not match the analyzed drift cycle, it will be necessary to expand the analyzed drift value. The determination of this relationship between magnitude and time will indicate the method of expanding the drift value.

Where it can be proven that there is no relationship between time and drift magnitude , the calculated drift may be used for any time period. However, extension of the calibration interval may also require that the instruments be evaluated for other time based failure mechanisms:

$$DA_{\text{any time interval}} = DA_{\text{analyzed}}$$

Where there is indication of a relationship between magnitude and time, it is necessary to increase the drift value to ensure that the increased time interval does not result in drift values in excess of predicted. If the drift analysis determines that slight time dependence exists (bounded by a non-linear extrapolation), a non-linear extrapolation of the drift value is used to determine drift for the interval of interest.

As an example if the device is currently calibrated on a monthly bases and the drift analysis determines a value for drift, and determines a mild dependence between drift magnitude and time. The drift value will be expanded based on the equation:

$DA_{Quarterly} = (114/38 \times DA^2_{Monthly})^{0.5}$
$DA_{Quarterly}\,(\text{random}) = (114/38 \times 2.124^2)^{0.5} = (3 \times\ 4.51138)^{0.5} = 3.679\%$

If the drift analysis determines that strong time dependence exists (bounded by a linear extrapolation), a linear extrapolation of the drift value is used to determine drift for the interval of interest.

As an example if the device is currently calibrated on a monthly bases and the drift analysis determines a value for drift, and determines a strong dependence between drift magnitude and time. The drift value will be expanded based on the equation:

$DA_{Quarterly} = 114/38 \times DA_{Monthly}$
$DA_{Quarterly}\,(\text{random}) = 114/38 \times 2.124 = 3 \times 2.124 = 6.372\%$

Summary

(a) Drift values derived from plant testing data in accordance with the Drift Analysis Design Guide [Ref. 6.17] are assumed to include the following effects for **normal** conditions:

- Drift (DR)
- Temperature Effect (TE_{cal})(20 °F calibration temperature range)
- Readability (RD)
- M&TE Uncertainty (MTE)
- Barometric Pressure Effect (PB)
- Power Supply Voltage Effect (VE)(assuming no calibration of the power supply)
- Humidity Effect (HE)
- Radiation Effect (RE)

(b) Accident or post-accident effects do not take credit for any environmental effects already included in analyzed drift, unless the conditions are shown to be the same as normal.

(c) Class 1 calculations shall use 95/95 tolerance intervals for DA. Class 2 calculations may use 95/90 tolerance intervals and Class 3 calculations may, under certain conditions, use 95/75 tolerance intervals for DA.

3.6.7 Drift (DR)

The input/output relation for an instrument may change with time. Drift is often specified by the instrument manufacturer based on testing under laboratory conditions. The period of drift applied to an instrument for the purpose of this method is dependent on the calibration period of the instrument. In many cases, the period for which drift has been specified does not agree with the calibration period of the instrument. For long test intervals, it is acceptable to assume the drift is not dependent upon total time, but the vendor specification represents two standard deviations of a distribution which applies to any time interval equal to the vendor's specification (t_d). Where drift is determined to have a linear relationship with time to adjust drift to match the calibration period of an instrument, the following equation is then applied:

Or where drift does not have a linear time to magnitude relationship:

$$DR = DRX * \sqrt{\frac{t_t}{t_d}}$$

Where,

DR	=	time dependent drift in percent of calibrated span
DRX	=	vendor's drift expression in percent of CS
t_t	=	instrument test interval (months) should include 125% of nominal test interval for technical specification devices.
t_d	=	drift interval specified by vendor.

Note: Calibrated span for trip units, bistables, switches, etc., refers to the input span.

If data is available to justify an alternative expression, drift may be a constant, a linear function, a step function, an exponential, or a polynomial.

Note: The following elements are associated with conditions that are generally called environmental influences or environmental effects. For more information on environmental categories and their relationship to setpoints, see Section 3.7, "Environmental Influences."

3.6.8 Temperature Effect (TE)

Temperature variation normally affects the uncertainty of an instrument. The temperature variation of concern is the difference between the temperature of the device at calibration and the temperature for the environment of interest. The environment of interest can be the peak temperature during an accident, the temperature at the next calibration, or the maximum temperature during normal operations. Because both the calibration temperature and the current temperature can vary, a bounding temperature difference for each environmental category is used to simplify the calculation while still providing the appropriate conservatism.

There are three general temperature categories that need to be considered: normal, accident and post-accident. The temperatures experienced during testing may be different from those during full power operations, however at Vermont Yankee, nearly all instruments may be calibrated at power and due to the compact plant layout and the design of the HVAC system, the temperature distribution during normal operations and testing are generally the same. For non-Class 1 setpoints, the range of normal temperatures may be assumed to be the range of testing temperatures. A possible exception would be the Turbine Building, which may be cooler during shut down periods, however in this instance, the normal range will be extended 10°F, so the value shown in the Table below applies to both conditions.

For Class 1 setpoints, outside the control room a calibration temperature range of 20°F shall be assumed, and any analyzed drift data would be assumed to account for that variation. For Class 1 setpoints inside the control room a calibration temperature range 10°F shall be assumed, and any analyzed drift data would be assumed to account for that variation. These assumptions are based on the consideration that many plant instruments may be calibrated on-line and that the plant temperature varies between calibrations. This variation in plant temperature is captured in the as-found to as-left difference between calibrations and therefore also in the analyzed drift values. The temperature effect for Class 1 setpoint calculations which then use analyzed drift (DA) data would account for the temperature difference between the calibration temperature range and the normal design temperature range. For instruments that are removed from service in the plant and shop calibrated or sent off-site for calibration, no calibration temperature variation may exist or the variation may be different from these assumed values. The calculation developer must determine the appropriate calibration temperature variation for these conditions.

Example:

To determine the error associated with an instrument installed in the VY Reactor Building occupied areas, determine the effective differential temperature. This effective differential temperature will then be combined with the vendor's error expression to determine the associated effect. Review Table 2 to determine if the location of instrument installation is defined and captured. The effective differential temperature is calculated as follows:

ΔT = (106 - 62) °F Maximum normal temperature variation
ΔT = 44 °F
ΔT_n = (44 - 20) °F reduce the maximum value based on the normal temperature error assumed included in the analyzed drift (20°F)
= 24°F

Where:
ΔT_n = Effective differential temperature for normal plant conditions.

Assuming a temperature error of 0.5 % of calibrated span per 100°F the final error for normal conditions would be determined as follows:

Error = 0.5% * 24/100 = 0.12% of calibrated span temperature error.

The temperature range for the Control Room is not specified by current plant documents, however the estimate shown in Table 2 below is reasonable based upon the type of heating and ventilation used. Other values in the following Table are taken from the Vermont Yankee Environmental Qualification Manual

[Ref. 6.21] and include normal temperature ranges for various plant areas. Plant areas not included in the Table require the calculation originator to determine the minimum and maximum normal as well as the maximum accident environmental conditions. Area values may be found in the VY Environmental Qualification Manual, the VY USAR, or other VY design documents.

Table 2: Normal Temperature Ranges		
Plant Area	**Minimum**	**Maximum**
Control Room	60°F	80°F
Reactor Building -		
Occupied Areas	62°F	106°F
Torus Area	60°F	120°F
RHR Corner Room at 213' - 9"	67°F	109°F
RHR Corner Room at 232' - 6"	60°F	104°F
Drywell - Operating & Hot Standby[2]		
Below 270'	140°F	160°F
Between 270' and 315'	175°F	195°F
Above 315'	260°F	280°F
Torus (Internal, Above Water Level)	60°F	120°F
Steam Tunnel	100°F	150°F
Turbine Building[3]		
Occupied Areas	85°F	105°F
Lube Oil Hallway	86°F	104°F

For accident and post-accident conditions, the concern is for high temperatures; therefore, the bounding difference is between the peak temperature during an accident and the lowest temperature at which the instrument would have been calibrated. The delay time of instrument heat up due to thermal inertia effects the actual temperature of an instrument during accident conditions. The vapor temperature during a HELB may reach a peak temperature approaching 300°F in some compartments; however the calculated temperature falls quickly to a much lower level. In those cases and in the absence of specific data to the contrary, temperature excursions shorter than 120 seconds may be neglected.

The EQ manual has graphs for compartment temperatures during specific events that should be used to determine the applicable temperatures. If no specific curve is applicable, the user should refer to the Attachment C of the EQ manual, "Envelope Accident Environmental conditions."

The following equation is for an uncertainty that is a linear function of temperature. This is conservative for most instruments.

$$TE_x = TEX(T_{x,max} - T_{x,min})$$

[2] Minimum is lower than implied by EQ manual to reflect surveillance data for reference leg thermocouples.
[3] Minimum is 10°F lower than otherwise calculated to allow for lower temperatures during shut down conditions.

where,

$T_{x,max}$ = Maximum temperature for the conditions of concern
$T_{n,min}$ = Minimum temperature during normal operations.
$T_{calibration}$ = Temperature effect accounted for in DA (if available).
TEX = Vendor's temperature effects expression in % CS per °F
Note: The subscript "x" can be: n (normal), a (accident), or p (post-accident).

Some pressure instruments, notably environmentally qualified Static O-Ring (SOR) switches and ITT-Barton gauge pressure transmitters, are sealed at approximately atmospheric pressure. When the instrument heats up, the internal pressure does not vent but builds up opposing the process pressure. Consequently, in addition to the usual temperature effect specified by the vendor, there is a negative bias effect due to the thermal expansion of trapped air. Not all SOR switches are sealed nor are all sealed instruments affected by this problem.

Summary

(a) Temperature excursions shorter than 120 seconds may usually be neglected.

(b) The temperature effect is calculated based upon the **difference** between the peak temperature for the condition being considered and the minimum normal temperature, less any temperature effect accounted for in analyzed drift data.

3.6.9 Barometric Pressure Effect (PB)

Except for transmitters and switches designed to measure pressure, this effect is negligible. Design pressure values for electronic devices are not needed since the devices will work correctly at any reasonable pressure where they are installed.

There are two general ways that barometric pressure can affect the output of an instrument. For pressure measuring devices with one side of the pressure cell exposed to the atmosphere, a change in barometric pressure has a direct bias effect on the output. If the instrument is calibrated in units of absolute pressure (psia) this is an error, if the units are gauge pressure (psig) the effect may be ignored.

If the instrument were sealed, a change in atmospheric pressure would cause an apparent error when calibrated using a vented test gauge and the effect should be included when calculating normal uncertainty, unless compensated for in the calibration procedure.

For accident conditions the effect is usually significant and should only be neglected when it can be shown that the loop function does not depend upon the absolute pressure.

3.6.10 Humidity Effect (HE)

Most modern instrumentation, except devices operating at high voltage and low direct currents (e.g., nuclear detectors and preamplifiers) do not display effects due to humidity exposure less than 90% relative humidity. For those high voltage/low current instruments specific guidance should be obtained from the vendor.

Some environmentally qualified instruments, particularly recorders and indicators have a separate humidity effect specified. This term may be neglected unless the expected humidity exceeds 90%. Generally there is no separate specification and the effect of humidity is included in the rated temperature or design basis accident response.

A change in humidity can also cause a change in the insulation resistance in a signal cable. This is discussed more in Section 3.10, "Insulation Resistance (IR) Leakage Effects."

3.6.11 Radiation Effect (RE)

Radiation can have a cumulative damaging effect on the materials and components of an instrument. This damage can affect the instrument uncertainty. At relatively high dose rates, the effect may also be rate dependent, which means the results of qualification testing may be misleading if the dose rate of the test greatly differs from those expected during a specific accident scenario.

This design guide assumes that the effects of radiation doses during normal plant operation (characterized by low dose rates) are compensated for by calibration. Therefore, the radiation dose of concern is the Total Integrated Dose (TID) received between calibrations and during an accident. The worst case for radiation effects would be if an accident occurred just before an instrument was to be calibrated. It would have received the normal dose plus the dose for the accident. Accident radiation effects need only be considered up to the time the loop performs its safety-related function.

For instruments in mild environments (TID per calibration interval less than 10^4 rads), the radiation effect can be neglected.

The following assumptions apply to the radiation effect for specific models of transmitter which are developed from specific references. The assumptions are identified by model and the corresponding references are included.

(a) The radiation effect for Rosemount 1152 transmitters is given by the step functions below. A step function is provided since the effect is not considered linear with dose. RE is the radiation effect and R is the radiation dose between calibrations.

These step functions are based on a combination of vendor information and interpretation of vendor test reports. The information for the upper step (highest radiation) comes from Ref 6.35. The information for part of the 0.5% CS step comes from Ref 6.28. The lowest radiation step is based on mild environments having no significant radiation effects. The 0.5% step is intended for use in calculating a testing uncertainty for instruments which normally receive small but significant doses between calibrations.

$$RE = \begin{cases} 0\%CS; R \le 1000\,rad \\ 0.5\%CS; 1000\,rad < R \le 1.0\,Mrad \\ 8.0\%URL; 1.0\,Mrad < R \le 5.0\,Mrad \end{cases}$$

(b) The radiation effect for Rosemount 1153 Series B transmitters is given by the step functions below. A step function is provided since the effect is not considered as linear with dose. RE is the radiation effect and R is the radiation dose between calibrations.

$$RE = \begin{cases} 0\%CS; R \le 1000\,rad \\ 0.5\%CS; 1000\,rad < R \le 1.0\,Mrad \\ 1.0\%URL; 1.0\,Mrad < R \le 5.0\,Mrad \\ 8.0\%URL; 5.0\,Mrad < R \le 22.0\,Mrad \end{cases}$$

These step functions are based on a combination of vendor information and interpretation of vendor test reports. The information for the upper step (highest radiation) comes from Ref 6.32. The information for part of the 1.0% URL step comes from Ref. 6.36 and part from Ref 6.34. The lowest radiation step is based on mild environments having no significant radiation effects. The 0.5% step is intended for use in calculating a testing uncertainty for instruments which normally receive small but significant doses between calibrations.

(c) The radiation effect for Rosemount 1153 Series D transmitters, excluding range code 0 (for range code 0, the upper step is 8.2% URL), is given by the step functions below. A step function is provided since the effect is not considered as linear with dose. RE is the radiation effect and R is the radiation dose between calibrations.

$$RE = \begin{cases} 0\%\,CS; R \leq 1000\,rad \\ 0.5\%\,CS; 1000\,rad < R \leq 1.0\,Mrad \\ 1.0\%\,URL; 1.0\,Mrad < R \leq 5.0\,Mrad \\ 6.0\%\,URL; 5.0\,Mrad < R \leq 51.9\,Mrad \end{cases}$$

These step functions are based on a combination of vendor information and interpretation of vendor test reports. The information for the upper step (highest radiation) comes from Ref 6.36. The information for part of the 1.0% URL step comes from Ref. 6.32 and part from Ref. 6.34. The lowest radiation step is based on mild environments having no significant radiation effects. The 0.5% step is intended for use in calculating a testing uncertainty for instruments which normally receive small but significant doses between calibrations.

3.6.12 Seismic/Vibratory Effect (SE)

The shaking and physical acceleration due to a seismic event may affect the uncertainty of an instrument, particularly instruments with mechanical parts. Instruments, which are mounted in locations subject to vibration from nearby machinery, may also be adversely effected.

The seismic effect is based upon the instrument response to the acceleration at the instrument location due to a Safe Shutdown Earthquake (SSE), which corresponds to a ground acceleration of 0.14 gravity [Ref. 6.10.1]. The original testing program for instrumentation simulated an SSE by testing each component to 2-axis horizontal acceleration of 1.5 gravities and vertical acceleration of 0.5 gravity [Ref. 6.10.2]. Earthquakes less than an OBE (0.07 gravity, Ref. 6.10.1) are considered not to have a significant effect on instrument uncertainty. Conversely, if the instrument has been qualified by test to accelerations exceeding 3 gravities in three axes, then the seismic effects may be considered negligible. The maximum qualified acceleration for the original GE supplied instrumentation is shown in FSAR Table C.2.7, "Summary of Results -- Class I Equipment Seismic Test."

Seismic effects during and after an event, are usually determined based on the instrument vendor's expression for seismic effect and the seismic response spectrum at the instrument's location. It is likely that a step function or other nonlinear form should describe this effect; consequently, no recommended form is shown. For original scope equipment qualified at less than 3 gravities, an allowance equivalent to ±2% of span shall be used, which corresponds to the testing margin used in the original tests.

The Engineering Design Basis does not consider coincident SSE and safety-related HELB to be a credible event; therefore, in cases where an instrument loop is required to operate for both a SSE and a HELB, only the worst overall loop uncertainty need be used [Ref. 6.26]. Coincident LOCA and SSE are considered credible in the design basis, however not with a licensing basis radiation release. Only the worst of (LOCA + SE) or (LOCA + RE) should be considered. The Engineering Design Basis document includes the following list of safety functions required operable during and following a design basis earthquake:

a. Reactivity Control
b. RPV Level and Pressure Control
c. Decay Heat Removal
d. Post-Accident Monitoring
e. Fuel Pool Cooling and Makeup

The corresponding systems are also shown in matrix form in the EDB document. Only those systems and functions require accounting for the seismic effect.

3.6.13 Process Static Pressure (SP) Effects

Several effects, generally applied only to differential pressure instruments, are associated with exposure to a high static line pressure that interferes with the basic measurement function. If an instrument is not exposed to the process or is not a differential pressure instrument, then these effects are not applicable and may be omitted from the uncertainty or setpoint calculation without comment. For differential pressure instruments, the effects may be applicable and the appropriate uncertainty should be included, or an explanation given why the effect is not applicable. For additional information, see Attachment C: "Process Corrections and Measurement Uncertainty."

Static Pressure Span Correction (SP_C)

Exposure of a differential pressure instrument to process static pressure may affect its span. Generally, this effect is a bias, directly dependent on pressure. This effect can be accounted for by calibrating the instrument at the operating pressure or by using a correction factor to compensate the calibration.

If the static pressure is not calibrated out, or if significant operation occurs at a pressure different than that for which it was calibrated, the static pressure correction should be included. Typical, this is not calibrated out and should be included in the analysis.

At low pressure S.C. should be incorporated with an understanding of how the instrumentation is being used. For example flow indicating instruments in the low pressure systems (e.g. Low Pressure Coolant Injection) could normally be at system pressure as high as 400 psig but be at much lower pressures when most monitoring is required.

Static Pressure Span Correction Uncertainty (SP_U)

When a correction is made to an instrument's calibration by using a vendor supplied expression, there is an additional uncertainty due to the uncertainty of the vendor expression used to correct for static pressure. This is, in effect, the random variations around the bias which occur during testing to determine the vendor correction expression. If the instrument is calibrated at the pressure at which it must later operate, there is no need to include this uncertainty. In that case, the instrument has been adjusted for that particular pressure in that particular installation, and the vendor expression was not used.

Static Pressure Zero Effect (SP_Z)

Static pressure zero effect is the shift of the zero point of the calibrated scale due to operation at a process pressure different than the pressure at which the instrument was calibrated. The uncertainty may be taken as a random term equal to the limits specified by the vendor. The effect is generally not predictable between instruments, so an expression cannot be used to correct for the difference in pressures. However, for a particular instrument the effect can be eliminated by calibrating at the desired operating pressure and adjusting the zero. Typically, this is not calibrated out and should be included in the analysis. See Attachment C for detailed discussion of the application of Static Pressure effects.

Over Pressure Effect (SP_O)

Over pressure effects should be considered when an instrument is operated outside of its normal operating limit. The normal operating limit is not the same as the design limit. Example: a transmitter may have an operating limit of 1000 psi, but its design limit may be 3000 psi. The effects above 1000 psi must be considered. For differential pressure instruments, there may be two operating limits, one for high static line (common mode) pressure and another for differential pressures. For Rosemount transmitters the Over Pressure rating applies to any differential pressure above the Upper Range Limit (URL).

3.6.14 Power Supply Voltage Effect (VE)

Power supply stability refers to the variation in the loop's power supply voltage under design conditions of supply voltage, ambient environment conditions, power supply accuracy, regulation, and drift.

This effect is usually linear with voltage variation, the equation to use is:

$$VE_x = VEX \times \Delta V$$

where,

VEX	=	instrument vendor's power supply effect expression in percent of CS per volt
ΔV	=	power supply stability in volts

This effect may be negligible, particularly for components with regulated power supplies. Power Supply effect is normally considered to be included in the plant specific drift DA term. However, if the power supply is calibrated prior to calibration of the loop components, then the VE term is not included in the DA term and must be considered separately.

3.7 Environmental Influences

The following environmental conditions for uncertainties are considered for an instrument loop at Vermont Yankee: normal, accident, post-accident, and seismic event.

Uncertainties during normal operations and during performance of periodic calibration will generally be needed for any loop of Class 1, 2 or 3.

Those instrument loops, which must perform a safety-related function during an accident, must have an uncertainty calculated for the bounding conditions that are expected to prevail, during the specific limiting accident event, for the time interval for which the safety-related function is required to be operable. This only applies to Class 1 functions. Additionally for Reactor Protection System Instruments (RPS) the calculation must verify that the RPS instrument will not fail, or spuriously operate for a High Energy Line Break (HELB) in the vicinity of the instrumentation. This is limited to instruments that are not required to function to mitigate the HELB in their vicinity. Devices which must function must consider accuracy of the trip point also.

Class 2, instruments used in the emergency operating procedures which are subject to an abnormal or harsh environment following an accident, should have post-accident uncertainties determined.

Seismic uncertainties are significant only for those Class 1 instruments which must operate during or after an earthquake. Indicators would not be useful during an earthquake (OBE or SSE), since operators would have significant difficulty reading any display type instrument (e.g., indicators, recorders, and printouts) accurately and operator action is not credited for some time after an earthquake. For those safety-related instrument functions, which are required for safe shutdown of the reactor, a seismic uncertainty should be calculated. Figure 2, illustrates the conditions considered for DBA evaluations.

3.8 Module Uncertainty (e)

The individual uncertainty elements are combined according to equations below, for devices which can be considered internally linear, to obtain the overall instrument uncertainty in terms of three groups of uncertainties: (1) random, (2) positive bias, and (3) negative bias. Bias uncertainties are combined algebraically and random uncertainties are combined using the Square-Root-Sum-of-Squares (SRSS). This insures that the total uncertainty is neither non-conservative (by using SRSS for all uncertainties) nor overly conservative (by combining all algebraically).

Note: It is possible to calculate uncertainty with excessive precision and also to introduce unnecessary round-off errors. To avoid calculations which are difficult to duplicate, module uncertainty calculated in %CS should be rounded to two decimal places (i.e. 2.87% CS). Intermediate values using SRSS should be carried to four decimal places. Final module, loop or Total Loop Uncertainty values should be rounded to the readability of the test equipment (if it is only possible to read the instrument to 1 psi increments a value of 1.02 psi has no meaning). All rounding where performed must be in the conservative direction. Rounding for values a factor of 10 smaller than the readability is not required, since these values would have no effect if considered in their error combination. For an increasing process condition to a trip setpoint the TLU values would be rounded up, the setpoint values would be rounded down, and the AV value would be rounded down.

For random uncertainties:

$$e_{xRi} = \sqrt{\sum_i u_{xRi}^2}$$

Where,

e_{xRi} = random uncertainty of the i^{th} device
u_{xRi} = an effect or uncertainty which is random as it applies to the i^{th} device

The subscript "x" represents the environmental conditions.

The bias terms of opposite signs are not usually allowed to cancel each other. This is done by having a positive bias equation and a negative bias equation.

$$e^{+}_{xBi} = \sum u^{+}_{xBi}$$

$$e^{-}_{xBi} = \sum_{i} u^{-}_{xBi}$$

Where,

e_{xBi} = the bias uncertainty, positive and negative, of the i^{th} device

3.8.1 Testing Conditions

For testing conditions, no instruments are exposed to the process, and there would be no earthquake. Therefore, the static pressure terms (SP) and seismic (SE) are not included. The barometric pressure effect (PB) would only be due to the variation in atmospheric pressure between calibrations, which is negligible for most cases. As explained in Section , the current leakage effect is negligible for normal (and testing) conditions. The radiation effect is the cumulative effect of normal operations since the previous calibration. Under testing conditions the total module error is typically all random. For testing a single instrument, this value is equal to the as-found tolerance (AF).

$$e_t = \sqrt{CE^2 + MTE^2 + DR^2 + TE^2_{cal} + HE^2_n + RE^2_n + VE^2}$$

For indicators or recorders, the instrument readability uncertainty (RD) is also included in the equation. If analyzed drift values are available, the equation simplifies to:

$$e_t = \sqrt{CE^2 + DA^2}$$

For indicators or recorders, readability uncertainty (RD) is not required, since it is included in analyzed drift (DA).

3.8.2 Normal Conditions

For normal conditions, with the instrument connected to the process, the static pressure effects may apply and the overall uncertainty may then contain bias components. The normal uncertainty is therefore given by the equations:

$$e_{nR} = \sqrt{CE^2 + MTE^2 + DR^2 + TE^2_n + HE^2_n + RE^2_n + VE^2} + \sqrt{SP^2_U + SP^2_Z}$$

For indicators or recorders, the instrument readability uncertainty (RD) is also included in the equation. If analyzed drift values are available, the random equation simplifies to (as before RD is included in DA):

$$e_{nR} = \sqrt{CE^2 + DA^2 + TE_{\Delta n}^2} + \sqrt{SP_U^2 + SP_Z^2}$$

Where:

$TE_{\Delta n}$ = The differential temperature effect between the testing range and normal design range (reduced by the 20°F delta assumed in DA for calibration conditions).

3.8.3 Accident and Seismic Conditions

Only Class 1 instruments need to consider Design Basis Accident (DBA) conditions. Some instruments may be in an environment where they could not be affected by an accident. The Vermont Yankee design basis recognizes the combination of an earthquake with most limiting events except the High Energy Line Break (HELB) of a seismically qualified line and a Loss of Coolant Accident (LOCA) with fuel failure. For instruments associated with those specific scenarios, two accident uncertainties need to be calculated.

Loss-of-Coolant Accident

For the LOCA, the first scenario is LOCA no seismic event and includes accident effects for TE, HE and RE, but not SE. The second scenario for Seismic with LOCA but without fuel Failure includes accident effects for TE, HE and SE, but not RE. In equation form:

LOCA no Seismic event.

$$e_{aR1} = \sqrt{CE^2 + PB^2 + MTE^2 + DR^2 + VE^2} + \sqrt{TE_{Loca}^2 + HE_{Loca}^2 + RE_{Loca}^2 + SP_U^2 + SP_Z^2}$$

LOCA with Seismic event but no fuel failure

$$e_{aR2} = \sqrt{CE^2 + PB^2 + MTE^2 + DR^2 + VE^2} + \sqrt{TE_{Loca}^2 + HE_{Loca}^2 + RE_n^2 + SP_U^2 + SP_Z^2 + SE^2}$$

For indicators or recorders, the instrument readability (RD) is also included in the equation. If analyzed drift values are available, the random equations simplify to (as before RD is included in DA) :

LOCA no Seismic event.

$$e_{aR1} = \sqrt{CE^2 + DA^2} + \sqrt{TE_{Loca}^2 + HE_{Loca}^2 + RE_{Loca}^2 + SP_U^2 + SP_Z^2}$$

LOCA with Seismic event but no fuel failure

$$e_{aR2} = \sqrt{CE^2 + DA^2} + \sqrt{TE^2_{Loca} + HE^2_{Loca} + SP^2_U + SP^2_Z + SE^2}$$

where,

TE_{LOCA} = Temperature effect for LOCA conditions
HE_{LOCA} = Humidity effect for LOCA conditions
RE_{LOCA} = Effect for postulated source term release

High Energy Line Break (Mitigation)

For the HELB, one value includes accident effects for TE and HE, but not SE. The second includes only SE. In equation form:

$$e_{aR1} = \sqrt{CE^2 + MTE^2 + DR^2 + RE^2_n + VE^2} + \sqrt{TE^2_{HELB} + HE^2_{HELB} + SP^2_U + SP^2_Z}$$

$$e_{aR2} = \sqrt{CE^2 + MTE^2 + DR^2 + TE^2_n + HE^2_n + RE^2_n + VE^2} + \sqrt{SP^2_U + SP^2_Z + SE^2}$$

For indicators or recorders, the instrument readability (RD) is included in the equation. If analyzed drift values are available, the random equations simplify to (as before RD is included in DA):

$$e_{aR1} = \sqrt{CE^2 + DA^2} + \sqrt{TE^2_{HELB} + HE^2_{HELB} + SP^2_U + SP^2_Z}$$

$$e_{aR2} = \sqrt{CE^2 + DA^2} + \sqrt{SP^2_U + SP^2_Z + SE^2}$$

where,

TE_{HELB} = Temperature effect for HELB conditions
HE_{HELB} = Humidity effect for LOCA conditions

For those loops, the most restrictive case of seismic or accident should be used to determine total loop uncertainty. In performing this calculation, however, the total loop uncertainty should be determined for all instruments under seismic conditions, and then for all instruments under accident conditions, and the more restrictive case used. Combining individual worst cases is not appropriate.

High Energy Line Break (Non-Mitigation)

As discussed in Section 3.7, for RPS channels sufficient margin must exist such that spurious actuation will not occur in a HELB environment during the time necessary to effect a controlled plant shutdown. This margin check is independent of setpoint analysis for HELB mitigation loops. This check is performed by determining the effects due to the HELB event and then adding these error values to the maximum normal operating value of the process variable measured. If the result is less than the trip setpoint spurious trip for HELP is assumed not to occur.

Other Design Basis Events

For other limiting events, the seismic effect is simply included in the calculation with the environmental effects:

$$e_{aR} = \sqrt{CE^2 + MTE^2 + DR^2 + VE^2} + \sqrt{TE_a^2 + HE_a^2 + RE_a^2 + SP_U^2 + SP_Z^2 + SE^2}$$

For indicators or recorders, the instrument readability (RD) is included in the equation. If analyzed drift values are available, the random equation simplifies to (as before RD is included in DA) :

$$e_{aR} = \sqrt{CE^2 + DA^2} + \sqrt{TE_a^2 + HE_a^2 + RE_a^2 + SP_U^2 + SP_Z^2 + SE^2}$$

And for any event the bias component of uncertainty is found from:

$$e_{aB} = SP_C + SP_O$$

Figure 2: **Deleted**

3.9 Process Corrections and Measurement Uncertainties (PM)

Process corrections are adjustments to the instrument calibrated range or setpoint. By themselves, they are not considered as uncertainties. The need for adjustments normally arises because of differences in location between the point of concern for a process variable and point of measurement and location of the sensor. Variations in process corrections, or in the process itself, may cause uncertainties (e.g., variations in the head correction, or fluid density of a flow system). Both the corrections and the uncertainty of the correction need to be considered. The variations discussed here are typical, but there can be others. More detailed discussion may be found in Attachment C.

3.9.1 Level Measurements

ISA-RP67.04 Part II, Attachment B, "Vessel/Reference Leg Temperature Effects on Differential Pressure Transmitters Used for Level Measurement," contains a detailed discussion and equations for evaluating the process uncertainties for a PWR steam generator level measurement. The methods described are generally applicable to any level measurement; however, at Vermont Yankee (or any BWR), the vessel level application in particular is complicated by the fact that pressure sensing lines may pass through multiple temperature gradients, consequently the user is cautioned to apply the principles described in ISA-RP67.04 Part II with care to ensure the model reflects the as-built design. The following variables are the principle determinants of level measurement error using differential pressure instruments:

- Process liquid density, determined by process temperature and pressure.
- Process vapor density, determined by process temperature and pressure.
- Reference leg density, determined by process pressure and environmental temperature.
- Tank vortexing, if applicable see mechanical design calculations.

There may be cases where the sensing lines to the transmitter are routed through different environments, then the different head effects on the two lines should also be accounted for in the overall PM allowance. The specific problem of Reactor Vessel Level measurement is addressed in Attachment C.

3.9.2 Flow Measurements

In ISA-RP67.04 Part II, Attachment C, "Effects on Flow Measurement Accuracy," contains guidance to account for fluid density effects and piping configuration in establishing PM for flow measurements. Attachment D of this guide, "Flow Loop Scaling and Uncertainty," extends the ISA-standards treatment to include flow element uncertainty and the propagation of uncertainty through a square root converter. Generally, the problem is complicated by the fact that both the flow element and square root converter are non- linear devices and that most process influences are functions of flow rate; consequently, the overall uncertainty must be evaluated at specific flow rate points of interest, which should include the Analytical Limit (AL) or Process Limit (PL), setpoint, and normal flow rates (representative values).

3.9.3 Pressure Measurements

ISA-RP67.04 Part II, Attachment F, "Line Pressure Loss/Head Pressure Effects," contains guidance to account for head effects in process piping under conditions where significant flow exists. Attachment C, "Process Corrections and Measurement Uncertainty," addresses the more common situation of head corrections (hC) and the resulting uncertainty (hU) associated with variations in temperature of the sense line. Pressure variations of the process, which also effect density may be ignored, unless the fluid is a compressible gas, since the change in pressure is sensed directly by the instrument and any residual bias is usually negligible. The calculation should include a derivation of hC, since the correction is usually significant and any errors in calculation represent an un-analyzed bias.

3.10 Insulation Resistance (IR) Leakage Effects

Reduced insulation resistance in the signal cables allows more current to leak between cables or to the ground. The change in current affects the loop uncertainty. For all but accident conditions, the leakage current should be negligibly small. When current leakage effect is present, it is normally a positive bias. The effect of current leakage on a loop's performance is a function of the amount of current leakage in an instrument loop's current carrying components. The effects of current leakage due to a harsh environment are developed in ISA-RP67.04 Part II, Attachment D, "Insulation Resistance Effects," for the typical current loop. Two and three-wire RTD circuits are also susceptible to significant IR loss.

There are four shunt resistances that have been identified which will produce significant leakage currents in harsh environments. They are:

- Cable insulation leakage
- Cable splice leakage
- Terminal boards
- Penetrations (if any)

At Vermont Yankee, environmentally qualified instrumentation have been evaluated for IR loss in VYC-700, "Post-Accident Insulation Resistance Effects on the Accuracy of Selected Environmentally Qualified Instrumentation" [Ref. 6.27]. The effects were found to be negligible.

3.11 Total Loop Uncertainty

The total instrument uncertainty (U_{xij}) is found by (1) combining all effects for a given device to find a total device uncertainty and then (2) combining the device uncertainties to find the total instrument uncertainty. The total loop uncertainty (U_{xL}) will be determined by combining the random and bias terms for the instrument uncertainty and the process uncertainties.

Most instruments and loops encountered at Vermont Yankee are linear in the way the input signal is processed, the major exceptions being flow loops and logarithmic display systems for radiation monitoring. If there are nonlinear devices in the loop, the total loop uncertainty must be determined for specific points of interest as described in Attachment D, "Flow Loop Scaling and Uncertainty" and Attachment E, "Special Considerations for Radiation Monitors."

The equations below present the method for determining total loop uncertainty for combinations of linear devices. If some of the instrument uncertainties are expressed as a percent of input or output, the total loop uncertainty must also be determined at specific points of interest, or a bounding input or output value must be used. The total loop uncertainty is typically shown with PM as a bias. If treated as a random term, justification shall be provided in the calculation.

Note: As noted before under Module Uncertainty, certain conventions for precision are necessary. For calculations performed in %CS, intermediate results under the SRSS operations should be carried to four decimal places and the final result rounded to one decimal place (i.e. ±3.1% CS). Final module, loop or Total Loop Uncertainty values should be rounded to the readability of the test equipment (if it is only possible to read the instrument to 1 psi increments a value of 1.2 psi has no meaning). All rounding where performed must be in the conservative direction (within the limitations discussed in Section 3.8). For an increasing process condition to a trip setpoint the TLU values would be rounded up, the setpoint values would be rounded down, and the AV value would be rounded down.

RANDOM

$$U_{xRij}=\sqrt{\sum_{i}^{j}e_{xRk}^{2}}=\sqrt{e_{xR1}^{2}+e_{xR2}^{2}+e_{xR3}^{2}\cdots+e_{xRj}^{2}}$$

where,

U_{xRij} = combined random uncertainty of the i^{th} through the j^{th} devices
= u_{xRL} for the total loop

e_{xRk} = the random uncertainty of the k^{th} device

The subscript "x" represents the environmental conditions (n = normal, a = accident, p = post-accident).

BIAS

$$U_{xBij}^{+}=\sum_{i}^{j}e_{xBk}+PM^{+}=e_{xB1}^{+}+e_{xB2}^{+}+e_{xB3}^{+}\ldots+e_{xBj}^{+}+PM^{+}$$

$$U_{xBij}^{-}=\sum_{i}^{j}e_{xBk}+PM^{-}=e_{xB1}^{-}+e_{xB2}^{-}+e_{xB3}^{-}\ldots+e_{xBj}^{-}+PM^{-}$$

where,

U_{xBij} = bias uncertainty, positive and negative, of the i^{th} through the j^{th} devices
= U_{xBL} for the total loop

e_{xBk} = the bias uncertainty, positive and negative, of the k^{th} device

Note: The subscript "x" represents the environmental conditions (n = normal, a = accident, p = post-accident).

The bias terms of opposite signs are not usually allowed to cancel each other. This is because the bounding conditions do not generally apply simultaneously. This is accomplished using separate positive bias and negative bias equations. Specific justification is required anytime offsetting bias will be used to reduce TLU or other error components.

3.12 Difference Uncertainties for Sequential Setpoints

For sequentially operating (stacked) setpoints, the difference uncertainty associated with two different bistables actuating out of sequence needs to be considered. Of similar concern is the situation of an indicator reaching an operating limit prior to an alarm sounding (which is intended to warn the operator of the approaching limit).

In either case, the uncertainty is calculated in the same fashion. Figure 3 is an example of such stacked setpoints. The figure shows one possible loop configuration, in this case, for a pressure measurement. The uncertainty of interest is that for the difference between two outputs from the same loop. Mathematically, the solution for random variables has the same form as for the sum (the general case of loop uncertainty).

The difference random uncertainty (u_{ij}) for two devices or loop segments is equivalent to the SRSS combination of the errors associated with the components not shared in the loop:

$$u_{ij} = \sqrt{e_i^2 + e_j^2}$$

where e_i and e_j refer to the device uncertainty or combined uncertainty of all those devices which are not common to both outputs. Bias components would sum algebraically. See the discussion of stacked setpoints in section 4.6.5 and Figure 8.

Example:

The normal total loop uncertainty to the alarm switch ($u_{n1\text{-}5}$) in Figure 3 might be 2.5% CS; however, the uncertainty of the alarm switch (u_5) might be 0.7% CS and that of the indicator (u_4) might be 1.0% CS. Since the transmitter errors and the I/E converter errors would be present for either loop function, they are not included in the difference evaluation. The difference uncertainty of the indicator and alarm switch ($u_{4\text{-}5}$) is:

$$u_{4,5} = \sqrt{u_4^2 + u_5^2}$$

$$u_{4,5} = \sqrt{1.0^2 + 0.7^2}$$

$$u_{4,5} = \sqrt{1.0^2 + 0.7^2} = 1.22\%\text{CS}$$

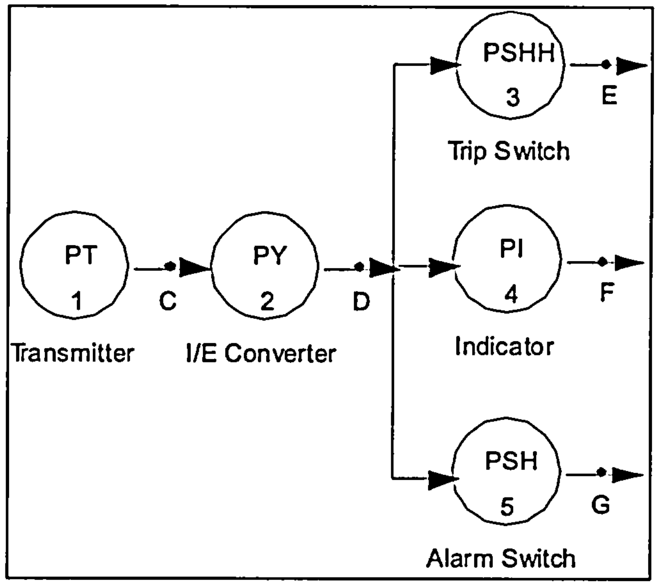


Figure 3: Stacked Setpoint Loop

4. SETPOINTS AND DECISION POINTS

This section discusses the methods that can be used to obtain a setpoint or decision point that will adequately fulfill the intended design function. A setpoint as used in this guide refers to the nominal value at which an automatic protective function or alarm is to be actuated. A decision point refers to an indicated value at which an operator action is to take place, either in accordance with the Technical Specifications or by procedure.

All setpoints are based upon a limit (or limits) which bound the range of the process variable over which an actuation is allowed to occur. Two parameters are required to adequately specify the limit: (1) the qualitative description or definition (what is to be accomplished under what conditions) and (2) the quantitative or analytical determination of the magnitude of the limit.

Once a total loop uncertainty has been calculated for the applicable conditions, the limiting setpoint (LSp) or decision point is found by adding either the positive or the negative uncertainty to the applicable limit. For Improved Technical Specification Values and Custom Technical Specification Values listing the Allowable Value (AV), the AV is determined by calculating the instrument channel uncertainty with the "un-measurable" uncertainties (process measurement effects, harsh environmental effects, seismic effects, etc.). This result is subtracted from the analytical limit (AL) to establish the AV. The LSp is then calculated by subtracting from the AV the combination of the "measurable" uncertainties (drift, calibration uncertainties, uncertainties observed during normal operations, etc.). In principle there is no difference between calculating the setpoint for an automatic actuation and an operator decision point based upon reading an indicator or recorder. Whenever "setpoint" is used alone in the following discussion, it is understood to refer to decision points as well. In practice there are some useful distinctions between the two. Those issues, which apply specifically to only setpoints or decision points, are so identified.

The limiting setpoint is the **least conservative** value for the setpoint, which accounts for the known uncertainties. There are several reasons for using a setpoint that is different from the LSp, for example:

1. Trip functions may have more than one Analytical Limit or Process Limit. Then the most conservative LSp is chosen.

2. Equalize the setpoints among loops of similar function, but diverse design (different equipment or installation and therefore different uncertainty).

3. Account for missing or uncertain vendor specifications. Also, over time vendor specifications may change. Including margin allows an increase in the instrument uncertainty without a required change in the setpoint.

4. A margin between the existing TS value and the setpoint is preferred even though the calculation supports a less conservative setpoint.

5. Human factors. Round numbers are more easily recalled. For example, a low pressure setpoint of 804.6 psia is more difficult to recall than a setpoint of 805 psia. Also available test equipment may not be readable to 0.1 psia.

6. Accommodate historical precedence. The plant already has existing setpoints. Where they are conservative with respect to the LSp and do not interfere with operations, there is no need to change them.

Figure 4, "Typical Safety-Related Setpoint Allowances ITS" and Figure 5 Typical Safety-Related Setpoint Allowances CTS" show in general terms the types of allowances included in a NSR (Class 1) setpoint determination for an increasing process trip. Class 2 calculations involve similar considerations, however there would be no Allowable Value involved. A Class 3 calculation, since it does not involve the safety analysis, would have a Process Limit instead of the Analytical Limit and there would be no consideration of accident conditions.

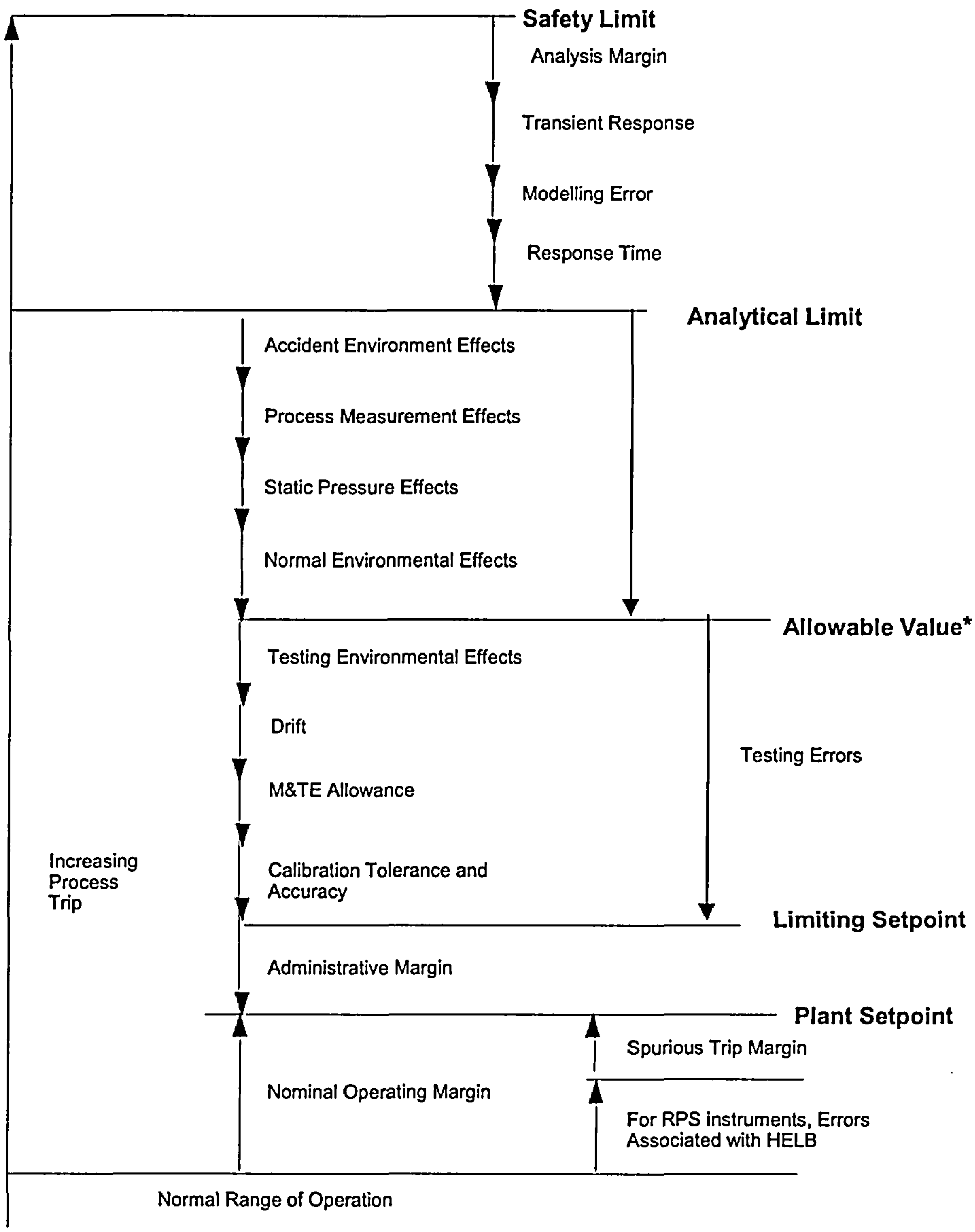
Setpoints with safety functions will generally be based upon established analytical limits or from a process limit derived from other design calculations. Setpoints without a safety function may be based upon a calculated process limit, but will frequently be based upon an estimated or qualitative limit.

The Setpoint Program is intended to support both the existing Technical Specifications and the Improved Technical Specifications Project if implemented. The following considerations apply:

- For setpoints to be evaluated for the Vermont Yankee Custom Technical Specifications (CTS) the values in the CTS are typically treated as Analytical Limits. There are no Allowable Values. Only normal uncertainties are applied between the Analytical Limit and the nominal trip setpoint.

- For setpoints to be evaluated for the Vermont Yankee Improved Technical Specifications (ITS) the values in the ITS are typically Allowable Values.

- For decision points to be evaluated for the Vermont Yankee Improved Technical Specifications (ITS) the values in the ITS are typically calculated including normal uncertainties in the same way a setpoint is calculated.



* Using ISA RP 67.04, Part 2, Method 1

Figure 4: Typical Safety-Related Setpoint Allowances (ITS and CTS/AV)

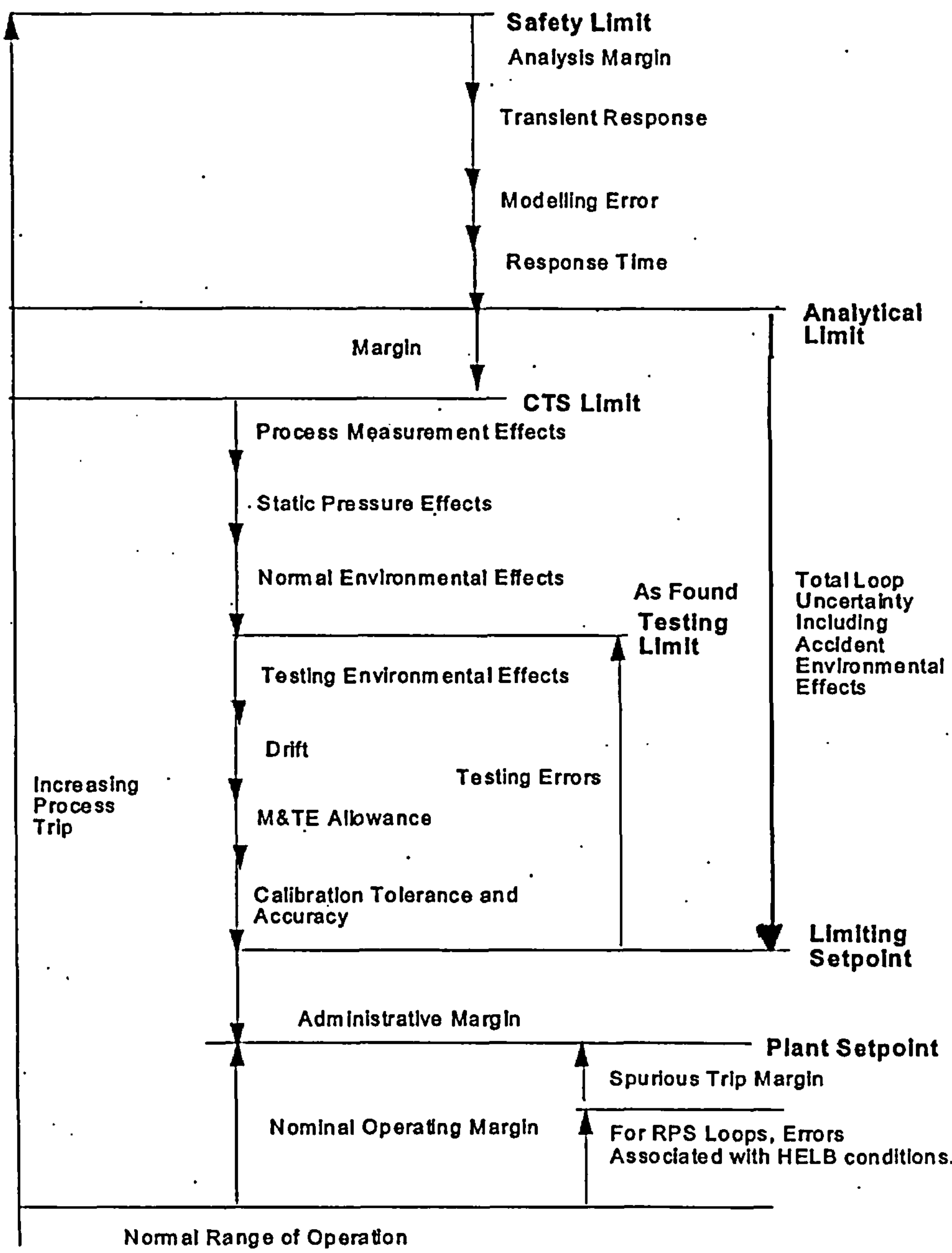


Figure 5: Typical Safety-Related Setpoint Allowances (CTS)

4.1 Setpoint Basis

The first and most important step in preparing a setpoint calculation is to clearly define the purpose and function of the trip actuation or indication being evaluated. The calculations being performed for Vermont Yankee will typically evaluate all of the outputs from a particular loop. This may involve more than one automatic actuation, alarm or indication function. For each of these functions the preparer must answer the following questions:

- What is the safety significance of the function being performed?
- Does this function correspond to an input to an accident or transient analysis. If so, what is the Analytical Limit?
- Does this function correspond to the initial conditions for an accident or transient analysis. If so, what is the value or description of that condition and when does it apply.
- Under what conditions must the function be operable (i.e. normal, accident or post-accident)?
- Under the ITS, is there an Allowable Value (AV) associated with the setpoint?
- Is the process increasing or decreasing as it approaches the setpoint [Sec. 4.6]?
- Does the function act as an anticipatory actuation or as a permissive for some other function [Sec. 4.6]?
- If there is no Analytical Limit (AL), is there a basis for a Process Limit (PL)? Is there an engineering calculation or other documented basis for a Process Limit?
- In the absence of a documented AL or PL, is there a basis for an estimated Process Limit?
- What is the normal range of the process? Does the existing setpoint provide adequate margin to operations?

The answers to these questions determine the classification of the setpoint and the steps necessary to produce an adequate calculation.

4.2 Setpoint Classification

The classification of each setpoint under the Vermont Yankee Setpoint Program is maintained as part of the Setpoint Program Manual, however the correct classification of a setpoint or decision point is the responsibility of the calculation preparer, based upon the current design basis.

4.2.1 Class 1 Setpoints and Decision Points

A setpoint is considered Class 1 if any of the following statements apply:

(a) The Vermont Yankee CTS lists the setpoint as a Limiting Safety System Setting (LSSS).
(b) The Vermont Yankee ITS shows the setpoint as an Allowable Value.
(c) The setpoint represents an input or initial condition for a Vermont Yankee accident analysis or transient analysis.
(d) The Vermont Yankee licensing basis shows that the setpoint is considered to be nuclear safety-related.
(e) The setpoint is determined to be of high risk significance in the Vermont Yankee PRA or IPE analysis.

Generally all of the above characteristics will apply, however there may be exceptions and the calculation preparer should be aware of that possibility.

4.2.2 Class 2 Decision Points

The title of this section is deliberate, since the vast majority of Class 2 functions are those related to trending and operator actions in the emergency operating procedures.

A decision point (or setpoint) is considered Class 2 if all of the following apply:

(a) The function is safety-related or applies to Category 1 and 2 post-accident trending and monitoring.
(b) The parameter monitored is required to perform an essential evolution in the EOPs.
(c) The function is not identified in Guidance & Methodology Associated with Vermont Yankee's Regulatory Guide 1.97 Program Commitments [Ref. 6.22] as a Type A variable .

4.2.3 Class 3 Setpoints and Decision Points

The most convenient way to identify Class 3 setpoints is to verify that the function they perform does not fall into either of the higher categories, as follows:

(a) The associated parameter is a RG-1.97 Category 3 variable [Ref. 6.22].
(b) The function is clearly non-nuclear safety-related.
(c) The setpoint is not itself an input to the accident or transient analysis, has no CTS LSSS or ITS Allowable Value.
(d) Does not perform a function that is required to operate in order for a safety-related system to perform its required function.
(e) Is not an essential parameter in the emergency operating procedures.
(f) The variable is determined to be of very low or no risk significance in the Vermont Yankee PRA or IPE analysis.

Classification in this category is always tentative until the basis for the setpoint is clearly established.

4.2.4 Class 4 Setpoints and Decision Points

This category has all the features of a Class 3 setpoint with the addition that there is no identifiable process limit or that instrument uncertainty is an insignificant portion of the available margin, or the impact on plant risk is insignificant.

4.3 Limits for Class 1 Setpoints

There are four (4) limits associated with nuclear safety-related setpoint determination. They are:

- Safety Limit (CTS & ITS) - In most cases, the Safety Limit (SL) was established during the design of the plant.

- Analytical Limit (CTS & ITS) - The Analytical Limit (AL) is used to:

  (a) Ensure that a Safety Limit is not challenged, and
  (b) Provide the process conditions for use in Vermont Yankee's accident and transient analyses.

- Technical Specification (CTS) - The Technical Specification Limit (TSL) is used to:

  (a) Ensure that a Safety Limit and the Analytical Limit are not challenged, and,

  (b) Provide the process conditions for use in Vermont Yankee's accident and transient analyses.

  (c) CTS applies during normal operation only.

- Allowable Value - The Allowable Value (AV), as applied in the ITS, provides a limit on the setpoint during testing to ensure the Analytical Limit is not challenged.

ISA-RP67.04 Part II limits its discussion to nuclear safety-related setpoints with Analytical Limits, equivalent to Class 1 setpoints. This guide treats the AL for Class 1 setpoints in accordance with the intent of ISA-RP67.04 Part II. Figure 4, Figure 5 shows the general relationship between the SL, AL, and AV for an increasing process trip for ITS. Figure 6 shows the general relationship between the SL, AL, and AV for an increasing process trip for CTS. Figure 6 shows the specific uncertainty terms applied to a decreasing process trip.

At Vermont Yankee, the CTS trip settings are labeled Limiting Safety System Settings and have been considered generally equivalent to the Analytical Limit, taking credit for additional margin incorporated in the accident analysis for harsh environmental conditions. For CTS, the existing Technical Specification Limit shall be evaluated against the setpoint. New or revised setpoint calculations shall explicitly use a new Analytical Limit provided by the DE&S Nuclear Engineering Department, from which the Limiting Setpoint (LSp), Allowable Value, and available margins may be calculated. For ITS the Allowable value will be used as the Limiting Safety System Setting and the LSSS will be based on the Allowable value for calibration until ITS is implemented;

1. An ITS evaluation will be conducted to identify the AV, LSP and administrative setpoint. Determination of AV includes the worst case uncertainty conditions. LSP must support the arithmetic addition of the as-found values for the loop components.

2. A CTS evaluation will be conducted to identify the LSP, ensure the LSP supports the AL (for harsh environments), and administrative setpoint.

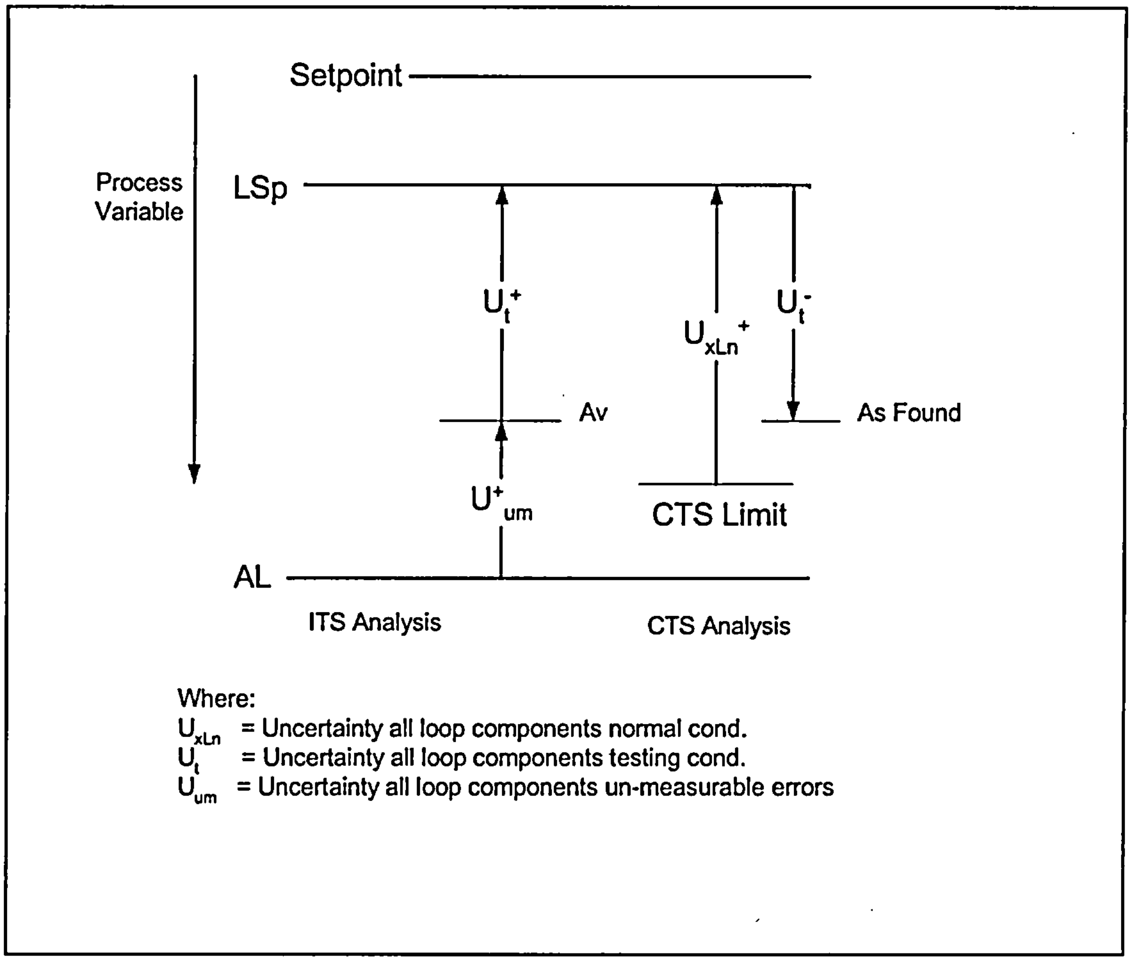


Figure 6: **Uncertainty Relationships for Class 1 Setpoints**

4.4 Class 2 and Class 3 Setpoints/Uncertainties

The Analytical Limit and Allowable Value are regulatory concepts and do not exist for Class 2 or Class 3 setpoints. Instead, the setpoint is based upon a Process Limit (PL) which is derived from the design function of the actuation or decision point. Generally if the setpoint has a protective function, then the PL may be found from a design specification, mechanical calculation or equipment vendor manual. The Process Limit may not be well defined or readily available, however the preparer shall ensure that for these setpoints, a reasonable estimate is provided.

For example, low pressure at the inlet of a pump can cause cavitation and eventual pump damage. Therefore, a process limit should be established which protects the pump against low pressures. In the absence of a formal calculation, the preparer may estimate the minimum pump suction pressure from the vendor's literature.

For many systems, the process limit will differ from the design limit of the physical equipment. For example, the highest pressure which a fluid process is expected to reach (transient) may be 1000 psig. The piping for that process is specified to have a design strength of 1500 psig. The pressure at which the pipe would rupture is even higher. In this case, the process limit (1000 psig) is not the same as the design limit (1500 psig).

Systems that do not figure directly in the safety analysis may have process limits imposed by various interface requirements. For many narrow range loops, the instrument input range may effectively impose upper and lower limits on the setpoint.

4.5 Class 4 Setpoints/Uncertainties

Class 4 setpoints have a low impact on plant safety. Class 4 analysis are performed to document engineering judgement or the use of non-Vermont Yankee methodologies. Class four setpoints will not normally have a process or design limit for component protection.

4.6 Setpoint Determination

The discussion which follows is complicated by (1) the need to accommodate biases, either process measurement (PM) uncertainties or static pressure (SP) effects and (2) calculation of Allowable Value testing limits applicable to safety-related Technical Specification (ITS and CTS) setpoints. Biases may be significant for any setpoint Class, however the calculation preparer may assume the worse case uncertainty applies in both directions, which would be conservative, and significantly simplify the calculation. Allowable Value calculations are applicable only to Class 1 setpoints. (See Section 4.6.2)

The parts of this section which are applicable depend upon the type of setpoint to be determined. Class 1 setpoints will use each sub-section. Class 2 and Class 3 setpoints will omit the sub-section on Allowable Value. Class 4 setpoints may need reference to the sub-section on Administrative Limits.

The order of the steps to find the setpoint for CTS is to (1) determine the Process Limit (PL) or Analytical Limit (AL), (2) Determine the CTS Limit (CTSL) (3) add the total loop uncertainty for normal environmental conditions to the CTS Limit and sign ($U_{xLn}^{\pm}$) to obtain a Limiting Setpoint (LSp), (4) add the testing uncertainty ($U_t^{\pm}$) to obtain the As Found (AF) Value, (5) combine with margin (M) to obtain the final setpoint. Margin.The appropriate sign of the uncertainty used for each step is shown in Table 3.

The order of the steps to find the setpoint for ITS is to (1) determine the Process Limit (PL) or Analytical Limit (AL), (2) add the un-measurable uncertainty ($U^{\pm}_{um}$) to obtain Allowable value (AV), (3) add the testing uncertainty ($U_t^{\pm}$) to obtain the Limiting Setpoint (LSp), (4) combine with margin (M) to obtain the final setpoint. The appropriate sign of the uncertainty used for each step is shown in Table 3.

Table 3: Uncertainty Sign for LSp and AV Evaluation		
	Setpoints	
Parameter	**Increasing**	**Decreasing**
LSp	Negative	Positive
AV	Positive	Negative

It should be noted that some channels might have, functionally, two directions of interest associated with the trip setpoint-reset relationship. For example, an operational function might be a protection system BLOCK ENABLE above a certain nominal value and the safety function may be the AUTO UNBLOCK setpoint which reinstates the protection system trip. In these, and similar, cases it is necessary for the calculation to identify the safety significant direction of interest, determine if the applying of uncertainties is warranted, and document the nominal reset value in order to capture the operational functional "setpoint."

4.6.1 Limiting Setpoint (LSp)

For CTS the LSSS value in the Technical Specifications, the CTS Limit (CTSL) is assumed as the starting point for the determination of the LSp. Proper plant operation is then confirmed by verification that the Analytical Limit will not be exceeded for any applicable plant environments. If the setpoint is based upon a Process Limit (PL) or Analytical Limit (AL), then LSp is calculated as:

$$LSp = CTSL + U^{\pm}_{xLn}$$

where,

CTSL = CTS Limit

$U^{\pm}_{xLn}$ = total loop uncertainty for normal environmental conditions Sign (+ or -) per Table 3.

For ITS if the setpoint is based upon a Process Limit (PL) or Analytical Limit (AL), then LSp is calculated as:

$$LSp = AL + U^{\pm}_{um} + U^{\pm}_{tjk}$$

or

$$LSp = PL + U^{\pm}_{um} + U^{\pm}_{tjk}$$

where,

AL = Analytical Limit

PL = Process Limit

$U^{\pm}_{m}$ = Uncertainty All Loop Components Un-Measurable Errors

$U^{\pm}_{tjk}$ = effective uncertainty for testing conditions, including devices tested ("j" to "k"). For example, if the loop included a flow element, transmitter, and trip unit, the flow element is not tested, AV would only include the uncertainty of the transmitter (device "j") and the trip unit (device "k").

4.6.2 Allowable Value (AV)

For Class 1 setpoints in the ITS and CTS, the Allowable Value (AV) is found from the limiting setpoint (LSp) in accordance with the equations below. Generally, the applicable instruments are only a part of the loop (excluding PM and SP terms).

$$AV = AL + U^{\pm}_{um}$$
$$AV = PL + U^{\pm}_{um}$$

where:

AL = Analytical Limit

PL = Process Limit

$U^{\pm}_{um}$ = Uncertainty All Loop Components Un-Measurable Errors

4.6.3 Setpoints and Administrative Limits

The final setpoint will in most cases, be exactly the current setting of the plant instrumentation, and the setpoint calculation is the documented basis for that value and record of the available margin. However it is probable that the Administrative Limits (as-found and as-left tolerance) will change.

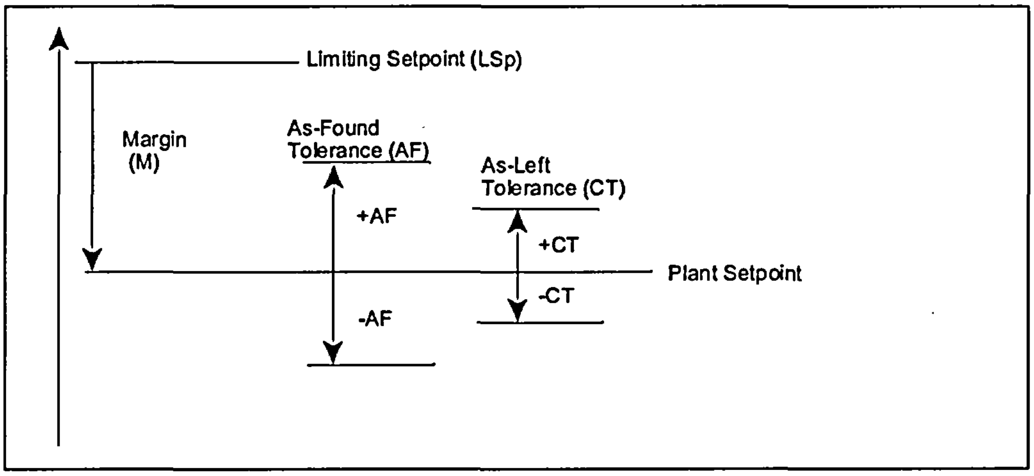


Figure 7: Setpoint and Administrative Limits

The available margin (M) is found from the LSp and Setpoint as follows:

$$M = |LSp - Setpoint|$$

If the existing setpoint is not acceptable, or for a new setpoint, there are several considerations which would cause the setpoint to be something other than the LSp.

(a) Additional margin is desired to ensure the AV is not challenged or to ensure the setpoint will not need to be changed if new information becomes available. Whenever possible, a margin of at least 0.5% CS should be used.

(b) a decision point should be set at a value easily remembered by the operator and easily read on the available indicators.

4.6.4 As-Found and As-Left Tolerances

Each calibration and functional test has two administrative limits determined by the setpoint calculation. The as-found tolerance (AF) for each instrument or device is numerically equal to the calculated testing uncertainty (e_t) and is used to evaluate operability and confirm the results of the calculation. The as-left tolerance (CT) or calibration tolerance is the final acceptance criteria for the test and confirms that the device has been restored to the necessary initial conditions for the next operating interval.

Vermont Yankee uses the as-left (AL) tolerance as the as-found (AF) tolerance for calibration purposes. The calculated AF is provided for performance of Operability evaluations when the actual plant AF is outside the acceptance criteria.

4.6.5 Sequential (Stacked) Setpoint Determination

For some systems, the actions to occur for a given overall operation must occur in sequence. Instrument setpoints can be established which insure that the order is maintained. Another situation where the order is significant is for annunciators and operator actions.

For example, the pressure in a tank should not exceed some limiting value (the process limit). A switch is installed which will open a valve to relieve the pressure if the pressure rises too close to the limit. However, there are other, probably preferable, means of relieving pressure, but which method is best can only be determined by an operator who is aware of plant conditions. Therefore, an indicator is installed and an operator decision point is established below the switch setpoint, with instructions to reduce pressure by the most appropriate method. Because an operator has other duties, he probably won't be watching the indicator continuously. An alarm, which provides a warning that the pressure is approaching the decision point, is installed with a setpoint below the decision point to alert the operator. If due to instrument uncertainty, the alarm annunciates after the decision point has been reached, or if the switch to relieve the pressure trips too soon, the purpose of the switches will have been defeated. Therefore, the range of values over which the switches may be expected to operate may not overlap the region of indication that corresponds to the operator decision point.

Figure 8 shows a diagram of the relationship between stacked setpoints. The individual module uncertainties are shown for the trip switch (e_S), indicator (e_I), and alarm (e_A). Difference uncertainties shown are subscripted to show that they apply to the combination of the alarm and indicator (U_{AI}), trip switch and indicator (U_{IS}), or whole loop (U_{xL}). These are calculated as shown in Section 3.12.

Again, a clear understanding of loop function is essential to correctly recognize stacked setpoints. Some loops have multiple functions that are only tangentially related to each other, others may have several tightly coupled functions that require that each setpoint and decision point follow one another in a specific sequence.

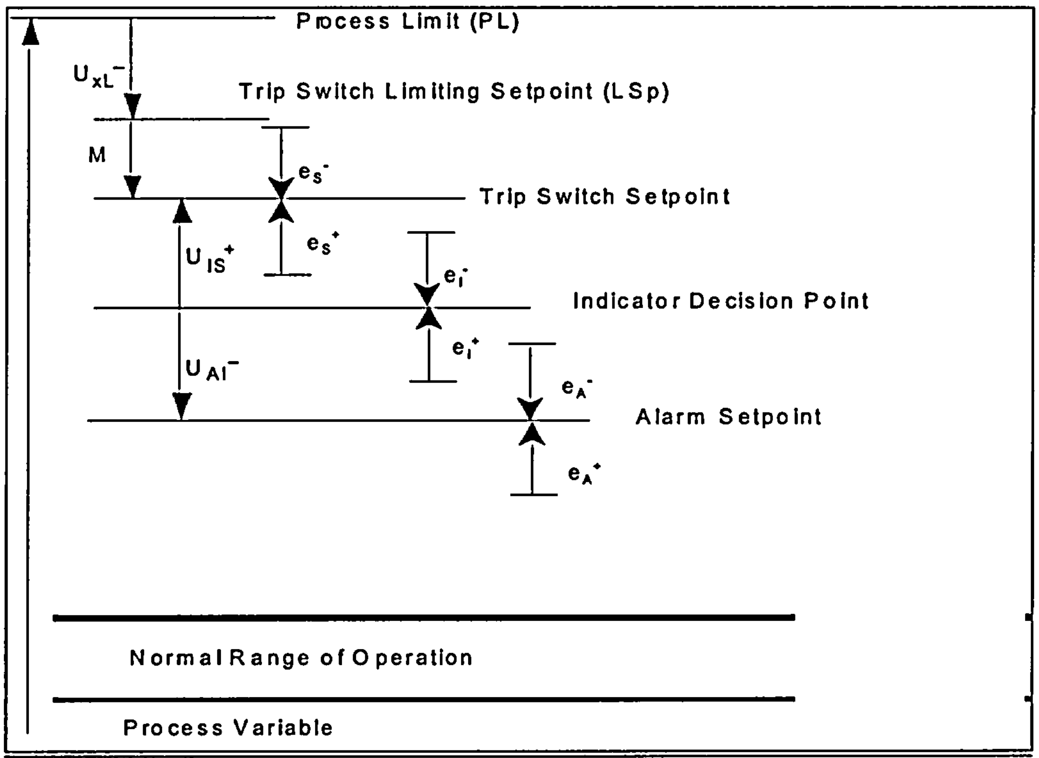


Figure 8: Sequential (Stacked) Setpoints

4.7 Design Considerations

Many design considerations have an influence on channel uncertainty and setpoint determination. The discussion here is not intended to be exhaustive, merely indicative of the type of factors the user should be looking for when preparing a calculation.

4.7.1 Scaling

Particularly in the cases of liquid level and flow measurements, the specific zero and full scale values chosen for a channel may have a profound effect on uncertainties at the process limit or setpoint.

- If the setpoint is near one end of the channel range, the uncertainties may be large enough that the expected trip action may not occur at all.
- Operator decision points in the lower 20% of a flow channel span may not be possible because the error is so large as to render the indication unreliable.
- Errors in elevations, tank dimensions, and flow orifice discharge coefficients may introduce systematic offset errors that are much more severe than the random uncertainty effects considered in this guide.
- If the process and environmental conditions assumed by the setpoint calculation are not the same as those used in the scaling calculation, then the calculated error may not include all significant error contributors.

4.7.2 Installation

All instruments have certain recommended installation requirements. If not followed, the installed loop may perform significantly worse than otherwise expected. Particularly sensitive are the placement requirements of flow orifices and elbow type flow elements (see Attachment D). The following is a list of some of the more common installation problems that need to be evaluated for an uncertainty calculation:

- Flow element piping not straight far enough upstream or downstream;
- Pressure at flow element not stable (pulsation);
- Condensate pots for level or pressure overfill, drain, or move relative to vessel;
- Narrow range level transmitters over ranged routinely, due to siphoning of reference leg;
- Slope of sense lines not constant, either draining or creating vapor traps.

5. DEFINITIONS AND ABBREVIATIONS

5.1 Definitions

- *accuracy* - In process instrumentation, degree of conformity of an indicated value to a recognized accepted standard value, or ideal value [Ref. 6.6].

- *accuracy, measured* - The maximum positive and negative deviation observed in testing a device under specified conditions and specified procedure [Ref. 6.6]. Determination of accuracy is illustrated in Figure 9.

- *accuracy rating (reference accuracy)* - In process instrumentation a number or quantity that defines a limit that errors will not exceed when a device is used under specified operating conditions. Reference accuracy is composed of repeatability (Figure 10), hysteresis (Figure 11), linearity and deadband. If all four components of accuracy are not measured, accuracy cannot be verified.

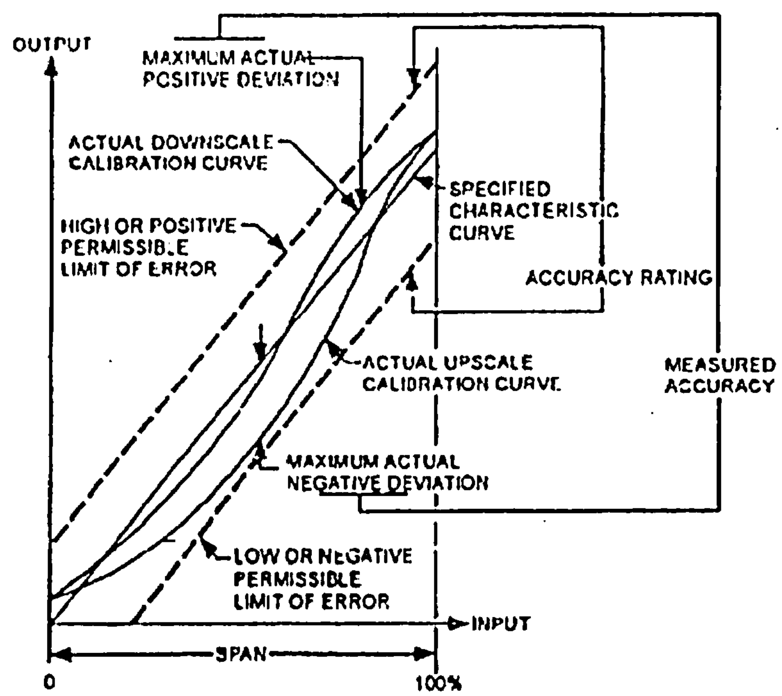


Figure 9: Accuracy

NOTE 1: When operating conditions are not specified, reference operating conditions shall be assumed.

NOTE 2: As a performance specification, accuracy (or reference accuracy) shall be assumed to mean accuracy rating of the device, when used at reference operating conditions.

NOTE 3: Accuracy rating includes the combined effects of conformity, hysteresis, dead band and repeatability errors. The units being used are to be stated explicitly. It is preferred that a ± sign precede the number or quantity. The absence of a sign indicates a + and a - sign. [Ref. 6.6]

- *Allowable Value (AV)* - A limiting value that the trip setpoint may have when tested periodically, beyond which appropriate action shall be taken [Ref. 6.5]. For Vermont Yankee the periodic testing is defined as the calibration. The limiting value for that the trip setpoint may have for other periodic testing is administratively controlled.

- *Analytical Limit (AL)* - Limit of a measured or calculated variable established by the safety analysis to ensure that a safety limit is not exceeded [Ref. 6.5].

NOTE: The analytical limit is the process limit as it applies to Class 1 setpoints.

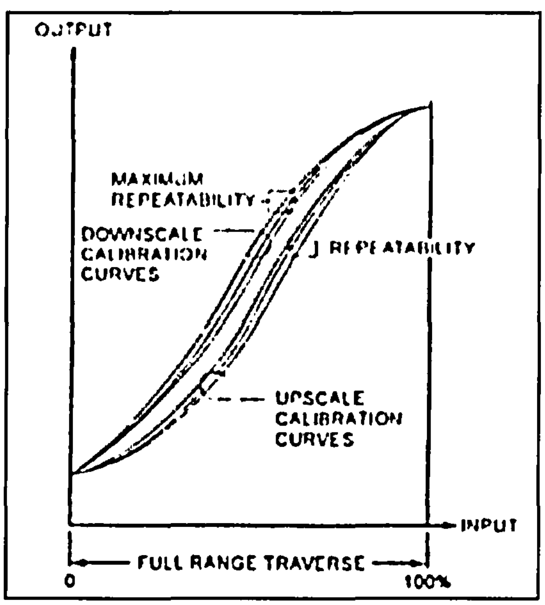


Figure 1: Repeatability

Figure 10: Repeatability

- *as-found* - The condition in which a channel, or portion of a channel, is found after a period of operations and before recalibration (if necessary) [Ref. 6.5].

- *as-found tolerance (AF)* - The calculated limits of testing uncertainty which apply to a given instrument or group of instruments, beyond which additional evaluation is required to determine operability [Sect. 3.8.1].

- *as-left* - The condition in which a channel, or portion of a channel, is left after calibration or final setpoint device setpoint verification [Ref. 6.5].

- *as-left tolerance* - See *calibration tolerance*

- *bias* - An uncertainty component that consistently has the same algebraic sign, and is expressed as an estimated limit of error [Ref. 6.5].

- *barometric pressure effect (PB)* - The change in the output of a gauge pressure instrument due to changes in the ambient pressure [Sect. 3.6.0(b)].

- *bistable* - A device that changes state when a preselected signal value is reached [Ref. 6.5].

  NOTE: As noted in the ISA-RP, as an example of the intended use of this term, electronic trip units at Vermont Yankee are considered "bistables".

- *calibration effect (CE)* - The total uncertainty associated with the calibration process, including MTE, CT, and possibly additional allowances [Sect. 3.6].

- *calibrated span (CS)* - The algebraic difference between the upper and lower values of an instrument's calibrated range, which may or may not be equivalent to the process span.

- *calibration tolerance (CT)* - The specific "leave as-is zone" or as left acceptance criteria which apply to the calibration of a given instrument [Sect. 3.6].

- *correction* - In process instrumentation, the algebraic difference between the ideal value and the indication of the measured signal. It is the quantity that added algebraically to the indication gives the ideal value [Ref. 6.6].

- *correction, head (HC)* - A correction applied to pressure instruments to account for differences in pressure between the point of measurement and the sensing device [Sect. 3.9].

NOTE: If the head correction is incorporated into the instrument calibration, it is not a part of the total loop uncertainty. However, variations in the head correction, usually due to temperature changes, between calibration conditions and required operating conditions (normal or accident) are included as process measurement uncertainty. If the correction is not accounted for, then it represents a bias.

- *dead band (DB)* - In process instrumentation, the range through which an input signal may be varied, upon reversal of direction, without initiating an observable change in the output signal [Ref. 6.6]. See Figure 11 normally considered as a component of Reference Accuracy.

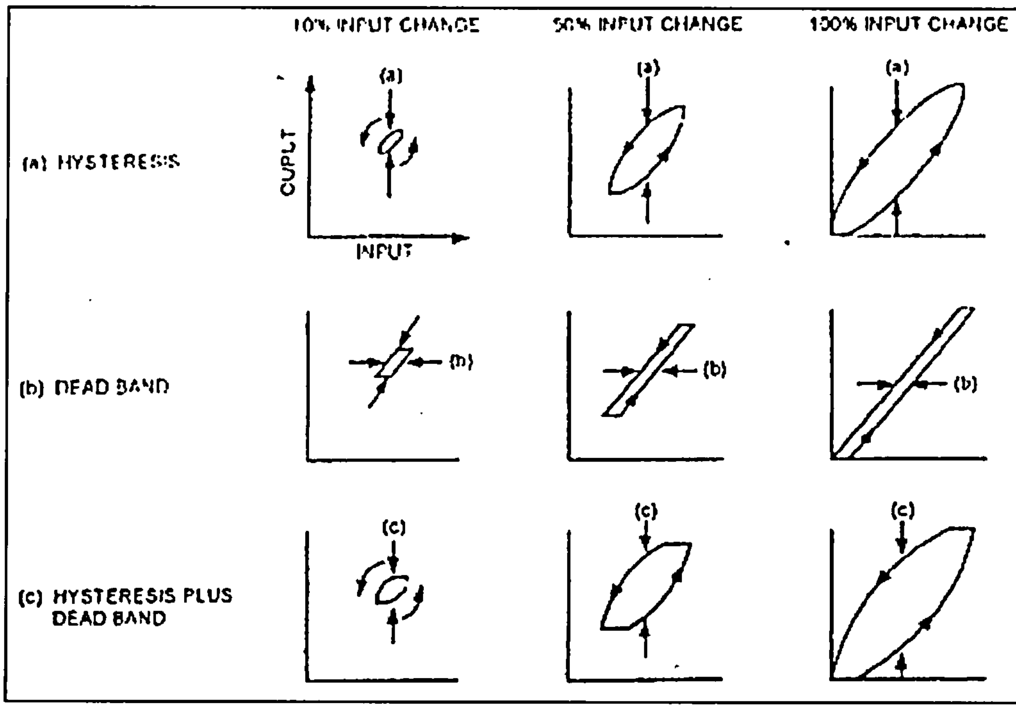


Figure 11: Hysteresis and Dead Band

NOTE: Some instruments, such as transmitters have a specification called variously sensitivity, backlash, or inertial error, which represents the minimum input change from the steady state, for a detectable change in output. For the purposes of this guide, these terms will be considered a constituent part of deadband, and thus part of Reference Accuracy.

- *drift (DR)* - An undesired change in output over a period of time where change is unrelated to the input, environment, or load [Ref. 6.5].

- *drift, analyzed (DA)* - A composite effect derived from statistical analysis of the measured change in output over the test interval for a group of instruments, expressed as a tolerance interval of specified confidence and proportion [Sect. 3.6 and Ref. 6.17].

  NOTE: For the purposes of this guide, analyzed drift is considered to include all of testing uncertainties. [Sect. 3.6].

- *effect* - A change in output produced by some outside phenomenon, such as elevated temperature, pressure, humidity, or radiation [Ref. 6.5].

- *error* - The algebraic difference between the indication and the ideal value of the measured signal [Ref. 6.5].

- *final setpoint device* - A component or assembly of components, that provides input to the process voting logic for actuated equipment [Ref. 6.5].

- *humidity effect (HE)* - The change in an instrument's input-output relationship due to variations of ambient humidity in the instrument's environment [Sect. 3.6.0(b)].

- *hysteresis* - The maximum difference for the same input between the upscale and downscale output values during a full range traverse in each direction.

- *instrument channel* - An arrangement of components and modules as required to generate a single protective action signal when required by a plant condition. A channel loses its identity where single protective action signals are combined [Ref. 6.7].

- *instrument loop* - A combination of one or more interconnected instruments arranged to measure or control a process variable or both [Ref. 6.7].

  NOTE: The term "instrument loop" is not defined in the ISA-RP or in ISA S51.1-1979 [Ref. 6.6], in this guide, loop will be used to describe the entire chain of instruments which effect the uncertainty of a particular process measurement or derived variable.

- *Limiting Safety System Setting (LSSS)* - Limiting safety system settings for nuclear reactors are settings for automatic protective devices related to those variables having significant safety functions [Ref. 6.5].

- *Limiting Setpoint (LSp)* - The least conservative setpoint which, allowing for uncertainty, provides actuation before the measured variable reaches the analytical or process limit.

- *margin (M)* - In setpoint determination, an allowance added to the instrument channel uncertainty. Margin moves the setpoint farther away from the analytical limit [Ref. 6.5].

- *measurement & test equipment effect (MTE)* - The inaccuracy introduced into the calibration process due to the accuracy of the measurement instruments used to calibrate the channel or device [Sect. 3.6.5].

- *module* - Any assembly of interconnected components that constitutes an identifiable device, instrument, or piece of equipment. A module can be removed as a unit and replaced with a spare. It has definable performance characteristics that permit it to be tested as a unit. A module can be a card, a draw out circuit breaker, or other subassembly of a larger device, provided it meets the requirements of this definition [Ref. 6.5].

- *module uncertainty (e)* - The aggregate uncertainty associated with a specific module, including random and bias effects [Sect. 3.8].

- *nuclear safety related instrumentation* - That which is essential to the following:

  - Provide emergency reactor shutdown
  - Provide containment isolation
  - Provide reactor core cooling
  - Provide for containment or reactor heat removal, or
  - 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 undo risk to the health and safety of the public. [Ref. 6.5]

- *overpressure effect (PO)* - The change in the output of a pressure instrument due to exposure to pressure outside its calibrated span. This can occur when an instrument is calibrated to detect pressure variations in a range less than the pressure to which the instrument is normally exposed [Sect. 3.6.0(c)].

- *power supply voltage effect (VE)* - The changes in an instrument's output due to power supply output variations [Sect. 3.6.0(c)].

- *primary element accuracy (PE)* - .. the accuracy of a component, piece of equipment, or installation used as a primary element to obtain a given process measurement. This would include the accuracy of a flow nozzle and/or the accuracy achievable in a specific flow metering run [Ref. 6.5].

- *process measurement uncertainty (PM)* - ... the basis ability to accurately measure the parameter of concern. This term is not governed by the accuracy of the instrumentation but by variation in actual process conditions that influence the measurement. Process influences such as temperature stratification, density variation, pressure variations, etc., which cause the basic measurement to be inaccurate, would all be considered in the PM term [Ref. 6.5].

- *process limit (PL)* - A limit on a plant process variable for equipment or site personnel protection and reliable operation.

- *process span (PS)* - The variation of the process variable which is detectable or meaningful to the instrument loop. For example, a flow process might vary from 0 to 100 gpm; however, the range 20-80 gpm is meaningful to the instrument (that is, it corresponds to the calibrated span of the instrument). In this case the process span is 20-80 gpm. [Sect. 3.6.0(c)].

- *radiation effect (RE)* - The change in an instrument's output due to the effects of ionizing radiation [Sect. 3.6.11].

- *random* - Describing a variable whose value at a particular future instant cannot be predicted exactly but can only be estimated by a distribution function [Ref. 6.5].

- *range* - The region between the limits within which a quantity is measured, received, or transmitted, expressed by stating the lower and upper range-values [Ref. 6.6].

- *readability uncertainty (RD)* - Uncertainty introduced into the calibration process by the resolution of the M&TE used or the uncertainty inherent in reading the output scale of panel indicators or recorders used in process measurement [Sect. 3.6.4].

- *safety limit (SL)* - A limit on an important process variable that is necessary to reasonably protect the integrity of physical barriers that guard against the uncontrolled release of radioactivity [Ref. 6.4].

- *seismic/vibratory effect (SE)* - The change in an instrument's output due to seismic activity or local vibration [Sect.]. The seismic/vibratory term could be used to account for any uncertainties associated with a safe shutdown or operating basis earthquake, physical equipment vibration-induced inaccuracies, etc. [Ref. 6.5]

- *sensor* - The portion of an instrument channel which responds to changes in a primary element or plant condition and converts the measured process variable into an electric or pneumatic signal [Ref. 6.5].

- *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 [Ref. 6.6].

  NOTE: This term has often been used to represent the smallest variation in signal which can be detected by the instrument. In this sense is equivalent to readability or deadband.

- *setpoint tolerance* - See calibration tolerance.

- *sigma (σ)* - Symbol for one standard deviation of a random distribution.

- *signal conditioning* - One or more modules that perform signal conversion, buffering, isolation, or mathematical operations on the signal as needed [Ref. 6.5].

- *static pressure effect (SP_x)* - The change in the output of a differential pressure instrument due to calibration at static pressure conditions different from the operating static pressure [Sect. 3.6.0(c)].

  NOTE: The subscript "x" = C - span Correction, U-correction Uncertainty, or Z-Zero effect.

- *temperature effect (TE)* - The change in an instrument's output due to variations of ambient temperature in the instrument's environment [Sect. 3.6].

- *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 [Ref. 6.4].

- *tolerance interval* - The usual notation is Y/P where Y, the confidence level is the first number to appear and P the proportion, the second number. The notation 95/99 then means a 95 percent confidence that the value will occur within the determined boundaries 99 percent of the time.

- *trip setpoint* - A predetermined value for actuation of the final setpoint device to initiate a protective action [Ref. 6.4].

- *uncertainty, dependent* - 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 [Ref. 6.5 and Sect. 3.3].

- *uncertainty, independent* - Uncertainty components are independent of each other if their magnitudes or algebraic signs are not significantly correlated [Ref. 6.5 and Sect. 3.3].

5.2 Abbreviations

Listed below are the symbols used to represent commonly used quantities throughout this design guide. Common formatting guides provide for consistent use of symbols. The general pattern is to follow the single character symbols for physical phenomena standardized by ASME, IEEE, and ICRU. Some uncertainties which are dependent only upon an intrinsic characteristic of an instrument are also single characters. The symbols for the effects or uncertainties associated with physical phenomena are two characters, with the symbol of the physical cause followed by a descriptive character which uniquely identifies the uncertainty. Some of the uncertainties are not related to physical causes, but to procedural allowances or tolerances. These will generally have the second character as an "A" or a "T". The last character of the symbol can indicate the type of value it represents: A - Allowance, E - Effect, L - limit, R - reading, S-span, T - tolerance, U - uncertainty, V - value.

Process and Environment Variables

The symbols below are used to represent physical quantities which are more commonly used in determining instrument uncertainties. The commonly used units are shown in parentheses. In some cases, two symbols are given for the same quantity. This is because both symbols are used in common engineering practice and any difference in meaning is obtained from the context in which they are used.

a	-	acceleration (multiple of gravitational acceleration, g)
ρ	-	density
d, D	-	diameter (feet, inches)
h	-	height (feet, inches)
H	-	Humidity (% relative humidity)
v	-	Specific volume
β	-	ratio of d/D (as for a flow measuring device)
I	-	Electrical current (Amp, mA)
p	-	pressure (psig, psia, psid)
q, Q	-	volume flow rate (gpm)
R	-	Radiation dose rate (mrad/hr, rad/hr)
T	-	Temperature (°F)
t	-	time
TID	-	Total Integrated Dose (rads)
V	-	Power supply stability (volts) (emf)
w	-	mass flow rate (lbm/hr, lbm/sec)
Z, z	-	elevation or height (feet, inches)

Uncertainties, Corrections, Effects, and Tolerances

Represented below are the various types of uncertainties or effects. There are three general categories of uncertainties: (1) intrinsic to an instrument, (2) effect as a result of external factors, and (3) administrative tolerances. There may also be combinations of uncertainties.

A	-	Accuracy
CE	-	Calibration Effect on accuracy
CT	-	as left Calibration Tolerance
DA	-	Drift, Analyzed
DR	-	DRift
ρE	-	density (ρ) Effect (i.e., as for gas measurements)
e	-	module uncertainty
EAP	-	Earliest Actuation Point
AF	-	As Found tolerance
hC	-	head Correction
hU	-	head correction Uncertainty error (e.g., due to density variations)
HE	-	Humidity Effect
IR	-	Insulation Resistance current leakage effect
LAP	-	Latest Actuation Point
LSp	-	Limiting Setpoint (calculated)
M	-	Margin allowance
MTE	-	Measurement & Test equipment Effect
OP	-	Over-Pressure effect
PB	-	Pressure effect, Barometric
PM	-	Process Measurement uncertainty (combined effect of process variations)
RD	-	Readability, or, resolution
RE	-	Radiation Effect
RST	-	Reset
SE	-	Seismic/vibratory Effect
S.C.	-	Static Pressure span Correction
SP_U	-	Static Pressure correction Uncertainty
SP_Z	-	Static Pressure Zero effect
TE	-	Temperature Effect
U	-	general uncertainty for a group of instruments
VE	-	power supply Voltage Effect

Miscellaneous

Provided below are some other abbreviations used in this design guide.

BOP	-	Balance of Plant
DBA	-	Design Basis Accident
HELB	-	High Energy Line Break
LOCA	-	Loss of Coolant Accident
MSLB	-	Main Steam Line Break
M&TE	-	Measurement & Test Equipment
NSSS	-	Nuclear Steam Supplier Systems
OBE	-	Operating Basis Earthquake
SRSS	-	Square Root Sum of the Squares
SSE	-	Safe Shutdown Earthquake
VYNPS	-	Vermont Yankee Nuclear Power Station

Effect Expressions

Vendor supplied expressions are used to describe the uncertainties and effects given in Section 4.2.4. The symbols are formed by adding the character "X" to the effect. For example, TEX - Temperature Effect expression, SP_ZX - static pressure Zero effect expression.

Subscripts

There are three groups of subscripts: (1) applicable environmental and boundary conditions, (2) uncertainty distribution (random or bias), and (3) applicable instrument or group of instruments.

Environmental

a	-	accident (defined by specific accident scenario)
p	-	post-accident, EOP use
n	-	normal
s	-	seismic event
t	-	testing

Uncertainty Distribution

B	-	Bias
D	-	Dependent (random)
R	-	Random (independent)
U	-	Uniform, random, independent

Instrument or Group of Instruments

i	-	represents ith instrument of the loop
j	-	used with "i", represent the group of instruments from "i" to "j"
L	-	entire loop through to end device. Having no instrument subscripts can imply the entire loop, using L explicitly states the entire loop.

The process measurement effect is considered the zeroth device.

Superscripts

Only two superscripts are used. They are used to indicate direction of the uncertainty when needed. The sign convention used by this design guide is the direction of the output for a given input. For example, an indicator which has an input of 100 psi, but reads 105 psi has a positive uncertainty, or error, of +5 psi. A shift in the setpoint of a bistable device has the opposite sign.

"+"	-	positive direction
"-"	-	negative direction

Symbol Format

For clarity, the order of subscripts is standardized. The order of the subscripts, when present, is (1) environmental conditions, (2) uncertainty distribution, (3) instrument or group of instruments. The first two categories of subscripts are letters and the third is generally numbers. In some cases a multi-character subscript to designate a particular device is beneficial. In this case, a comma separates the first two categories of subscript from the instrument subscript. Examples are shown below.

e_{nRi}	-	Normal random uncertainty of the ith device
$TE_{a,Xmtr}$	-	Accident temperature effect on the transmitter
$S.C._{,R1}$	-	Random static pressure correction error for the first device
A_0	-	Accuracy of the zeroth device (primary element)
U_{nL}	-	Normal uncertainty of the entire loop.
$U_{n1,3}$	-	Total normal uncertainty for devices 1 through 3.
U_{nL4}	-	Total loop uncertainty for normal conditions for the channel ending with device 4 (for cases where there are multiple end devices within an overall loop).

6. GENERAL REFERENCES

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6.1.1. 10CFR50.36, "Technical Specifications"

6.1.2. 10CFR50.49, "Environmental Qualification of Electrical Equipment Important to Safety for Nuclear Power Plants"

6.1.3. 10CFR50.73, "Licensee Event Report System"

6.2 USNRC Regulatory Guide 1.105, Revision 2, February 1986, "Instrument Setpoints"

6.3 INPO Good Practice TS-405, INPO 84-026, Revision 1, "Setpoint Change Control Program"

6.4 ANSI/ISA Standard S67.04 Part I-1994, "Setpoints for Nuclear Safety-Related Instrumentation Used in Nuclear Power Plants"

6.5 ISA RP67.04-1994, Part II-1994, "Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation" Second printing May, 1995

6.6 ISA-S51.1-1979 ® 1993, "Process Instrumentation Terminology"

6.7 ANSI/ISA-S5.1-1981, "Instrumentation Symbols and Identification"

6.8 ISO/TAG-4/WG-3-1992, "Guide to the Expression of Uncertainty in Measurement"

6.9 "Technical Specifications for Vermont Yankee Nuclear Power Station," U.S. Nuclear Regulatory Commission

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6.10.1. Attachment A: "Seismic Analyses"
6.10.2. Attachment C: "Structural Loading Criteria"

6.11 YNSD WE-002, "Design Document Control," Revision 11, IR WE-002-1

6.12 YNSD WE-103, "Engineering Calculations and Analyses," Revision 17, IR WE-103-2

6.13 AP 0017, "Calculations and Analyses," Revision 4

6.14 AP 0022, "Setpoint Change Requests," Revision 10

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6.16 YOQAP-I-A, "Yankee Atomic Electric Company Operational Quality Assurance Program," Revision 26 (December 21, 1995)

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6.22 'Guidance and Methodology Associated with Vermont Yankee's Regulatory Guide 1.97 Program Commitments," Vermont Yankee Design Engineering, Revision 0, December 12, 1996.

6.23 Vermont Yankee Motor Operated Valve Program Manual

6.23.1 Motor Operated Valve Program Plan, Revision 1

6.23.2 Guideline for the System and Functional Design Basis Review of Vermont Yankee MOVs, Revision 1

6.23.3 Guideline for the Component Review of Vermont Yankee MOVs, Revision 4

6.23.4 MOV Electrical Standard Guideline, Revision 0

6.23.5 Vermont Yankee In-Situ Differential Pressure Testing Valve Review and Testing Requirements, Revision 0

6.23.6 Vermont Yankee Engineering Guideline for Evaluation of MOV Design Basis Capability, Revision 1

6.23.7 Validation of MOV Design Assumptions Based on Vermont Yankee DP Tests and Industry Information

6.24 R. P. Benedict, Fundamentals of Temperature, Pressure and Flow Measurements, J. Wiley, 1984

6.25 Flow of Fluids through Pipes, Valves and Fittings, Crane Co., Technical Publication 410

6.26 Vermont Yankee Project, "Engineering Design Bases," Revision 4

6.27 Calculation VYC-700, "Post-Accident Insulation Resistance Effects on the Accuracy of Selected Environmentally Qualified Instrumentation," Revision 0

6.28 "Low Level Radiation Test Report for Rosemount Model 1152 Pressure Transmitter," Rosemount Report 8805A.

6.29 "30 Month Stability Specification for Rosemount Model 1152, 1153 and 1154 Pressure Transmitters," Rosemount Report D8900126, Revision A

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6.32 "Model 1153 Series B Alphaline Pressure Transmitters for Nuclear Service, Instruction Manual," Rosemount Publication MAN 4302, May 1993

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6.34 "Type Test Report Results of Low Radiation Dose Rate and Low Level LOCA Evaluation for Model 1153 Series B," Rosemount, Rosemount Report D8600063, Revision A

6.35 "Rosemount Model 1152 Alphaline Nuclear Pressure Transmitters," Rosemount Publication 4235, February 1994

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ATTACHMENT A: Graded Approach to the Determination of Instrument Channel Accuracy

1.0 INTRODUCTION

The Vermont Yankee setpoint methodology was developed and is defined by this standard to provide the basis, consistent with ANSI/ISA-S67.04-Part I, for the determination of instrument setpoints, allowable values and instrument loop accuracy. This ISA standard defines the requirements for establishing and maintaining setpoints for nuclear safety-related instrumentation. In addition, ISA-RP67.04-Part II provides guidance for implementing ANSI/ISA-S67.04 and imposes rigorous requirements for instrument uncertainty calculations and setpoint determination for safety-related instrument setpoints in nuclear power plants.

ISA-RP67.04-Part II recognizes that the historical focus of ANSI/ISA-S67.04 was the class of setpoints associated with the analytical limits as determined in the accident analysis. The accident analyses were required to be performed with a high confidence interval. These Analytical Limits have a traceability to this same high confidence interval and should maintain this same confidence interval. These setpoints have typically been interpreted as the reactor protection (RPS) and emergency core cooling systems (ECCS) setpoints. The RPS and ECCS setpoints are those critical to ensuring that the integrity of the multiple barriers to the release of fission products are maintained. The Recommended Practice also states that setpoints that are not part of the safety analysis and are not required to maintain the integrity of the fission product barriers may not require the same level of rigor or detail as described by the Recommended Practice. For these non-RPS and non-ECCS setpoints, a graduated or "graded" approach is appropriate for setpoints that:

- provide anticipatory inputs to the RPS or ECCS functions, but are not credited in the accident analysis or,
- Support operation of, but not the initiation of, the ECCS setpoints,
- Do not have traceability to a limit bases on a high confidence interval analysis,
- Do not support risk significant components.

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

This Attachment provides the associated graded methodology for the determination of instrument loop accuracy at Vermont Yankee nuclear stations. The instrument loop accuracy may then be used to determine the associated instrument setpoints The Vermont Yankee "graded methodology" is summarized in Table A1.

2.0 DETERMINATION OF INSTRUMENT LOOP ACCURACY

2.1 CLASSES OF CONFIDENCE INTERVAL

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

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

3.2 CLASS 1

Calculation of instrument loop accuracy, instrument setpoints and allowable values in Class1 shall use the equations in the design guide . These equations use a 2σ confidence interval and require that determination of instrument loop accuracy always err on the side of conservatism.

Class1 setpoints are consistent with ISA S67.04, Part I and ISA RP67.04, Part II. In order to ensure that protective actions occur 95% of the time with a high degree of confidence before the analytical limits are reached.

3.3 CLASS 2

Class 2 instrument loop accuracy is calculated using the equations in the design guide with the following exceptions:

1) Random errors are evaluated at a 90 % confidence interval.
2) Bias errors may be combined using SRSS.
3) Where it can be determined that a setpoint function is only evaluated in a single direction, either increasing or decreasing, single side of interest confidence levels may be utilized .

3.4 CLASS 3

Class 3 instrument loop accuracy is calculated using the equations in the design guide, the exceptions in Class2 and the following additional exceptions:

1) Random errors are evaluated at a 75% confidence interval.

2) Uncertainties applicable to the entire instrument channel are used wherever available, e.g. channel drift and channel temperature uncertainty vs. module/component drift and module/component temperature uncertainty.

3) All terms are expected to be approximately normally distributed. Therefore, all terms can be combined using SRSS.

4) For bistables, the RA term does not require inclusion of the hysteresis/linearity components. Only the RA uncertainty OR the ST uncertainty, whichever is larger shall be used

3.5 CLASS 4

Class 4 instrument loop accuracy may be calculated using the equations in the design guide and include the exceptions in Class2 and 3. For calculations associated with Class 4 instrument loops, the basis for determining the instrument loop accuracy shall be documented.

7. Table A1, Graded Methodology

CLASS	TYPICAL APPLICATION	METHODOLOGY	APPLICABLE UNCERTAINTY METHODS
1	• Protection setpoints • ECCS/RPS/	$2\sigma + \Sigma e_i$	• Consistent with ISA S67.04, Part I and ISA RP67.04, Part II. • Ensures protective actions occur 95% of the time with a high degree of confidence before the analytical limits are reached. • Random and bias error combination: $Z = \pm[A^2 + B^2 + C^2 + (E + F)^2]^{1/2} \pm (\lvert F \rvert) + (L) - (M)$ Z = resultant uncertainty, combination of random and bias uncertainties A,B,C = random, independent terms D,E = random dependent terms (independent of A,B and C) F = abnormally distributed uncertainties and/or bias (unknown sign) L,M = biases with known sign
2	• EOP operator action setpoints • RG 1.97 category 1 and 2 variables	$\sigma + \Sigma e_i$	• Bias errors combined using SRSS in accordance with ASME PTC 19.1: $e_i = \pm[F^2 + L^2 + M^2]^{1/2}$ where F, L and M are bias errors as shown above • Single side of interest confidence interval evaluation where the evaluated setpoint is in a single direction: $Z = 0.468\sigma + \Sigma e_i$
3	• RG 1.97 category 3 variables	$\sigma + \Sigma e_i$	• Uncertainties applicable to the entire instrument channel are used wherever available, e.g. channel drift and channel temperature uncertainty vs. module/component drift and module/component temperature uncertainty. • Single side of interest confidence interval evaluation where the evaluated setpoint is in a single direction: $Z = 0.468\sigma + \Sigma e_i$ • Where all terms are expected to be approximately normally distributed, the sum is assumed to be approximately distributed for n≥4: $Z = [\sigma_n^2 + e_n^2]^{1/2}$ • For bistables, the RA term does not require inclusion of the hysteresis/linearity components, therefore use the RA uncertainty OR the ST uncertainty, whichever is larger.

CLASS	TYPICAL APPLICATION	METHO-DOLOGY	APPLICABLE UNCERTAINTY METHODS
4	• Documentation of setpoint accuracy (e.g. non-safety, non-tech spec compliance) • Other regulatory related setpoints (consequences of non-compliance are deemed acceptable)	as appropriate	• Engineering Judgment shall be documented • Engineering evaluation/conclusions shall be documented • Vendor, Vermont Yankee, or other methodologies may be utilized where appropriate

NOTE: The reduction of confidence interval is taken at the total loop uncertainty level. Errors or allowances for calibration tolerance or M&TE are not reduced for the determination of actual field settings or for the selection of the M&TE used for the calibration. In the rare case where the algebraic summation of Setting Tolerances or as-left tolerances is greater than total loop uncertainty, the summation shall be used to determine the plant setpoint or channel accuracy.

QA RECORD?

_X_ YES

___ NO

RECORD TYPE NO. 09C16004

Safety Class/P.O. NO. (if applicable) NNS

YANKEE ATOMIC ELECTRIC COMPANY
CALCULATION/ANALYSIS FOR

TITLE ______

PLANT: VERMONT YANKEE CYCLE 20

CALCULATION NUMBER VYC- XXXX

	PREPARED BY/ DATE	REVIEWED BY/ DATE	APPROVED BY/ DATE	SUPERSEDES CALC./REV. NO.
ORIGINAL				N/A
Revision 1				Original
Revision 2				Revision 1
Revision 3				Revision 2

KEYWORDS Logic Response Time

COMPUTER CODES: None

EQUIP/TAG NOs.: N/A

SYSTEMS: Reactor Protection System, Emergency Core Cooling System

REFERENCES:

FORM WE-103-1
Revision 5

Table of Contents

Page

REVISIONS SHEET....4

1. PURPOSE....5
   - 1.1. Calculation Objectives....5
   - 1.2. Systems & Components....5
2. METHODS AND ASSUMPTIONS....6
   - 2.1. Governing Procedures And Programs....7
   - 2.2. Criteria....7
   - 2.3. Process Corrections and Measurement Uncertainties (PM)/ Primary Element Accuracy (PE)....8
   - 2.4. Assumptions....8
3. INPUT data....11
   - 3.1 Process and Loop Data....11
   - 3.2 Environmental ConditionsConditions....12
   - 3.3 Primary Element (e_1) Data....13
   - 3.4 Power Supplies Data (e_2)....13
   - 3.5 Transmitter (Switch) Data (e_3)....14
   - 3.6 Trip Unit Data (e_4)....15
   - 3.7 Calibration M&TE input data....16
4. CALCULATION DETAIL....16
5. RESULTS AND CONCLUSIONS....16
   - 5.1 Process Measurement Uncertainties (PM - e_0)....16
   - 5.2 Primiary Element Uncertainties (PE - e_1)....16
   - 5.3 Loop Module Uncertainties....16
   - 5.4 Loop Channel Uncertainties....17
   - 5.5 Setpoint Determinations....17
   - 5.6 Graphical Representation of the CTS Setpoint....18
   - 5.7 Graphical Representation of the ITS Setpoint....19
   - 5.8 Calibration and Test Results....20
   - 5.9 Conclusions and Summary of Recommendations....20
   - 5.10 VYPP-15 Impact Considerations....20
6. REFERENCES....21
   - 6.1 General References....21
   - 6.2 Procedures....21
   - 6.3 Calculations and Bases....21
   - 6.4 Drawings....21
   - 6.5 Vendor Data....21

TABLES

Table 1 - Equipment Summary 5
Table 2 - Channel Identification 6
Table 3 - EQ Matrix Data 6
Table 4 - Normal Area Temperatures 8
Table 5 - Process/Loop Inputs 12
Table 6 - Environmental Input Data 12
Table 7 - Primiary Element Input Data 13
Table 8 - Power Supply Input Data 13
Table 9 - Transmitter (Switch) Input Data 14
Table 10 - Trip Unit Input Data 15
Table 11 - Calibration M&TE Input Data 16
Table 12 - Loop Module Uncertainties 16
Table 13 - Loop Channel Uncertainties 17
Table 14 - Setpoint Results 17
Table 15 - Calibration Setpoint and Ranges 20
Table 16 - Calibration Tolerances 20

FIGURES

Figure 1 - Setpoint (Current Technical Specifications) 18
Figure 2 - Setpoint (Improved Technical Specifications) 19

ATTACHMENTS

ATTACHMENT A: Logic Sketch (pages)
ATTACHMENT B: MathCad / EXCEL Calculation Sheets (for section 4.0 calculation detail if used) (pages)
ATTACHMENT C: Applicable Vendor information (pages)
ATTACHMENT D: Calibration History and M&TE (pages)
ATTACHMENT E: Drift Calculation information (pages)
ATTACHMENT F: Excerpts supporting calculation (pages)
ATTACHMENT J: WE-103 Review Forms. (page)

Rev. No.	Approval Date	Reason & Description of Change
Original	3/13/91	Initial Issue.
1		**Major rewrite.** Revise method and format to comply with VY Uncertainty and Setpoint Design Guide & incorporate the calculation of limits for Improved Technical Specifcations. Due to the extent of input/output and format changes, this revision is a major re-write and revision bars are not used. ***Add a statement for any other change that may have been performed***
2		
3		
4		

1. PURPOSE

1.1. Calculation Objectives

1.1.1. This calculation has been developed in support of the Vermont Yankee Instrument Uncertainty and Setpoints program and covers ***some set of instrumentation*** (Set point Class XX: Nuclear Safety Related). This calculation is a **Major Rewrite of Revision XX** and has the following major objectives:[Ref.]

1.1.2. Document the instrument loop functions and the basis for the setpoints associated with those functions.

1.1.3. Establish the total loop uncertainty for each output function and verify consistency with the design basis.

1.1.4. Calculate the limiting setpoints.

1.1.5. Evaluate the adequacy of existing Setpoint Administrative Limits.

1.1.6. Provide as-found and as-left tolerances for use in instrument calibration and functional test procedures. Verify and document process corrections, instrument scaling, and calibration methods.

1.2. Systems & Components

1.2.1. This calculation applies to the Main Steam Line High Flow/Bypass Flow Trip of the Nuclear Boiler System. The specific components addressed are listed below in the equipment summary table.

Table 1 - Equipment Summary

Tag No.	Location	SYS	SC	Description	MFG.	Model	CWD
				Engineering Function not MPAC			

1.3. Instrument Loop Function (Abbreviated)

Provided a discussion of the general function of the loop components. This should define the setpoint functions of indication or alarm function.

Table 2 - Channel Identification

Isolation Channel	A-1	B-1	A-2	B-2
Primary Element				
Power Supply				
Transmitter				
Trip Unit				
Relays				
Slave Relay				
ERFIS Computer Point				
Annunciator				
Associated Relays				

1.3.1. Normal Operations

Provide discussion and references

1.3.2. Accident Conditions

Discussion and references

1.3.3. Post-Accident or EOP Functions

Discussion and references

Table 3 - EQ Matrix Data

Services	Location	Accident	Cat	TBN1	F1	Duration
Function 1	Volume	LOCA				
		MS				
		HPCI				
		RCIC				
		RWCU				
		HHS				
Function 2	Volume	LOCA				
		MS				
		HPCI				
		RCIC				
		RWCU				
		HHS				

2. METHODS AND ASSUMPTIONS

This calculation has been prepared in accordance with the Governing Procedures and Programs listed in Step 0. Standard methods employed in this calculation are explained in the "Vermont Yankee Instrument Uncertainty and Setpoints Design Guide". [Ref.]

2.1. Governing Procedures And Programs

2.1.1. Vermont Yankee Instrument Uncertainty and Setpoints Design Guide, Rev. 0. [Ref.]

2.1.2. Yankee Nuclear Services Engineering Instruction, WE-103, Rev. 15, Analyses and Calculations. [Ref.]

2.1.3. Vermont Yankee Engineering Procedure, AP 0017, Rev. 4, Calculations and Analyses. [Ref.]

2.1.4 Yankee Nuclear Services Engineering Instruction, WE-108, Rev. 5, Computer Codes. [Ref.]

2.1.5 VYDEP-15, "Calculations,"
AP 0022, Rev. 10 "Setpoint Change Requests"[Ref.]

2.2. Criteria

2.2.1. Numerical combination for the calculations of M&TE, Total Loop Uncertainty, Setpoint determination and other associated values have been calculated using Microsoft Excel Spreadsheets (Math Soft Mathcad documents). Representative calculations in Attachment(s) XXXX and YYYY(Microsoft Excel Spreadsheets/Math Soft Mathcad 6/7Documents) were manually verified using a hand calculator, in accordance with WE-108, Computer Codes. (***Calculations for M&TE errors from attached spreadsheets must also be verified if different from M&TE calculation***) [Ref.]

2.2.2. No errors were found in the manual verification of the calculations performed with the Software in Attachment(s). Physical evidence of the check (by the Preparer and to the extent necessary Reviewer) is provided by check marks next to each verified calculation. Where multiple calculations are generated by coping cells or formulas selected samples have been verified.

2.2.3. Microsoft Excel (Math soft Mathcad) stores numbers with 15 digits of accuracy, all calculation outputs displayed within this calculation are rounded from the values stored by Microsoft Excel. Rounding errors induced by Microsoft Excel are assumed to be negligible within this calculation. [Ref.]

2.2.4. Computer specifications

PC used for this calculation - Serial No. XXXXXXXX

IBM Pentium 133MHz.
16MB of Ram.
Math co-processor installed.
Running in 386 Enhanced Mode.
Software
Dos Version 6.22.
Windows Version 95.
Microsoft Excel Version 5.0c.

(Be specific enough with hardware and software so that if a problem is found it can be traced)

2.3. Process Corrections and Measurement Uncertainties (PM)/ Primary Element Accuracy (PE)

2.4. Assumptions

2.4.1. Calibration of instruments is assumed to be at a temperature within the ranges shown in the following table:

Table 4 - Normal Area Temperatures

Ref.	Plant Area	Min.	Max.

2.4.2. The temperature variation within a cabinet is assumed to be the same as the variation of the room in which it is located. The temperature difference between the room and the cabinet is therefore constant. Calibration data is collected with the equipment at the operating temperature of the cabinet. [Ref.]

2.4.3. At Vermont Yankee, environmentally qualified instrumentation have been evaluated for IR loss in VYC-700, Post-Accident Insulation Resistance Effects on the Accuracy of Selected Environmentally Qualified Instrumentation, where the IR effects were found to be negligible. For the purposes of this calculation, the IR effects on channel accuracy will be assumed to be negligible. [Ref.]

2.4.4. For Custom Technical Specifications, the Technical Specification value is assumed based upon the normal/seismic conditions. There are no harsh environment conditions for this service. [Step 0]

2.4.5. Current calibration practice is to perform a nine point calibration of the Transmitter. Previously calibrations were performed in a single direction using only three cardinal points. This method of calibration did not verify that the linearity, repeatability and hysteresis of the transmitter were within the performance specifications. Therefore, in accordance with section 3.6.2.A of "Vermont Yankee Instrument Uncertainty and Setpoint Design Guide", calibration effect is determined by the relation CE=CT+A. Once the current calibration method has verified transmitter performance the calibration effect may be revised to CE = CT. [Ref.]

2.4.6. The overall Analyzed Drift (DA) term tends to account for Reference Accuracy, M&TE errors, and for normal environmental effects, including temperature (a 20°F variation is assumed in the calibration process), radiation, power supply voltage variations, humidity and barometric pressure. The drift information for XXXX is based on drift calculation VYC-XXXX where DA terms are provided for the instruments. [Ref.]

2.4.7. The effects of radiation are taken for normal conditions only since there is no consideration of radiation effects during HELB and for LOCA, the RPS trip occurs prior to the harsh environment. For normal conditions, it is assumed that the DA term includes the normal radiation effects. [Assumption]

2.4.8. It is assumed that the M&TE components will be limited to those devices, which support the QA requirement that M&TE accuracy is better than or equal to the accuracy of the device being calibrated. Errors associated with M&TE are assumed to be accounted for in the DA term for those devices which are contained in the drift analysis calculations. [Ref.]

2.4.9. The analyzed drift value for the calibration points for these instruments. The following considerations apply in the assumption of this value. [Ref.]
The analyzed drift shows an increasing (decreasing, no) trend. The significance at the 95% level of the slope is greater than 0.05 (***State specific values for point or points of interest***), thus there are no strong time dependent characteristics. The ADR values at XXX% have been used. The current plant setpoint is set at XXXX (XXX% of Calibrated Span) [Ref.]
From review of the drift analysis and the scatter plots, the data is bounded by a normal distribution with no evidence of time dependency. The value provided for 512 days is assumed for the 684 day operating cycle. Since the absolute value of the mean (***State specific value***) does not exceed the maximum value of non-biased mean at a standard deviation of greater than 0.1 (***State specific value***) and 0.5 (***State specific value***), the presence of bias is assumed to be negligible and the DA term can be used without bias correction. [Ref.]

With a calibration frequency of once per cycle, the following equation is used for the DA: [Assumption 2.4.10]

$DA_{Operating\ Cycle} = DA_{512\ Days} = DA_{548\ Days} = DA_{684\ Days}$ ***(No indication of time dependence)***

[Ref.]

$DA_{Operating\ Cycle} = DA_{684\ Days} - ((DA_{512\ Days}{}^{2} * (684/512))^{1/2}$ ***(slight indication of time dependence)***

$DA_{Operating\ Cycle} = DA_{684\ Days} - DA_{512\ Days} * 684/512$ ***(indication of time dependence)***

2.4.10 The calibration interval is assumed to occur once during each operating cycle (18 months + 25% or 22.5 months).

2.4.11 For gauge pressure instruments, static pressure zero (SPZ) and span (SPC) effects do not apply. Overpressure effect (PO) may be neglected if the transmitter is not subjected to more than its maximum calibration design pressure. Any uncertainty due to high pressure is part of the specified accuracy since the purpose of the transmitter is to measure that pressure. No device downstream of the transmitter or primary element is exposed to the process [Ref. "Instrument Uncertainty and Setpoints Design Guide," Vermont Yankee,].

2.4.12 Barometric pressure variation (PB) does not affect electronic components. Only gauge pressure devices are effected by barometric pressure variations [Ref. "Instrument Uncertainty and Setpoints Design Guide," Vermont Yankee,]]. NOTE: However, absolute pressure devices may have an additional M&TE error if the calibration method is affected by changes in barometric pressure.

2.4.13 Accuracy is not considered for digital signals. The only way to change the accuracy of a digital signal is to lose a bit. If the signal is a simple "on-off", then the error is either 0% or 100%, with no intermediate values. If the signal is a computer input coming from an analog-to-digital converter, and given that the A/D converter is operating properly, any computer hardware malfunction will cause the program to halt, leading to a loss of output. This means that the uncertainty of computer displays is the same as the uncertainty of the output from the corresponding analog-to-digital converter combined with any uncertainty introduced by the software [Ref. 4.1]. Note: signal sampling rate, word size (8 bit, 16 bit etc) can affect the precision of the digital signal at the time of interest. These errors (generally small) must be considered when establishing computer point error.

2.4.14 Radiation effects are not applicable to devices receiving less than 104 rads TID over 40 years and vendor information is not needed for such devices. A TID of 104 rads over 40 years corresponds to 470 rads over a 18-month (+25% = 22.5 mo.) calibration interval. Therefore, any dose less than or equal to 1000 rads for a calibration interval less than 45 mo. will also have negligible effect. The dose rate is not significant at these levels [Ref. "Instrument Uncertainty and Setpoints Design Guide," Vermont Yankee,]].

2.4.15 Operator decision points have been rounded conservatively to the next division marking for operators convince. [Ref. 4.1] When choosing an operator decision point, readability (RD) of indicators and recorders may be accounted for by choosing some point which is on a division (mark) more conservative than the limiting operator decision point (LSp). This way an operator can readily determine whether he meets the operator decision point. For general information about what is the uncertainty of a reading, readability is to be included as is done for other effects [Ref. "Instrument Uncertainty and Setpoints Design Guide," Vermont Yankee,].

2.4.16 Drift values derived from plant testing data in accordance with the Drift Analysis Design Guide are assumed to include the following effects for normal conditions:

- Drift (DR)
- Temperature Effect (TE) (Note: Calibration Delta T only)
- Readability (RD)
- M&TE Uncertainty (MTE)
- Barometric Pressure Effect (PB)
- Power Supply Voltage Effect (VE)
- Humidity Effect (HE)
- Radiation Effect (RE)

2.4.17 Values of uncertainty to be applied when evaluating EOP decision points are calculated in accordance with a best estimate combination of temperature, pressure, and radiation dose. This approach is based on the realization that excessive conservatism may lead to faulty decisions with consequences just as severe as those resulting from overly optimistic margin assumptions. The EOP harsh environment assumed for this calculation corresponds to 90% of the pressure, temperature and radiation at 30 minutes into the appropriate limiting Design Basis Accident shown in Attachment B of the VY Environmental Qualification Manual [Ref. "Vermont Yankee Environmental Qualification Program Manual," Rev. 36.].

(NOTE: any unverified assumption (i.e. drift is equal to Reference accuracy) must be independently supported and justified or have reference to a program which will verify the assumption and revise the calculation should the assumption proved incorrect.)

3. INPUT data

Data used to calculate loop uncertainties, process corrections, setpoints, and decision points are tabulated below with the applicable reference or basis and assumptions

3.1 Process and Loop Data

- Presented below are the input values required to calculate the process measurement uncertainty and those parameters such as calibration frequency which are common to all loop components.

Table 5 - Process/Loop Inputs

Basis	Description	Data
Ref.	***Design Information***	
Ref.	Technical Specification Limits	
Ref.	Analytical Limit ITS	
Ref.	Reference Elevation Process Tap Elevation Primary Containment Penetration Elevation	
Ref.	Calibration Interval- CTS	
Ref.	Calibration Interval- ITS	
Ref.	Functional Test Interval-CTS	
Ref.	Functional Test Interval-ITS	

3.2 Environmental Conditions

The following information provides the limiting environmental conditions expected for each loop instrument and the plant spaces traversed by the instrument sensing lines. The loop instruments, excluding the flow elements, are located outside the drywell in Volume 43. The flow elements are located upstream of the inboard MSIV's within the drywell.

Table 6 - Environmental Input Data

Basis	Description	Data

3.3 Primary Element (e_1) Data

Table 7 - Primary Element Input Data

Basis	Description	Data
	Make	
	Part Number	
	Discharge Coefficient	
	Reference Temperature	
	Reference Pressure (P1)	
	Fluid Density at Ref. Temp. & Pressure	
	Rated Accuracy (RA)	
	Throat Diameter ID (d)	
	Pipe Diameter ID (D)	
	Maximum Flow Maximum Pressure	
	Full Meter Flow Full Meter Pressure	
	Rated Flow Rated Pressure	

Example primary element tables for flow elements revise or delete as necessary for specific primary elements.

3.4 Power Supplies Data (e_2)

Table 8 - Power Supply Input Data

Reference	Description	Data
	Make/Model	
	Output supply voltage	
	Combined Source and Load Effect (RA)	
	Temperature Effect (TE)	
	Seismic Effect (Evaluated)4 (SE)	
	Calibration Tolerance (CT)	

Revise or remove as necessary.

3.5 Transmitter (Switch) Data (e_3)

Table 9 - Transmitter (Switch) Input Data

Basis	Description	Data
	Make/Model	
	Calibration span (CS)	
	Upper Range Limit (URL)	
	Calibrated output span	
	Accuracy rating (RA)	
	Power Supply Effect (VE)	
	Deadband (DB)	
	Rated drift (DR)	
	Rated temperature effect	
	Rated seismic effect (SE)	
	Rated static pressure zero effect (SPZ)	
	Rated static pressure span correction (SPC)	
	Rated static pressure span correction uncertainty (SPU)	
	Radiation effect (RE)	
	Calibration tolerance (CT)	
	Analyzed drift (DA) @ 0% Analyzed drift (DA) @ 50% Analyzed drift (DA) @ 100%	

3.6 Trip Unit Data (c_4)

Table 10 - Trip Unit Input Data

Basis	Description	Data
	Make/Model	
	Calibration span (CS)	
	Repeatability Normal Temperature (60-90°F) (RA_t)	
	Repeatability High Temperature (40-104°F) (RA_n)	
	Analog Out Normal Temperature (60-90°F) (RA_t)	
	Analog Out High Temperature (40-104°F) (RA_n)	
	Seismic Effect (SE)	
	Temperature Effect (TE)	
	High Gross Failure Setpoint (For Information Only)	
	Low Gross Failure Setpoint (For Information Only)	
	Current Trip Setpoint	
	Current Calibration Tolerance	
	Calibration Tolerance Recommended (CT)	
	Analyzed Drift (DA)	

Expand sections as necessary for total number of loop devices each loop component should have a table describing attributes.

3.7 Calibration M&TE input data

Table 11 - Calibration M&TE Input Data

Reference	Description	Required Scale/Range	Calculated Accuracy

4. CALCULATION DETAIL

The detailed calculation of the primary element, process measurement uncertainties, module uncertainties and loop uncertainties has been done using Microsoft Excel Version 5.0c (See section 2.2 for verification) and is documented as Attachments xx, xx & xx. For detail of the values presented in the body of this calculation, refer to the attachments listed. [Attachments]

5. RESULTS AND CONCLUSIONS

5.1. Process Measurement Uncertainties (PM - e_0)

5.2. Primary Element Uncertainties (PE - e_1)

5.3. Loop Module Uncertainties

The module uncertainties were calculated in Attachment 4 using Microsoft Excel, the results are listed below. For full details refer to Attachment XX.
[Att., Ref.]

Table 12 - Loop Module Uncertainties

Module Uncertainties	e_{Test} (As Founds)	Normal Random	Nml (+) Bias	Nml (-) Bias	Seismic Random	Seismic (+) Bias	Seismic (-) Bias
(PM) - e_0							
(PE) - e_1							
Power Supply - e_2							
Transmitter/Switch - e_3							
Trip Unit - e_4 Monthly							
Trip Unit- e_4 Quarterly							

5.4. Loop Channel Uncertainties

5.4.1. The channel uncertainties were calculated in Attachment XX using Microsoft Excel, the results are listed below.
For details, refer to Attachment XX. [Att. X, Ref.]

Table 13 - Loop Channel Uncertainties

Channel Uncertainties	Nml (+) Bias %	Nml (+) Bias psid	Nml (-) Bias %	Nml (-) Bias psid	Seismic (+) Bias %	Seismic (+) Bias psid	Seismic (-) Bias %	Seismic (-) Bias psid
Setpoint								

5.5. Setpoint Determinations

Results are presented below for the Limiting Setpoint (LSp), Allowable Value (AV), and the Technical Specifications Limit. Also calculated is the Acceptance Value (ACV) by algebraically adding the as-found tolerances for the loop devices to the existing setpoints. The calculation of this value and the margin from Allowable Value (AV) ensures that the Allowable Value (AV) will not be exceeded during surveillance. All the available margins are shown below. The current setpoint of XXXX will (will not) support the CTS and ITS limits. [Att. 5]

Table 14 - Setpoint Results

Hi Flow Setpoint Values	CTS		ITS	
	PROCESS	OUTPUT	PROCESS	OUTPUT
Analytical Limit (AL)	-	-		
Allowable Value (AV)	-	-		
TLU Testing $(e_{3Test}^2 + e_{4Test}^2)^{1/2}$	-	-		
ACV $(e_{3Test} + e_{4Test})$	-	-		
TLU Seismic				
Technical Specification Limit (TS)				
Limiting Setpoint (LSp)				
Additional Margin LSp to Stpt (M1)				
Current Setpoint			-	-
Proposed ITS Setpoint	-	-		
Margin Setpoint to Normal (M2)				
Normal Operating Value				

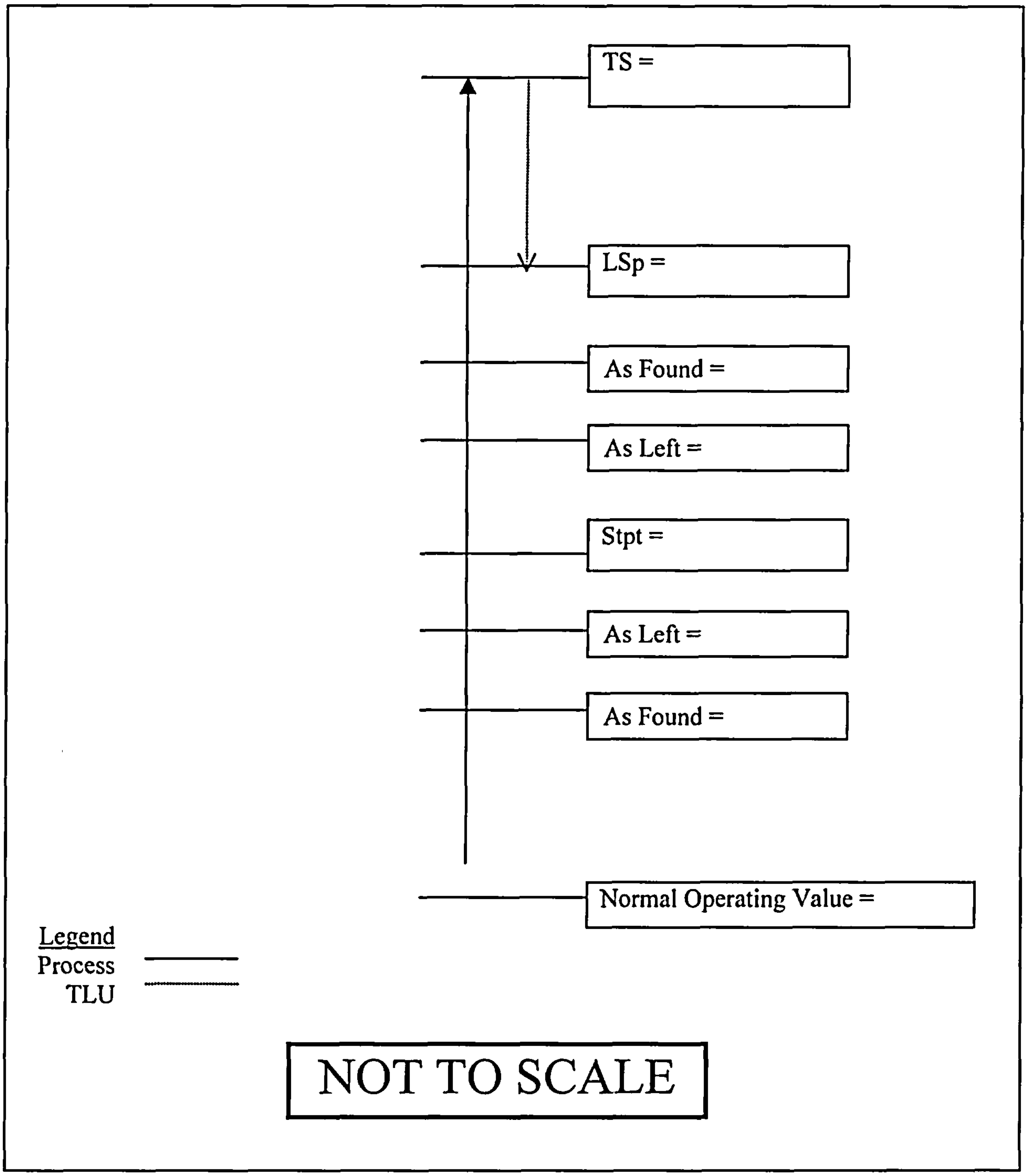
The results of Table 19 are presented graphically in Figures 1 & 2.

(M1) is the margin from the current or ITS proposed setpoint to the Limiting Setpoint (LSp - Stpt).

(M2) is the margin from the current or ITS proposed setpoint to the Normal Operating Value including the TLU Seismic (Stpt - (Norm Op Value + Abs Value TLU Seismic).

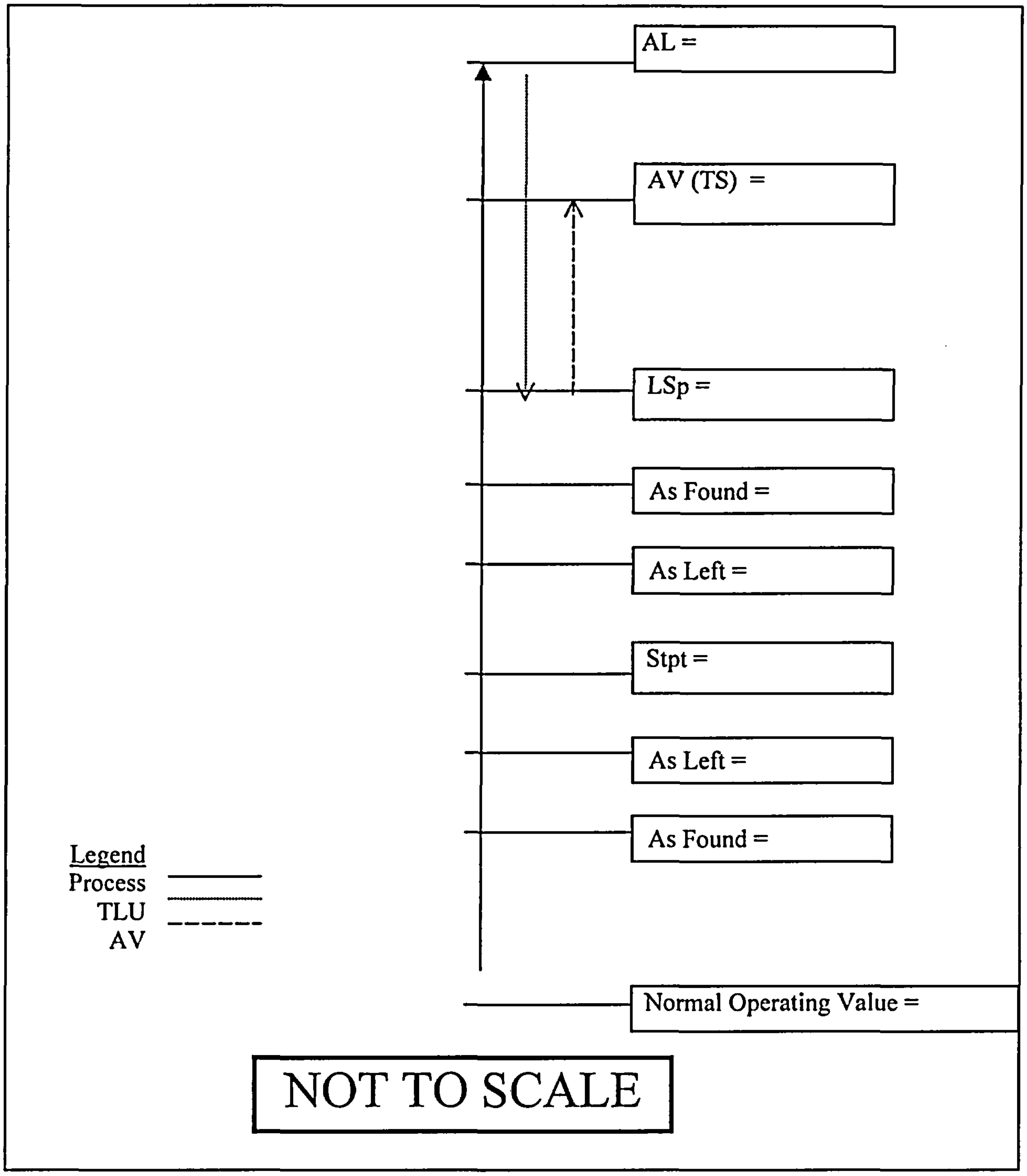
5.6 **Graphical Representation of the CTS Setpoint**

Figure 1 - Setpoint (Current Technical Specifications)



5.7 Graphical Representation of the ITS Setpoint

Figure 2 - Setpoint (Improved Technical Specifications)



5.8 Calibration and Test Results

5.8.1 In order to support and implement the results of this calculation, the loop instruments are to be calibrated according to the following tables:

Table 15 - Calibration Setpoint and Ranges

Description	Value (Process Units)	Value (calibration Units)
Transmitter Input Range		
Transmitter Output Range		
Trip Unit Setpoint (CTS)		
Trip Unit Setpoint (ITS)		

5.8.2 Test As Found (AF) and As Left (AL) Tolerances (CT) are shown below:

Table 16 - Calibration Tolerances

Module AF & AL Tolerances	Tags	As Found	As Left
(Power Supply) - e_2			
Transmitter Process			
Transmitter Electronic			
Trip Unit - Monthly			
Trip Unit - Quarterly			
Slave Trip Unit - Monthly			
Slave Trip Unit - Quarterly			

5.9 Conclusions and Summary of Recommendations

5.10 VYPP-15 Impact Considerations

VYPP-15 Section 2.1 [Ref. XXX] requires that applicable alarm responses, standard and off normal operating procedures, and EOPs be included in the evaluation. This calculation will evaluate the accuracy of loop components, including indicators and recorders where applicable. The accuracy determined by this calculation will be used as an input for generic evaluations for alarm response, operating procedure, off normal operating procedure, and EOP impact. The interdepartmental review will also ensure associated procedures or operator interfaces are considered as an output of this calculation. Therefore, this calculation adequately addresses the impact to the License and Design bases of the plant as well as the impact to plant procedure and operations.

The following has been considered and is either addressed in this analysis or via the Interdepartmental review process:

FSAR changes
Technical Specifications (Custom & Improved Technical Specifications)
Procedures
Technical Programs
Prints
Related Design Basis Calculations (input/output)
Design Basis Documents

Based on the above, all impact considerations of VYPP-15 are addressed.

6. REFERENCES

NOTE: It is necessary to provide selected pages of various references as attachments. References which are included in their entirety as attachments are not listed in the reference section.

6.47 General References

6.48 Procedures

6.49 Calculations and Bases

6.3.1 VYC-1758 Rev. 0 "Measuring and Test Equipment Uncertainty Calculation"

6.4 Drawings

6.5 Vendor Data

VY INDEPENDENT REVIEW CHECK LIST.

CALCULATION BODY REVIEWS

Cover Sheet

Cover sheet is most current WE-103 form.

Revision Level is appropriate and reflected in the calculation signature block and page numbering at top.

Title is appropriate for the calculation.

Data for RMS is populated with as few pointers like "See Section 6" as possible.

Keywords are reasonable for calculation and match keyword thesaurus.

Table of Contents

Page numbers coincide with paragraph numbering
Tables and figures are listed
Attachments are listed with appropriate descriptive titles

Revision Sheet

Revision description is adequate for changes made to existing calculation

Calculation Text

Calculation paragraph numbering is sequential

Spelling errors are minimized (Spell Check Performed ?)

Margins are at least ½" wide, left margin must be ½" to rev. bars

Font size is at least 10 point

Shading is not acceptable

Links to references are made within the body of the calculation (preferably shown near right margin)

Footer shows "Vermont Yankee Design Engineering" and "Page x of xx"

Header shows calculation title (abbreviated if necessary), calculation number and revision level

Tables contain appropriate information with links to references

Footnotes are clear and font size is at least 10 point

Data obtained from spread sheet attachments is accurately transferred and checked

PP 7007 form is accurately completed

Purpose

Objectives meet the requirements of the Design Guide

Setpoint Classification is provided with justification

Equipment Table includes Tag #, System, Safety Class, Engineering Function (NOT THE MPAC DESCRIPTION), Manufacturer, Model, Input, Output and CWD

Instrument loop function is accurate for all conditions

Loop diagram is provided as attachment

Method of Solution

Governing procedures and programs are listed and linked to references

Computer specifications and software is listed

Explanation of spread sheets is included for rounding errors

Discussion of manual verification of spread sheets is included

Explanation of uncertainty terms are provided (either in calc text or attachment)

Inputs and Assumptions

Environmental Data is clear (Location, Min and Max Parameters from EQ Manual or Design Guide)

Assumptions are clear and defendable with references provided

Component tables provide all data required for the calculation with references

Technical Specification values and calibration intervals are listed (Contact J. Lewis as necessary)

Improved Technical Specification calibration interval is listed (Contact J. Lewis as necessary)

Current plant calibration values and intervals are listed (Contact J. Lewis as necessary)

Analytic Limit is supported by reference

Normal Operation values are supported by reference

Calculation Detail
Results & Conclusions

VYPP-15 Criteria section provided

Table provided for:

Device uncertainties provide uncertainty term (e1) and values in %CS and calibration or field units.

Loop uncertainties in %CS and calibration or field units except for non-linear Devices where final values shall be displayed as 1% of point of interest or field units.

MTE uncertainties with acceptable options from MTE inventory is listed (VY MTE Tag numbers should not be listed, just Manuf/Model/Range).

Necessary values to populate the PP 7007 form (AL,AV,LSp,Setpoint,Norm Operation, etc.).

Table for comparison of existing setpoint, CTS setpoint and ITS setpoint.

All values required to populate a setpoint change request should be present within the calculation text.

Required values for SCR:

Present Setpoint
New Setpoint
Device Uncertainties
Loop Uncertainties
Model Number
Manufacturers Accuracy
Technical Specification
LSp
Correction Factors (head, etc.)

Requirements shall be worded strongly enough to convey importance.

Recommendations should provide upside and downside of non-compliance.

Graphical representation of setpoint relationship should be provided for end user being careful not to provide too much as to make confusing.

References

References to current rev. level

All references required are listed

Attachments

Provide number of pages in Attachment

LOOP DIAGRAM

Preferred as Attachment 1

Shown in sufficient detail to understand function of loop

ERFIS DATA TRENDS

A good visual tool is to provide trends from ERFIS data for applicable parameters

CALCULATION ATTACHMENT SPREADSHEETS

Uncertainty terms are defined - Pressure Transmitter (PT) = e1
Equations are shown and all terms defined

Bias terms are applied appropriately

Manual verification has been performed and indicated as such

Values are carried forward as necessary to provide for easy reviews

Significant digits displayed are reproducible with hand calculator - Experience with Excel requires 4.

UNDER NO CIRCUMSTANCES WILL MATH ERRORS BE TOLERATED!!!!!! - These are accuracy calculations.

Final values shall be displayed in %CS and calibration or field units except for non-linear devices
Where final values shall be displayed as % of point of interest or field units.

Assumptions within spreadsheets are listed in calculation Assumptions Section and referenced back.

REFERENCE ATTACHMENTS

Attachments should include references not easily retrievable (memos, telecons, vendor data, etc.)
Copies should be the best available for reproduction.

Attachments are numbered VYC –XXXX Attachment X Page X of XX and title, or provided stamp is used.

ATTACHMENT C: **Process Corrections and Measurement Uncertainty**

Discussion of corrections to limits or setpoints involves three locations. The first is the location where the process variable must be controlled. In some cases, such as those where flow is the significant process variable, the process variable is the same for a wide range of locations. In other cases, the process variable may vary continuously, but be of direct interest at only one point; for example, at the suction of a pump to insure minimum pressure to prevent cavitation. The second important location is the point of measurement. This is the location where the significant process variable is sensed. In the case of a flow variable, it is where the flow rate may be converted to a pressure difference. In the case of pressure measurement, it is the location of the taps to the process. The third important location is the instrument location. Differences between any of these three can cause differences in where a setpoint should be set.

Differences between the point of concern and the point of measurement and represent a change in the value of the limit or zero point of the measured variable. That is the process limit at the point of concern is translated to the point of measurement, and any appropriate adjustment in its value is made during the translation. If there are variations in the adjustment due to changes in process conditions, the most common or usable adjustment is used, and the variations around that adjustment are considered as process uncertainties.

Differences between the point of measurement and the instrument location generally will cause an adjustment to the final setpoint. This can either be by means of a change in the value of the setpoint or by changing the zero point of the instrument scale so the adjustment is considered but is calibrated out. The most common example of this is a head correction to account for pressure differences between the point of measurement and the location of the instrument. Elevation differences and density of the fluid cause the pressure differences. The most common or usable pressure difference is used as the head correction itself. Variations in the setpoint adjustment can occur if there are variations in conditions in the instrument tubing from the point of measurement to the instrument location. For example, environmental temperature around the instrument tubing can change which will cause a change in the density of the fluid in the tubing. The variation in density will cause a variation in the head correction that should be made.

In the case of switches connected directly to the process, to compensate for the head correction itself or for uncertainties in that correction, the setpoint will have to be shifted.

1. STATIC PRESSURE EFFECTS (SP_C)

1.1 Static Pressure Span Correction (SPC)

Exposure of an instrument to process static pressure may affect its span. Generally, this effect is a bias, directly dependent on pressure. This effect can be accounted for by calibrating the instrument at the operating pressure or by using a correction factor to compensate the calibration.

If the static pressure is not calibrated out, or if significant operation occurs at a pressure different than that for which it was calibrated, the static pressure effect should be included.

An example of this is where a transmitter provides input to both a trip unit and an indicator. The indicator is used during normal operation, and therefore, the pressure used for correction is the normal operations pressure. However, the switch is required during an accident condition that has a different pressure (higher or lower). There is a bias error caused by the difference between the calibration pressure (normal operations) and the accident pressure. This error should be considered in the setpoint calculation.

The static pressure span effect has both random and bias parts. The bias portion can be calibrated out by following the vendor instructions. There is an uncertainty of the bias term given by the random correction error term. If the adjustment is not made to the instrument, then the bias error should be used in the uncertainty analysis. Note that the sign of the correction is opposite that of the error that results if the correction is not made.

For Rosemount transmitters (models 1151, 1152, 1153), static pressure span correction is calculated as follows:

$$-SP_C = SPX_C \left(\frac{p_{op}}{1000} \right)$$

where,

$-SP_C$	=	static pressure correction in % of input differential pressure (p),
SPX_C	=	vendor's static pressure expression in % of input p per 1000 psi
p_{op}	=	operating static pressure

$$mA_{min,cal} = mA_{min} + \left(\frac{-SP_C\, dp_{min}}{dp_{span}} \right) mA_{span}$$

$$mA_{max,cal} = mA_{max} + \left(\frac{-SP_C\, dp_{max}}{dp_{span}} \right) mA_{span}$$

where,

$mA_{min,\,cal}$	=	corrected output mA at instrument zero (minimum output)
mA_{min}	=	nominal output mA at instrument zero (minimum output)
$mA_{max,\,cal}$	=	corrected output mA at full scale (minimum output)
mA_{max}	=	nominal output mA at full scale (minimum output)
dp_{min}	=	differential pressure at instrument zero (minimum input)
dp_{max}	=	differential pressure at instrument full scale (maximum input)

NOTE: Liquid level measurements with Rosemount transmitters are typically designed so that the reference leg is connected to the low (L) side of the transmitter. As used in the preceding formula, minimum input is then at a negative pressure, zero (pressure) is elevated, and the output (mA) increases with increasing level.

Example

A reactor level transmitter, Rosemount 1152, range code 4, has an input range of -112.8 inWC to -42.3 inWC (70.5 inWC span), for a nominal 4 - 20 mA output (16 mA span). The maximum static pressure is 1068 psia:

SPX_C = +0.87% input p per 1000 psi (from vendor manual)
p_{op} = 1068 psia

$$-SP_C = SPX_C\left(\frac{p_{op}}{1000}\right) = 0.87\left(\frac{1068}{1000}\right) = 0.929\%$$

$$mA_{min,cal} = mA_{min} + \left(\frac{-SP_C\, dp_{min}}{dp_{span}}\right) mA_{span} = 4 + \left(\frac{0.929\% \times -112.8}{70.5}\right) x16 = 3.762\ mA$$

$$mA_{max,cal} = mA_{max} + \left(\frac{-SP_C\, dp_{max}}{dp_{span}}\right) mA_{span} = 20 + \left(\frac{0.929\% \times -42.3}{70.5}\right) x16 = 19.911\ mA$$

If the correction is not applied to the calibration, then the resulting error is:

$$SP_C(zero) = -\left(\frac{3.762 - 4}{16}\right) * 100 = 1.49\%\ CS$$

$$SP_C(span) = -\left(\frac{19.911 - 20}{16}\right) * 100 = 0.56\%\ CS$$

Note: 1) VY does not normally correct for static pressure during the calibration process. 2) Use care when determining the actual operating pressure range for the specific application, it could be non-conservative to include the static pressure correction error if critical operations are at low-pressure conditions.

1.2 Static Pressure Span Correction Uncertainty (SP_U)

When a correction is made to an instrument's calibration by using a vendor supplied expression, there is an additional uncertainty due to the uncertainty of the vendor expression used to correct for static pressure. This is, in effect, the random variation around the bias, which occur during testing to determine the vendor correction expression. If the instrument is calibrated at the pressure at which it must later operate, there is no need to include this uncertainty. In that case, the instrument has been adjusted for that particular pressure in that particular installation and the vendor expression was not used. VY typically does not calibrate out the static pressure span effect.

1.3 Static Pressure Zero Effect (SP_Z)

Static pressure zero effect is the shift of the zero point of the calibrated scale due to operation at a process pressure different than the pressure at which the instrument was calibrated. The effect is generally not predictable between instruments so an expression cannot be used to correct for the difference in pressures. However, for a particular instrument the effect can be eliminated by calibrating at the desired operating pressure and adjusting the zero. A correction factor may also be shop determined, as defined in the Rosemount manuals, and applied to the field calibration. VY typically does not calibrate out the static pressure span effect.

1.4 Overpressure Effect (SP_O)

Over pressure effects should be considered when an instrument is operated outside of its normal operating limit. The normal operating limit is not the same as the design limit. Example: a transmitter may have an operating limit of 2000 psi, but its design limit may be 4500 psi. The effects above 2000 psi must be considered. For differential pressure instruments, there may be two operating limits, one for high static line (common mode) pressure and another for differential pressures. For Rosemount transmitters the overpressure rating applies to any differential pressure above the Upper Range Limit (URL).

2. LINE PRESSURE LOSS EFFECTS

2.1 Adjustment to Process Limit

The flow of liquids and gases through piping causes a drop in pressure from Point A to Point B (see **Figure 1**) due to fluid friction. Many factors are involved, including length of piping, diameter of piping, fluid viscosity, fluid velocity, etc. If, for setpoint calculation purposes, the setpoint is based on pressure at a point in the system that is different from the point of measurement, the pressure difference effect between those points must be considered.

This is most effectively done by transferring the limit from the point of concern to the point of measurement. In **Figure 1** Point A is the point of concern and Point B is the point of measurement.

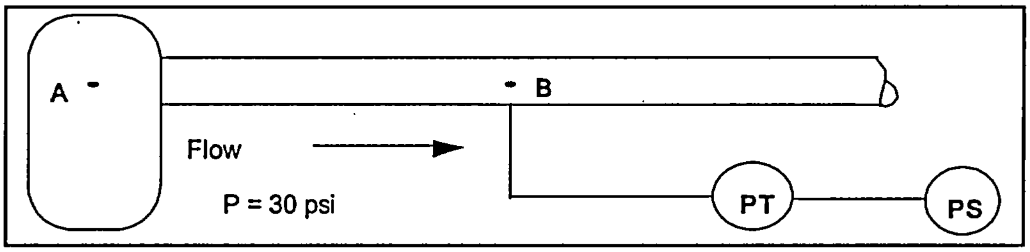


Figure 1: Pressure Drop

For this example, protective action must be taken before the pressure at Point A exceeds the process limit (PL) of 1500 psig. Therefore, the pressure switch setpoint must be below the process limit by at least the total loop uncertainty; in this example assumed to be 10 psi. The setpoint must also account for the pressure loss of 30 psi between Points A and B. For this example no other adjustments, such as those due to elevation differences in the instrument tubing, are considered significant.

The pressure drop between Points A and B are accounted for by transferring the limit at the point of concern to the point of measurement and adding the appropriate pressure change.

$$PL_{meas} = PL_{concern} + \Delta P = 1500 + (-30) = 1470\,\text{psig}$$

The channel equipment errors are then subtracted from the PL at the point of measurement.

If the change in pressure had not been considered, the setpoint would have been 1490 psig (= 1500 -10). With a setpoint of 1490 psig at Point B, the pressure at Point A when the switch trips at its nominal value would be 1520 psig. This exceeds the process limit and is a non-conservative result. The pressure change must be considered to obtain a setpoint that properly protects the process limit.

In some cases, the point of measurement is upstream from the point of concern. For example, a switch is upstream of a pump that is intended to protect the pump from low suction pressure. The pressure rise from point of concern (suction) to the point of measurement (P > 0) must also be added to the limit at the point of concern to prevent a non-conservative setpoint. In this case, the change was a pressure rise rather than a drop, but the process decreased to the limit rather than increased. The result was the same in that the effect of the pressure change in the process piping must be considered to properly protect the process limit.

There are cases where neglecting the pressure change results in an overly conservative rather than non-conservative setpoint, and may interfere with normal plant operations.

Note that the line losses are bias terms. The effect must be added or subtracted from the process limit, depending on the particular circumstances.

2.2 Uncertainty Due to Line Pressure Loss Effects

In Section 2.1, the pressure drop was assumed to be 30 psi. This was due to frictional losses between Points A and B. Frictional losses are very dependent upon flow rate, and somewhat dependent upon the fluid density. The general relation between density, flow rate, and pressure drop can be expressed as:

$$\Delta P = \rho K Q^2$$

The relative change in the pressure drop can be approximated from the relation:

$$\frac{\Delta P_A - \Delta P_B}{\Delta P_B} = \frac{\rho_A Q_A^2 - \rho_B Q_B^2}{\rho_B Q_B^2} = \frac{\rho_A Q_A^2}{\rho_B Q_B^2} - \frac{\rho_B Q_B^2}{\rho_B Q_B^2} = \frac{\rho_A Q_A^2}{\rho_B Q_B^2} - 1$$

If the 30 psi pressure drop was determined for a temperature of 100°F (= 61.996 lbm/ft^3) and 10,000 gpm, the relative pressure drop for 300°F (= 57.307 lbm/ft^3) and 8,000 gpm is:

$$\frac{\Delta P_A - \Delta P_B}{\Delta P_B} = \frac{57.307(8000)^2}{61.996(10000)^2} - 1 = 0.5921 - 1 = -40.8\%$$

$$30 \text{ psi} - (40.8\% * 30 \text{ psi}) = 17.76 \text{ psi}$$

The relative change is 40.8% and the new pressure drop is 17.76 psi. This change represents a possible uncertainty in the process correction and should be included as part of the process measurement uncertainty, PM. In determining the pressure variation for a given system, the flow equations for that system should be used rather than the approximations used in this example. Generally, Darcy's formula can be used to determine head loss in a piping system.

$$DP = \frac{\rho * f * L * v^2}{144 * D * 2 * g}$$

Where:

DP_n	= pressure change in psi
ρ	= Fluid Density
f	= Friction factor
v_n	= Mean velocity of flow, in feet per second
L	= Length of Pipe in feet
D	= Internal Diameter of pipe, in feet
g	= Acceleration of gravity.

Once the initial head loss has been determined, most of the equation can be assumed to be unchanged for conditional changes. The friction factor which is based on the Reynolds number for laminar flow and the Reynolds number and relative pipe roughness for turbulent flow, the density and the mean velocity of flow can be assumed as the only variables for changing flow conditions or evaluating measurement errors.

3. HEAD CORRECTION

Head correction is an adjustment made to the setpoint or transmitter zero to account for elevation differences between the instrument location and the location where the process is sensed, the point of measurement. This is most commonly of concern for pressure or level measurements. The adjustment is to either change the setpoint by amount of the head correction or to calibrate out the head correction so the zero point of the scale has been shifted to correspond to zero at the point of measurement. When the adjustment is determined, an elevation difference and density are used. The density may vary during normal operations or during an accident, most commonly due to temperature variations in the environment around the instrument tubing. The variation in density causes an uncertainty in the head correction. Variation in elevation could occur in some cases due to expansion of component due to heating. For most cases, this is considered to be negligible.

Since the changes are predictable, they are biases. The uncertainty, however, can have a range of errors from a negative bias to a positive bias, depending upon the environmental conditions. For example, a pressure transmitter could have been calibrated for a temperature in the instrument tubing of 150°F. However, operation is such that the temperature can vary from 100°F to 250°F. When the temperature is 100°F, the error will be in one direction; when the temperature is 250°F, the error is in the opposite direction. These errors are not random since the direction and magnitude of the error is readily predictable from a readily measured quantity. This error is commonly expressed as percent of ideal output, not %CS. VY head corrections can normally be found in calculation VYC-1597 "Head Correction".

There are two general categories of head correction:

1. Those due simply to a difference between point of measurement and the location of the instrument. An example of this is discussed in Section 2.1, and

2. Those due to elevation and density differences which are a part of the measurement process. An example of this is discussed in Section 3.

3.1 Effect of Elevation Difference on Pressure Measurement

The system shown in **Figure 2** is similar to the system shown in **Figure 1** but now includes an elevation difference between the point of measurement and the instrument location. The pressure is sensed at Point B but the instrument is at Point C, which is an elevation Z below Point B. The switch associated with the instrument at Point C must trip before the process limit is exceeded. The process limit at Point B is 1470 psig and the TLU is 10 psi. Without considering the elevation difference, the setpoint would be 1460 psig. Both the process piping and the instrument tubing are filled with a fluid. The density of the fluid and the elevation difference together cause a pressure difference, which for this example will be assumed as 20 psi. Because the instrument is below the point of measurement, the pressure will be higher at the instrument than at the point of measurement. The proper setpoint when the elevation difference is considered is 1480 psig. If the setpoint is set at 1460 psig, the pressure at Point B when the switch trips at its nominal value would be 1440 psig. This is conservative, but may affect normal operations.

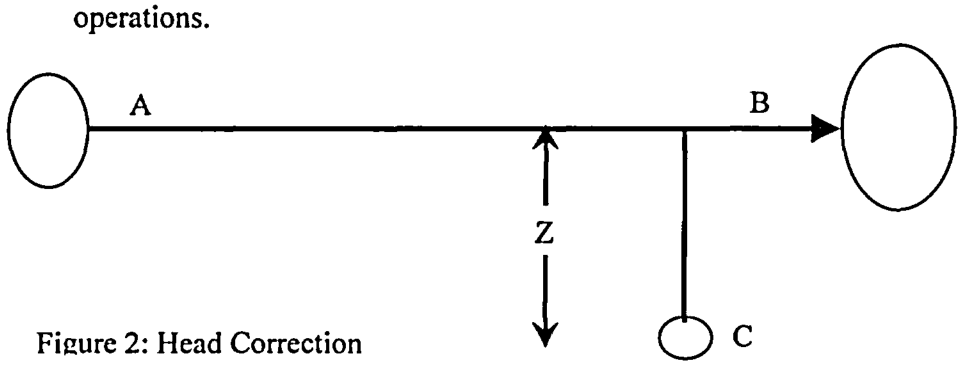


Figure 2: Head Correction

If the instrument had been above the point of measurement then ignoring the elevation difference would have been non-conservative. If the fluid was a liquid, then there may have been larger problems. The instrument could have been installed incorrectly since the device should normally be mounted above gas lines and below liquid lines.

In either case, the numerical value of the setpoint need not necessarily be changed; the zero of the scale on the instrument could be increased so that the 20 psi pressure difference is calibrated out.

The head correction would be found using the basic relation

$$P_C = P_B + \rho Z g$$

where:

P_C = pressure at instrument (location C)
P_B = pressure at process tap (location B)
ρ = fluid density in sense line
Z = elevation change from C to B
g = acceleration of gravity

This can be generalized to:

$$hC = [(\rho_1 * g_1 * Z_1) + (\rho_2 * g_2 * Z_2) + (\rho_n * g_n * Z_n)$$

where for several sections of Z, either density (ρ) or acceleration (g) may be changing over sections of elevation (Z). In the usual case, g is considered a constant equal to 1, and the density is taken to be constant over segments of the line length.

$$hC = [(\rho_1 * Z_1) + (\rho_2 * Z_2) + (\rho_n * Z_n)$$

An increase in elevation from the instrument location to the process connection is a positive value and results in a positive head correction.

3.2 Head Correction Uncertainty (hU)

Head correction uncertainty is considered as a part of the overall process measurement uncertainty (PM) included in the total loop uncertainty. Because it is a common type of uncertainty, it has a more descriptive symbol, hU. The uncertainty of the head correction is the difference between the head correction which should be applied due to actual condition, hC_A, and the head correction which was applied at calibration conditions, hC_C. It is caused by the variation in density from the calibration conditions. The expression for head correction uncertainty as a fraction of the head correction is:

$$hU = \frac{hC_A - hC_C}{hC_C} = \frac{hC_A}{hC_C} - \frac{hC_C}{hC_C} = \frac{hC_A}{hC_C} - 1$$

If the density does not vary with elevation (i.e., all sections of tubing have the same density), the expression can be simplified to:

$$hU = \frac{\rho_A}{\rho_C} - 1 = \frac{1/V_A}{1/V_C} - 1 = \frac{V_C}{V_A} - 1$$

where:

V_A = specific volume for actual conditions
V_C = specific volume for nominal conditions for calibration.

4. LEVEL MEASUREMENT UNCERTAINTY

4.1 Basic Equations

When differential pressure transmitters are used to measure liquid level in vessels, changes in density of the reference leg fluid, or vessel fluid, or both, can cause uncertainties if the level measurement system is not automatically compensated for density changes. This occurs because differential pressure transmitters respond to hydrostatic pressures (head), which are directly proportional to the height of the liquid column multiplied by the liquid density. Therefore, measurement errors may be caused by the liquid density changes, as a function of temperature and pressure, while the actual level in the vessel or reference leg remains constant. This changes the pressure delivered to the differential pressure transmitters, which makes the indicated level appear different from the actual level since the transmitter by itself cannot distinguish the difference in pressure caused by the density changes

In level-measuring applications at Vermont Yankee, a variety of specific situations are encountered. It is not practical to cover the details of each; however, the situation described below encompasses the basic theory and method that may be applied to specific systems.

The level measuring system is calibrated for some assumed operating conditions (e.g., normal or accident). The differential pressure transmitter or switch may be in a distinctly different environment from the vessel. This is the case for reactor vessel level measurement. No automatic vessel or reference leg density compensation is provided.

The usual assumption is that the top of the vessel and the top of the reference leg are exposed to the same pressure. Often the reference leg fluid is a compressed liquid, assuming a saturated liquid may or may not introduce negligible error. However, the equations presented below do not require that the reference leg be filled with liquid, only that it remain either filled or empty at all temperatures.

Figure 3 shows a closed vessel containing a liquid with a gas (steam) blanket and a reference leg for level measurement. The transmitter produces a signal proportional to the pressure difference.

There are two parts to adjusting for temperature differences for level measurement. The first part is determination of the differential pressure that should exist for certain levels for the base conditions. This is similar to the head correction (hC) calculation. The second part is the determination of the uncertainty in the level due to variations in temperature and operating pressure. This is simply a variation of the head correction calculation using different density conditions.

The differential pressure transmitter is calibrated to read level correctly at the assumed base conditions. As long as the actual vessel and reference leg conditions remain the same as the base conditions, the indicated level is a linear function of the measured differential pressure and no vessel/reference leg density effects are created. However, when the actual conditions differ from the base conditions, a process level measurement uncertainty (PM) is created.

4.2 Reactor Vessel Level Measurement

Figure 3 is based upon an illustration from the present error analysis for Vermont Yankee reactor vessel level [VYC-332]. Vessel conditions are at saturation, the reference leg is normally at a lower temperature, but the same pressure, and therefore is compressed.

Explanation of Symbols:

h_S - height of steam to condensate pot water level (Z_u-Z)
h_L - height of liquid in vessel, above lower tap (Z-Z_Z)
h_{RD} - height change of reference leg in drywell
h_{VD} - height change of variable leg in drywell
h_{RR} - height change of reference leg in reactor building
h_{VR} - height change of variable leg in reactor building
Z - elevation of water level above reference point
Z_Z - elevation of 0% indicated level above reference point

Z_F - elevation of 100% indicated level above reference point
Z_U - elevation of condensate pot water above reference point
Z_L - elevation of lower tap above reference point
ρ_S - steam density in the vessel ($= 1/v_S$)
ρ_D - water density in drywell portion of either leg ($= 1/v_D$)
ρ_L - water density in the vessel ($= 1/v_L$)
ρ_R - water density in the reactor building for either leg ($= 1/v_R$)
P_A - pressure at point A.
P_B - pressure at point B.
P_R - pressure for the reference leg of the transmitter
P_V - pressure for the variable leg of the transmitter.

From geometry of the vessel and reference leg and basic equations relating elevation, density, and pressure, the following equations are valid.

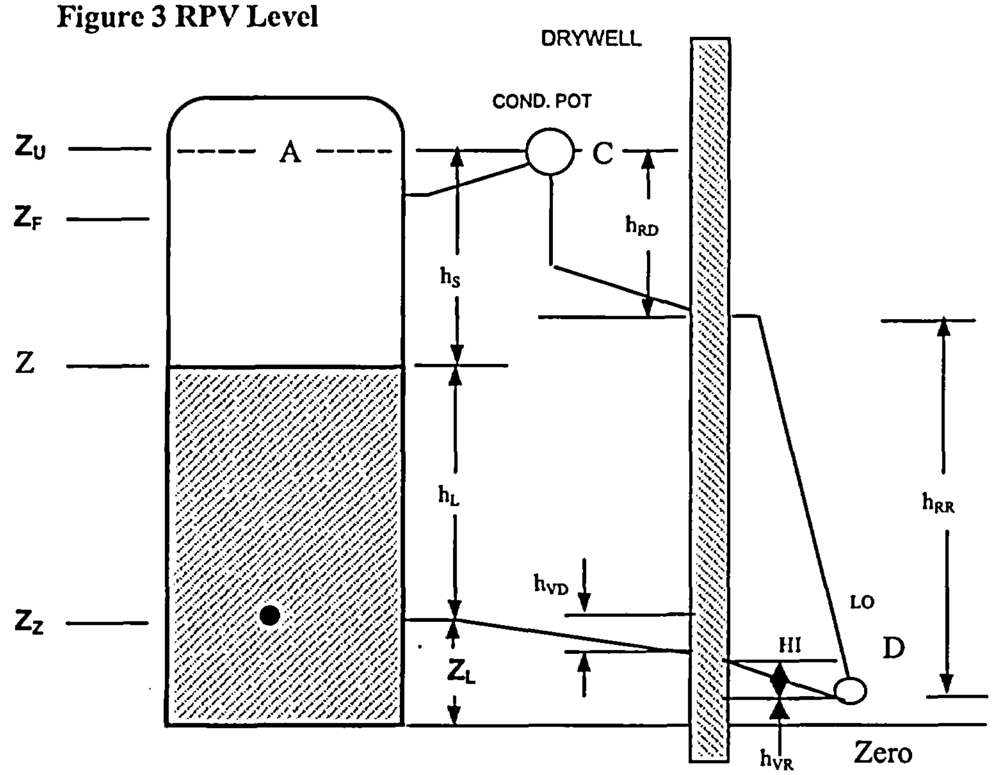
$$h_{RR} + h_{RD} = h_{VR} + h_{VD} + h_L + h_S$$

$$P_B = P_A + g\,(h_S\,\rho_S + h_L\,\rho_L)$$

$$P_R = P_A + g(h_{RR}\,\rho_R + h_{RD}\,\rho_D)$$

$$P_V = P_B + g(h_{VR}\,\rho_R + h_{VD}\,\rho_D)$$

Figure 3 RPV Level



To determine differential pressure the "LO" pressure side of the transmitter is subtracted from the "HI" pressure side of the transmitter. If the reference leg is attached to the "LO" side of the transmitter, then the differential pressure (P) is as follows:

$$\Delta P = P_V - P_R = g\{(h_S\rho_S + h_L\rho_L + h_{VD}\rho_D + h_{VR}\rho_R) - (h_{RD}\rho_D + h_R\rho_R)\}$$

Note: The reference leg is actually at a constant value equivalent to the maximum value of the variable leg. This means that as level decreases the differential pressure becomes more negative. For this application level equal to the condensate pot would result in a zero differential pressure.

If the reference leg is connected to the "HI" side of the transmitter or switch, then the sign of the pressure difference is reversed. However, the process measurement uncertainty calculated below is of the same sign since it involves a ratio in which the direction of the pressure difference cancel.

The ΔP which should exist for some indicated level (Z) is found by substituting $Z\text{-}Z_Z$ for h_L and $Z_U\text{-}Z$ for h_S.

$$\Delta P = g\{(Z_U - Z)\rho_S + (Z - Z_Z)\rho_L + h_{VD}\rho_D + h_{VR}\rho_R) - (h_{RD}\rho_D + h_{RR}\rho_R)\}$$

Note that at the elevation and latitude of Vermont Yankee, g may be set to one (1).

Setting Z equal to Z_L, solving for P then setting Z equal to Z_U, solving for P, determines the pressure differentials at which the loop should be calibrated. The value for the densities, ρ_{LO}, ρ_{DO}, ρ_{RO}, and ρ_{SO}, should be the appropriate values for the calibration conditions.

Once the P's associated with the limits of calibration and normal level conditions have been determined, the equations may be revised for differences in elevations, densities, or gravity to determine the associated PM error.

These equations are valid for any consistent set of units; however, the Steam Tables provide specific volume in units of ft^3 per lbm, so if elevations are expressed in feet, resulting pressures will be in lb. per ft^2, which may be divided by 144 to find psi. If the result is desired in inches of water column (inWC), then from Crane's Flow of Fluids: 1 psi = 27.7276 inWC and:

$$1\frac{lb}{ft^2} = \frac{27.7276}{144} = 0.192553 \text{ inWC}$$

Example:

The Fuel Zone level measuring loops at Vermont Yankee have the following conditions (from VYC-332):

Base Conditions:

(1) Vessel Pressure = 1020 psia (saturated), $v_{S0} = 0.43620$, $_{S0} = 2.29253$ lb/ft^3, $v_{L0} =$ 0.02166, $\rho_{L0} = 46.16166$ lb/ft^3

(2) Drywell temperature = 160 °F, $v_{D0} = 0.016343$, $\rho_{D0} = 61.18828$ lb/ft^3

(3) Reactor Building temperature = 100 °F, $v_{R0} = 0.016080$, $\rho_{R0} = 62.18905$ lb/ft^3

(4) $Z_Z = 151.5$ inches above vessel bottom = 12.625 ft.

(5) $Z = 400$ inches = 33.333 ft.

(6) $Z_U = 545.75$ inches = 45.479 ft.

(7) $Z_L = 129.0$ inches = 10.750 ft.

(8) Vessel lower tap @ 129 in., condensate pot @ 545.75 in.

(9) Drywell penetration: reference @ 373 in., variable @ 97 in.

(10) $\Delta h_D = h_{RD} - h_{VD} = (545.75 - 373) - (129 - 97) = 140.75$ in. = 11.729 ft.

(11) $\Delta h_R = h_{RR} - h_{VR} = 373 - 97 = 276$ in. = 23.0 ft. (both legs converge @ 97 in.)

Actual Conditions:

(12) Vessel pressure =1000 psia (saturated), $v_S = 0.44596$, $\rho_S = 2.24235$ lb/ft^3, $vL = 0.021591$, $\rho_L = 46.31559$ lb/ft^3

(13) Drywell temperature = 180 °F, $v_D = 0.016457$, $\rho_D = 60.76442$ lb/ft^3

(14) Reactor Building temperature = 120 °F, $v_R = 0.016155$, $\rho_{R0} = 61.90034$ lb/ft^3

To determine the differential pressure for the zero and full span condition, during calibration each segment of the liquid must be evaluated. For the zero span condition the elevations and conditions are as follows:

For the variable leg (inside the vessel and the variable leg connection):

From the condensing pot to the normal level 545.75 - 400 inches (12.1458 feet) at reactor steam density (2.2925 lbs/ft^3).

From the normal level to the instrument zero 400-151.5 inches (20.7083 feet) at reactor steam density (2.2925 lbs/ft^3).

From the instrument zero to the lower tap elevation 151.5-129 inches (1.875 feet) at reactor liquid density (46.1617 lbs/ft^3).

From the lower tap to the drywell penetration 129-97 inches (2.667 feet) at drywell liquid density (61.1883 lbs/ft^3).

From the drywell penetration to the instrument the variable and reference lines run parallel therefore, no calculation is required.

For the reference leg:

From the Condensing pot to the drywell penetration 545.75-373 inches (14.396 feet) at drywell liquid density (61.1883 lbs/ft^3).

From the drywell penetration to parallel with the variable leg 373-97 inches (23 feet) at reactor building density (62.1891 lbs/ft^3).

For the full span condition the elevations and conditions are as follows:

For the variable leg (inside the vessel and the variable leg connection):

From the condensing pot to the normal level 545.75 - 400 inches (12.1458 feet) at reactor liquid density (46.1617 lbs/ft^3).

From the normal level to the instrument zero 400-151.5 inches (20.7083 feet) at reactor liquid density (46.1617 lbs/ft^3).

From the instrument zero to the lower tap elevation 151.5-129 inches (1.875 feet) at reactor liquid density (46.1617 lbs/ft^3).

From the lower tap to the drywell penetration 129-97 inches (2.667 feet) at drywell liquid density (61.1883 lbs/ft^3).

From the drywell penetration to the instrument the variable and reference lines run parallel therefore, no calculation is required.

For the reference leg:

From the Condensing pot to the drywell penetration 545.75-373 inches (14.396 feet) at drywell liquid density (61.1883 lbs/ft^3).

From the drywell penetration to parallel with the variable leg 373-97 inches (23 feet) at reactor building density (62.1891 lbs/ft^3).

ΔP_{ZO} = (12.14583*2.2925) + (20.7083*2.2925) + (1.875*461617) + (2.667*61.18828)-(14.39583*61.1883)-(23.0*62.1891) =
-1986.145 *lb* / ft^2 =
[-1986.145 lb/ft^2]/[144 in/ft^2] =
-13.793 psi *27.728 inwc/psi
-382.44 in WC

ΔP_{SO} = (12.14583*46.1617) + (20.7083*46.1617) + (1.875*461617) + (2.667*61.18828)-(14.39583*61.1883)-(23.0*62.1891) =
- 544.86 *lb* / ft^2 =
[-544.86 lb/ft^2]/[144 in/ft^2] =
-3.784 psi *27.728 inwc/psi
-104.916 in WC

Then the zero and span shift are calculated using the same equations and replacing the applicable densities. These equations may be used to determine the differential pressure at any point in the span simply by changing the desired level and correcting the density for the desired conditions. Normally the fluid above the desired level will be steam and the fluid below the desired level will be liquid. The following example calculates the differential pressure for the 400 inch level:

ΔP_{Z400} = (12.14583*2.2925) + (20.7083*46.1617) + (1.875*461617) + (2.667*61.18828)-(14.39583*61.1883)-(23.0*62.1891) =
-1077.689 *lb* / ft^2 =
[-1077.689 lb/ft^2]/[144 in/ft^2] =
-7.484 psi *27.728 inwc/psi
-207.515 in WC

5.0 FLOW MEASUREMENT PROCESS UNCERTAINTIES

In most flow applications at Vermont Yankee, process liquid and gas flow is measured using orifice plates, venturis, or elbow taps along with differential pressure transmitters. The measurement of concern is either the volumetric flow rate or the mass flow rate. The flow element converts flow rate to differential pressure. For most uncertainty calculations, the flow rate is specified and the uncertainty is associated with the differential pressure measurement. This is the condition when a process limit is specified. The general relation is:

$$\Delta P_x = K \rho_x Q_x^2$$

Where:

x can be A for actual or C for calibration or design conditions

ΔP	=	differential pressure at flow element taps
ρ	=	nominal (upstream) fluid density
K	=	constant depending on system of units and element type.
Q	=	volumetric flow rate

As shown above, the density of the fluid has a direct influence on the differential pressure that the pressure transmitter sees. A flow orifice is design to operate at a specified temperature. At these conditions, it provides its best accuracy. Operations at different temperatures affect the density of the fluid and therefore the differential pressure across the orifice. The remainder of the instrument loop will interpret this changed ΔP as a change in flow rate, Q, rather than a change in density. This is, therefore, a bias error for the instrument loop.

The actual, or indicated, pressure differential, DP_A, is that caused by the actual density, r_A, and the actual flow rate, Q_A. The calibration pressure differential, DPC, is caused by operation at the calibration density, r_C, and at the calibration flow rate, Q_C, which is held equal to the actual flow rate, Q_A, since the flow rate is specified as the process limit or some other point of interest. The error in the pressure difference can be expressed as a ratio of the difference between indicated (due to actual density) and as calibrated for a given flow rate. The relation between density, ρ, and specific volume, v, ($\rho = 1/v$) is also used.

$$\frac{\Delta P_A - \Delta P_C}{\Delta P_C} = \frac{\rho_A}{\rho_C} - 1 = \frac{v_C}{v_A} - 1$$

Because the temperature can increase above and decrease below the calibration temperature, there are both positive and negative biases possible. This error is expressed as a fraction of ideal output, not of calibrated span, in which the actual (indicated) DP_A differs from the expected DP_C for a given flow rate.

Example

As an example of the use of the equation above, 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 inWC at 100 gpm flow at 120°F and 250 psia. Assume further that under accident conditions the temperature rises to 300 °F with saturated conditions at an actual flow of 50 gpm. It is desired to find the process measurement uncertainty, PM, for this change in process conditions, and the indicated flow.

The first step is to determine the relationship between Q and DP. From the basic relation:

$$\Delta P_X = K_\rho x Q_X^2$$

$$K_\rho = \frac{\Delta P_C}{Q_C^2}$$

$$= \frac{1}{100}$$

At an accident flow rate of 50 gpm the design differential pressure would be:

$$\Delta P = \frac{1}{100}(50)^2 = 25\,\text{inWC}$$

However, the density has changed. Using thermodynamic steam tables:

$v_C = 0.01619\ ft^3/lbm$ @ 120 °F and 250 psia.
$v_A = 0.01745\ ft^3/lbm$ @ 300 °F saturated

Substituting these values into the uncertainty equation results in a relative error of:

$$\frac{\Delta P_A - \Delta P_C}{\Delta P_C} = \frac{v_C}{v_A} - 1 = \frac{0.01619}{0.01745} - 1 = -7.22\%$$

This is a actual error of 1.81 inches of water (-7.22% of 25 inches).

Therefore, the rise in temperature reduces the actual differential pressure input to the transmitter to 23.19 inches of water (= 25 -1.81). Substituting this differential pressure into the flow equation and rearranging to solve for flow rate results in an indicated flow of:

$$Q = \sqrt{100\Delta P} = \sqrt{(100)23.19} = 48.16\,\text{gpm}$$

ATTACHMENT D: Flow Loop Scaling and Uncertainty

Flow orifices are non-linear devices; however, the errors can be written such that they can be combined with the uncertainties of linear devices as if they were linear devices, but only for specific points of interest. The errors are propagated from the input through the non-linear device and then combined with the errors of the instruments on the downstream side of the non-linear device. The methods of this Attachment effectively propagate any errors on the input side of the flow element to the output side. Therefore, when the equations of this Attachment are used, the flow orifice uncertainties and those of any square root converter can be combined with the uncertainties of other instruments as if they were linear but only at the specific point where the error propagation is performed.

1. BASIC EQUATIONS

This section is included to provide guidance on how the flow versus differential pressure relation should be developed for a flow orifice whenever a change in the calibration data for the transmitter is deemed appropriate. The primary reference will be the ASME standard "Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi" (ASME MFC-3M-1989). This is a recent publication and has considered several of the other common references used to obtain similar relations. Therefore, this standard will be considered as superseding earlier references. Other references may give similar results, but for consistency, this standard is to be used for future work.

The basic equation for determining flow rate is Eq 13 from the standard. The equations will be presented here, with possible variation in symbols to be consistent with other symbols used in this design guide.

$$w = 0.09970190\,CYd^2\sqrt{\frac{\Delta P\rho}{1-\beta^4}}$$

where:

w - mass flow rate (lbm/sec)
C - discharge coefficient
Y - expansion coefficient, for liquid this is 1
d - bore diameter of orifice plate or throat diameter of nozzle or venturi (inches)
ΔP - pressure difference across orifice or nozzle (in WC, see Note 2 of Table 1 in MFC-3M-1989, also entry for $\rho_{w,68 F}$.
ρ - fluid density, for this design guide the density will be determined upstream of the orifice or nozzle (lbm/ft^3)
β - ratio of bore or throat diameter to pipe inside diameter, d/D, see Table 1 of the Standard.

This can be converted to measure volume flow rate in gallons per minute (gpm) by using the appropriate unit conversions [5].

[5] Example CRC Handbook of Mathematical Sciences 5th edition: From Pounds H_20 (39.2°F)/min to Gal(US)/min Multiply by 1/0.1198298)

$$Q=(60)*(8.34517)*(0.09970190)\,CYd^2\sqrt{\frac{\Delta P}{\rho(1-\beta^4)}}=49.92176\,CYd^2\sqrt{\frac{\Delta P}{\rho(1-\beta^4)}}$$

To determine the ΔP which will exist for a given flow rate, the equation above can be rearranged.

$$\Delta P=\left(\frac{Q}{49.92176\,CYd^2}\right)^2\rho(1-\beta^4)$$

This type of rearrangement is needed to determine the calibration characteristics of a differential pressure transmitter that is used to measure flow rate. The transmitter is designed to produce a linear output signal (current) for a linear input signal (differential pressure). Two points are needed to define the line. The common points are the two endpoints of the line, zero differential pressure (zero flow) and the design differential pressure (from the design flow rate). At the design conditions, temperature and flow, the quantities ρ, β, d, Y, and C are evaluated. Common practice is then to consider that these quantities are constant. When that is done, the form of the equation is:

$$\Delta P=kQ^2$$

where k is the flow coefficient and is expressed by:

$$k=\frac{\rho(1\beta^4)}{\left(49.92176\,CYd^2\right)^2}$$

The density, ρ, is a function of temperature and pressure. The expansion factor, Y, can vary with pressure ratio for compressible fluids. For liquids it is constant at a value of one. Determination of the expansion factor for compressible flow is not discussed in this guide. Information is provided in the ASME standard for those who must consider compressible flow (e.g. steam). The bore diameter, d, and diameter ratio, β, can vary with temperature due to the expansion of the flow element and pipe with temperature. The discharge coefficient, C, is a function of pipe diameter, D, the diameter ratio, β, and Reynolds number. Reynolds number is, in turn, a function of flow rate, pipe diameter, and fluid properties at the flowing conditions. The Reynold number contribution to discharge coefficient is small, and therefore, discharge coefficient is nearly constant for most flow conditions. However, there is a small error associated with assuming that the discharge coefficient is constant. Equations will be presented later which will allow determination of that error. At very low Reynolds numbers, and at or near the transition point from laminar to turbulent flow, the equations for the determination of differential pressure may not be valid. Where operation is considered for low Reynolds number conditions (less than 2000) specific orifice calibration confirmation is required. Also the change in flow coefficient below Reynolds numbers of 10,000 becomes more and more non-linear with the flow decrease, due to this specific discharge coefficients should be calculated for flows in these regions.

Note that equations above do not include a thermal expansion correction factor, F_a, which is used in some publications. This correction factor is discussed in Section 4.2 of the Standard and is used for initial sizing of the bore. Once the primary element has been manufactured, the effect of thermal expansion on the bore and pipe diameter are included using Equations 19a and 19b of Section 4.3 of the Standard, which are repeated below, again with slight symbol changes.

$$d = [1 + \alpha_{PE}(T - T_{meas})]d_{meas}$$
$$D = [1 + \alpha_{PE}(T - T_{meas})]D_{meas}$$

Attachment E of the Standard provides some values for the thermal expansion coefficient, α, which may be useful. As stated in Section 4.3 (d) of the Standard, the measurement temperature, T_{meas}, is assumed to be 68°F. The diameters given from the equations above are to be used for further calculations to determine volume flow rate or differential pressure.

The determination of the discharge coefficient for an orifice plate in Section 7.3.1.1 of the Standard. The exact equation will depend upon the type of taps used, but all have a series of terms which are a function of the diameter ratio, β, and the pipe diameter, D, and an additional term which is a function of Reynolds number. The equations for the discharge coefficient can be expressed by the general form below, where "M" is the series of terms which are a function of β and D.

$$C = M + \frac{91.71\beta^{2.5}}{R_D^{0.75}}$$

The relation for Reynolds number in terms of the volume flow rate is:

$$R_D = \frac{50.657\,Q\rho}{\mu D}$$

Note: the discharge coefficient is relatively constant for Reynolds numbers above $2 * 10^5$. Transition of flow from turbulent to laminar occurs somewhere between Reynolds numbers of $2 * 10^3$ and $1 * 10^4$. In this region the relative change in uncertainty of the coefficient of discharge, for a given change in Reynolds number, is very large. These changes in the discharge coefficient can result in substantial errors in the flow measurement. Measurement of flow in these areas may require additional condition specific testing or a more extensive evaluation of the discharge coefficient and other flow condition errors. The calculation preparer must ensure that the specific pipe conditions (e.g. pipe full, adequate flow profile, etc.) are know for the point of interest of the calculation.

2. FLOW ELEMENT ERRORS

There are three causes of errors in the flow measurement. First is the uncertainty of the coefficients used to determine the differential pressure or flow rate. This can be termed flow element accuracy. Second is a temperature and or pressure variation, which occurs during normal operation, which will affect material properties such as density (discussed in Attachment C) and pipe size (i.e., thermal expansion). The third is the flow rate itself, which will cause the discharge coefficient to vary slightly.

The relative change of differential pressure produced by the actual operating conditions, P_A, compared to the design conditions, P_D, for the same flow rate is:

$$\frac{\Delta P_A - \Delta P_D}{\Delta P_D} = \frac{k_A Q^2 - k_D Q^2}{k_D Q^2} = \frac{k_A - k_D}{k_D} = \frac{k_A}{k_D} - 1$$

This equation shows that for a decrease in the flow coefficient, the relative error will be negative. This means that the indicated flow will be less than the actual flow. The instrument loops are designed to interpret a change in differential pressure as a change in flow rate. For example, the differential pressure is less for a less dense fluid at the same volume flow rate (k_A is smaller). With a smaller differential pressure, the instrument loop indicates this as a smaller flow, since it does not know that the change was caused by a change in density rather than a change in flow.

2.1 Flow Element Accuracy

There are three primary components of the inaccuracy of a flow element: (1) uncertainty of the discharge coefficient, C; (2) bore diameter uncertainty, d; and (3) pipe diameter uncertainty. Section 10.2.2 of the Standard discusses how the uncertainties are to be combined. More uncertainties than the three just listed are presented in Section 10.2.2; however, they are treated elsewhere in this design guide, or considered insignificant (i.e., no uncertainty for expansion factor for liquids). Simplifying the equation of Section 10.2.2 to include only the three primary components of uncertainty (for liquids) results in the equation below.

$$PE_Q = \frac{\delta Q}{Q} = \sqrt{\left(\frac{\delta C}{C}\right)^2 + \left(\frac{2\beta^4}{1-\beta^4}\right)^2 * \left(\frac{\delta D}{D}\right)^2 + \left(\frac{2}{1-\beta^4}\right)^2 * \left(\frac{\delta d}{d}\right)^2}$$

where:

PE_Q = primary element uncertainty as a fraction of input
$\delta Q/Q$ = uncertainty of flow,
$\delta C/C$ = uncertainty of discharge coefficient,
$\delta D/D$ = uncertainty of upstream pipe diameter,
$\delta d/d$ = uncertainty of orifice bore diameter,
β = diameter ratio = d/D.

The uncertainty of the bore and pipe diameter should be obtained from vendor manufacturing data. Section 7.3.2.1 of the Standard provides an estimate of the uncertainty of the discharge coefficient. This information is reproduced below. However, this information assumes that turbulent flow exists at the associated Reynolds number.

2 in. $\leq$ D $\leq$ 36 in. (nominal sizes)	$0.2 \leq \beta \leq 0.6$	$0.6 \leq \beta \leq 0.75$
$10{,}000 < R_D \leq 10^8$	0.6%	β%
$2{,}000 \leq R_D \leq 10{,}000$	$(0.6 + \beta)$%	

Table D1: Discharge Coefficient Uncertainty

The standard presents additional information in its Sections 6.4.1, 6.4.2, and 6.4.3, which should be considered. In particular any additional uncertainty due to fittings (e.g., pipe elbows, tees, etc.) should be considered and included as part of PE.

The ASME Standard assumes a fixed differential pressure and an uncertainty in the flow rate. The uncertainty of the flow rate needs to be converted to an uncertainty of the differential pressure to be consistent with the other uncertainty terms in this design guide.

This error may be determined by solving the differential pressure equation for the base flow and then revising the equation to calculate the differential pressure difference based on the change in flow.

Given a one percent of full scale flow error, for a system with a 5000 gpm flow in a schedule 80-10 inch pipe with an installed orifice having a beta ratio of 0.725 and a calculated flow coefficient of 0.72, assuming a expansion factor of 1. Determine the error in percent of differential pressure.

$$\Delta P = \left(\frac{Q}{49.92176\,CYd^2}\right)^2 \rho(1-\beta^4)$$

Solve the equation for the point of interest:

$$98.7059 = \left(\frac{5000}{49.92176 * 0.72 * 1 * 9.562^2}\right)^2 * 58.9214 * (1-0.725^4)$$

Solve the equation for the positive and negative application of the flow error (0.01*5000 = 50 gpm):

$$100.6898 = \left(\frac{5050}{49.92176 * 0.72 * 1 * 9.562^2}\right)^2 * 58.9214 * (1 - 0.725^4)$$

$$96.7416 = \left(\frac{4950}{49.92176 * 0.72 * 1 * 9.562^2}\right)^2 * 58.9214 * (1 - 0.725^4)$$

$$\frac{100.6898 - 98.7059}{98.7059} * 100 = +2.01\%$$

$$\frac{96.7416 - 98.7059}{98.7059} * 100 = -1.99\%$$

The differential pressure error is approximately ±2.0% at the point of interest. Note: since the flow error is 50 gpm at all times the effect in terms of % of reading or point of interest will be greater as flow rate decreases. The error must be evaluated at the point of interest for the flow element.

2.2 Temperature Variations

To account for any change in the normal operating temperature, a new constant k as defined in this Attachment or the ASME Standard should be determined, and at the same design flow as was used to determine the original constant. The relative error of differential pressure produced by the actual operating conditions, ΔP_A, to the design conditions, ΔP_D, for the same flow rate is given by the equation at the beginning of Section 2.

For many situations, the temperature variation is significant only for its effect on density, which is covered in Attachment C. That is the change in the diameter, d, and the diameter ratio, β, do not change significantly due to thermal expansion. Similarly, the discharge coefficient, which is a function of d, β, and Reynolds number (a function of flow, density and viscosity), does not change significantly. When all other terms, except density are considered as constant (all at the design flow rate), the expression for relative error can be expressed as shown below (from Attachment C).

$$\frac{\Delta P_A - \Delta P_C}{\Delta P_C} = \frac{\rho_A}{\rho_C} - 1 = \frac{\frac{1}{v_A}}{\frac{1}{v_C}} - 1 = \frac{v_C}{v_A} - 1$$

This error may also be evaluated by solving the equation in section 2.1 above for the effect of the change in temperature on each of the variables. Where a detailed knowledge of the errors associated with process conditions changes are required the ratio method may not have sufficient detail.

2.3 Flow Variations

The discharge coefficient can vary with flow rate and cause the flow coefficient, k, to vary. As explained above, most commonly used instruments only "know" about design conditions and, therefore, assume that k is constant. The relative error of differential pressure produced by the actual operating conditions, ΔP_A, where the discharge coefficient, C, and therefore, the flow coefficient, k, varies with flow as compared to the differential pressure that would have been produced if the discharge coefficient were constant at the design value. All terms in the flow coefficient, k, except the discharge coefficient are constant and can be factored out. The resulting equation is:

$$\frac{\Delta P_A - \Delta P_D}{\Delta P_D} = \left(\frac{C_D}{C_A}\right)^2 - 1$$

This equation shows that as discharge coefficient rises, the relative error becomes negative. Inspection of the basic flow equation shows that as the actual flow falls (decreases) below the design flow the Reynolds number falls also. From the discharge coefficient formula, it can be seen that as Reynolds number falls (decreases), the discharge coefficient rises (increases) above the value that existed for design flow. Therefore, flows below design flow induce a small negative bias error.

Example

The error due to variation in flow for a 12 inch schedule 80 pipe (id 11.374), with an orifice plate with a bore of 7.2 inches ($\beta = 0.6330$) and flange taps, with a design flow of 8,000 gpm. The temperature of the water is 100°F so μ is 0.66 centipoise and ρ is 61.996 lbm/ft^3. For flange taps the equation for the discharge coefficient is:

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^8 + \frac{0.0900\beta^4}{D(1-\beta^4)} \frac{0.0337\beta^3}{D} + \frac{91.71\beta^{2.5}}{R_D^{0.75}}$$

Substituting all values except R_D results in:

$$C = 0.5959 + 0.0312 * 0.6330^{2.1} - 0.1840 * 0.6330^{8}$$

$$+ \frac{0.0900 * 0.6330^{4}}{11.374 * (1 - 0.6330^{4})} - \frac{0.0337 * 0.6330^{3}}{11.374} + \frac{91.71 * 0.6330^{2.5}}{R_D^{0.75}}$$

$$C = 0.617484 + \frac{29.23916}{R_D^{0.75}}$$

Substituting all values except flow rate into the equation for Reynolds number results in:

$$R_D = \frac{50.657 * Q * \rho}{\mu * D}$$

$$R_D = \frac{(50.657) * Q * (61.996)}{(0.66) * (11.374)} = 418.4Q$$

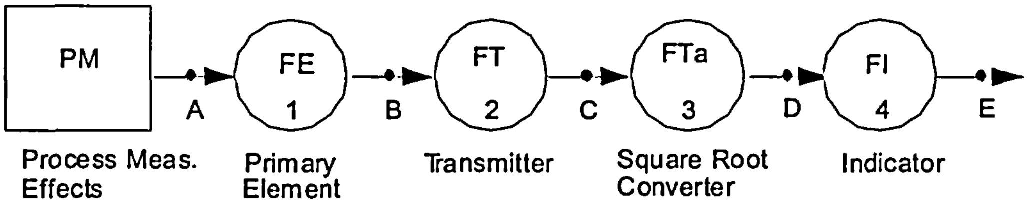
For a design flow rate of 8,000 gpm, the Reynolds number is determined to be 3,347,200 and the discharge coefficient, CD, is determined to be 0.617858. For an actual flow of 1,000 gpm, the Reynold number is determined to be 418,400, and the discharge coefficient, CA, is determined to be 0.619262. Therefore, the relative error is:

$$\frac{\Delta P_A - \Delta P_D}{\Delta P_D} = \left(\frac{C_D}{C_A}\right)^2 - 1 = \left(\frac{0.617858}{0.619262}\right)^2 - 1 = -0.004529$$

This is a -0.453 % error in the differential pressure at a flow rate of 1,000 gpm.

3. FLOW LOOP UNCERTAINTY PROPAGATION

3.1 Non-linear Devices



The loop displayed above has two non-linear conversions, the first a conversion from flow to differential pressure takes place in the flow element. The second non-linear process occurs in the square root extractor. For this loop, the conversion of process errors to differential pressure errors has been covered in the first part of this Attachment. The propagation of the errors associated with flow transmitter (and the converted process errors) is the purpose of this section.

Calculation model errors result from the use of a mathematical model to calculate a variable from measured process variables. These errors may be non-linear over the process range. To ensure that non-linear considerations do not produce non-conservative results in setpoint calculations the following error combination method may be used when a loop contains one or more non-linear devices.

1. Individual device uncertainties are calculated in the same manner as the existing methodology.

2. A total uncertainty for each device would be calculated then the error associated with all the devices on the input side of the non-linear devices would be combined (by SRSS usually) to determine a total uncertainty.

3. The input point of interest value and the input errors are converted to process values (e.g. milliamps).

4. Determine the transfer function for the non-linear device.

5. Using the transfer function substitute the point of interest for the applied value. The output value is the pure signal value.

6. Add the input error values determined above to the point of interest value. Substitute this value for the applied value in the transfer function. Subtract the value from step 5 above from this propagated value. The result is the positive error value.

7. Subtract the input error values determined above to the point of interest value. Substitute this value for the applied value in the transfer function. Subtract the value from step 5 above from this propagated value. The result is the negative error value.

8. The resultant uncertainty would be evaluated via the SRSS method with all the device uncertainties on the output side of the non-linear (or multiple-input device). Since current methodology is to measure errors on the output side of components, the propagated errors would be combined with the This value would be the Total Loop Uncertainty.

   Because of the method of error combination used in the formulas, non-linear device errors cannot be made dependent with errors from other loop devices. The errors for the non-linear device must be combined only in the manner specified in the equations. Once the formula has been used and the error on the output side of the non-linear device has been determined the error may then be combined with the errors from the rest of the devices on the output side of the non-linear device.

Example

Determine the Total Loop Uncertainty for the following flow loop at a point of interest of 40 gpm:

DEVICE	DESCRIPTION	INPUT/OUTPUT RANGE	DEVICE UNCERTAINTY
FE	Orifice Plate	0-5000 GPM/0-100 INWC	0.8% of span
FT	Diff. Press. Xmtr.	0-100 INWC/4-20 MA	1.2% of span
I/E	Current to Voltage Converter	4-20 MA/1-5 V	0.7% of span
FY	Square-Root Converter	1-5 V/1-5 V	0.9% of span
FS	Bistable	1-5 V/0-5000 GPM	0.5% of span

Calculate Input Error to non-linear device

The input error to the FY is the SRSS of the FE, FT, and I/E device uncertainties is as follows: Note: this assumes that any process related errors (e.g. flow bases errors) have been propagated through the flow to differential pressure conversion as discussed above.

Input error =

$$e_a = \sqrt{(0.008)^2 + (0.012)^2 + (0.007)^2} = 0.016$$

Calculate Output Error from non-linear device

The transfer function for a square root device is

$$C = K * \sqrt{A}$$
$$e_c = \sqrt{A + e_a} - \sqrt{A}$$

where:

e_c	=	Output Error from non-linear device in output signal units.
e_a	=	Input Error to non-linear device in input signal units
A	=	Point of Interest (input signal in signal units) A in this case is the full transfer function as follows:
C	=	Output Value for the equivalent value of A
K	=	Any constant multiplier use to scale the output for the device.

To convert from an input value to an output value and therefore to determine the output error requires that we work with the

$$C = K * \sqrt{\frac{\text{AppliedValue} - \text{InputMinimum}}{\text{InputSpan}}} * \text{Output Span} + \text{Output} - \text{Minimum}$$

For this example,

e_a = 1.6 % of square root extractor input span (calculated above)

convert the flow point of interest to signal units

Point of Interest = $(400\ \text{gpm}/5000\text{gpm})^2 * 100$ inwc = 0.64 inwc

This is differential pressure value must be converted to a signal value at the input of the square root converter. Use the scaling vales to determine the input signal at the point of interest.

0.64 inwc/100 inwc span * 16 mA =0.1024 mA
0.1024mA/ 16 mA * 4 volts + 1 volt minimum output span = 1.0256 volts square root extractor input value

Convert the error to signal units

0.016* 4 volts = 0.064 volts

Substituting into the error propagation equation:

True Output =

$$C = \sqrt{\frac{1.0256-1}{4}} * 4+1$$

C = 1.32

<u>Output with error =</u>

$$C = \sqrt{\frac{1.0256+0.064)-1}{4}} * 4+1$$

C = 1.59867

$$C = \sqrt{\frac{1.0256-0.064)-1}{4}} * 4+1$$

$$C = \sqrt{\frac{-0.0384}{4}} * 4+1$$

Note: the propagation of the negative error results in imaginary numbers since the error is actually larger than the signal value. The error associated with the positive side of the propagation is 0.27867/0.32 *100

Therefore the error associated with this point of interest is: over 87% of the actual signal.

Calculate Total Loop Error (TLE)

The TLE is the SRSS of the non-linear device Output Error with the device uncertainties of the devices downstream and the output errors of the non-linear device. For this example, the Bistable and the output of the square root extractor act as the only downstream devices. The span errors are used to determine the total error in signal units.

Therefore:

Convert down stream errors to equivalent volts.

For the square root extractor error is 0.9% of 4 volts = 0.036 volts

For the bistable indication 0.5% of 4 volts = 0.02 volts

Evaluate the error as a fraction of expected signal or pure signal.

$$TLE=\sqrt{(0.2786)^2+(0.036)^2+(0.02)^2}$$

= 0.28163 volts error for a signal value of 0.32 volts. Error is 88 % of the signal value.

TLE = 0.88 * 400 = 352 gpm

Additional methods of calculating the modeling error for non-linear devices may be applied, two example methods are the use of Partial derivatives and perturbation techniques as discussed in Attachment K of Reference 2.1.6. It is acceptable to construct a Monte Carlo model of the loop and perform a statistical analysis of the error based upon the specific transfer function for each loop component.

Modeling error may be ignored for loops where the calibration is performed at the loop trip setpoint, or the point of interest for indicators and the input signal for calibration is on the input side of the non-linear device.

ATTACHMENT E: **Special Considerations for Radiation Monitors**

1. INTRODUCTION

When reduced to its essence, a setpoint calculation is simply an estimate of uncertainty. Protective actions are set to initiate as close to some limit as the total measurement uncertainty will allow. In a conventional instrument loop, this limit is expressed in units of a single process variable (i.e., gpm) for a single known substance (i.e., borated water). The estimated uncertainty is in turn found from relatively well understood environmental effects and other characteristics of the instrument loop which in principle can be measured or compensated for in routine calibrations.

Radiation monitors in stark contrast, respond to a characteristic radiation property, such as photon flux (photons/cm^2-s), in a plant area or effluent stream, while their setpoint limits may be calculated levels of off-site radioactivity (μCi/cc) or dose (rem). The uncertainties which need to be considered in performing radiation monitor setpoint calculations may include factors related to instrument linearity, detector geometry and energy response, source term composition, sample flow, process/vent flow, effluent dilution, and off-site dose assessment. Uncertainties related to processes downstream of the monitor, such as atmospheric diffusion, are beyond the scope of this guide and are assumed to be included in the process limit.

A common setpoint basis for radiation monitors is the detection of any significant radiation above background. From the perspective of this guide, the maximum expected background is a control limit and the positive (U+) uncertainty is applied to arrive at the setpoint. Other applications, such as effluent monitors, are calculated using the negative (U^-) uncertainty is applied to an upper process limit.

The discussion which follows provides guidance for evaluating uncertainty contributors that are largely unique to radiation monitors. Other contributors, generally applicable to all instrument systems, are discussed in the body of this guide and should be evaluated in the setpoint calculation. Response time allowances may be crucial to radiation monitor setpoint determination and the calculation preparer should carefully verify that appropriate allowances are included in the process/analytic limit.

1.1 Combining Uncertainties

The general output equation for digital radiation monitors is of the form:

$$OR = k(IV) = k(R\varepsilon)$$

where:

OR = output reading in engineering units
k = conversion and correction constants
IV = monitor input value
R = radiation variable of interest
ε = detector efficiency

The preferred method is to assume the value of (k) is without error at some reference condition and calculate the uncertainty as a function of (Rε). As can be seen in the following sections, the effective expression has many more terms; however, the basic product form is maintained.

For random, independent effects:

$$\{d(OR)\}^2 = U^2 = \left(\frac{\partial U}{\partial R}\right)^2 (\partial \varepsilon)^2 + \left(\frac{\partial U}{\partial \varepsilon}\right)^2 (\delta R)^2$$

which is more conveniently expressed as the ratio of uncertainty to output as:

$$\left(\frac{U}{OR}\right)_R^2 = \left(\frac{\delta \varepsilon_R}{\varepsilon}\right)^2 + \left(\frac{\delta R_R}{R}\right)^2$$

where:

$\delta\varepsilon$ = uncertainty in detector efficiency
δR = uncertainty in radiation value due to process effects

For systematic (bias) effects, the corresponding expression is:

$$\left(\frac{U}{OR}\right)_B = \frac{\delta \varepsilon_R}{\varepsilon} + \frac{\delta R_B}{R}$$

Unfortunately, unless the effects are small, the nonlinear nature of the monitor transfer function causes this equation to substantially overestimate the bias effects. An alternate approach, which is also consistently conservative but to a lesser extent, is to propagate the effects for each point of interest using the basic response function:

$$\left(\frac{U}{OR}\right) = \frac{\delta (OR)_R + \delta (OR)_B}{OR}$$

$$= \frac{[(R + \delta R_B + \delta R_R)(\varepsilon + \delta \varepsilon_B + \delta \varepsilon_R] - R\varepsilon}{R\varepsilon}$$

2. PROCESS CONSIDERATIONS

Radiation monitors are typically either particle counting systems (cpm) or operate in a current mode (pA) which is proportional to radiation flux, such as neutron fission chambers or gamma ion chambers. When a setpoint is calculated, the quantity of interest is usually activity concentration (µCi/cc) or exposure (mR/hr). There are conversion factors in the monitor data base which allows the monitor to read directly in the unit of interest. If the conversion is performed digitally, math errors may be neglected.

3. PRIMARY CALIBRATION

When the sensitivity factors are derived from a one-time primary calibration, it can have a profound effect on total measurement uncertainty.

Ideally, a primary calibration would be based upon multiple measurements of mono-energetic, NITS traceable sources, over the complete counting and energy range of several monitors. The sources would be in precisely the same composition and geometry as the intended application. This form of calibration would allow statistical prediction of the mean detector response and tolerance band for the entire population of detectors with a 95% confidence.

Liquid and gaseous effluent monitors, however, are usually calibrated with a small number of nonideal sources which match the monitor geometry, supplemented by solid or liquid sources, which deviate in composition and geometry from the process sample. Relating the supplemental source response to the sample geometry often involves some significant leaps of faith. Particularly with beta detectors, simply multiplying the source response by a constant may introduce substantial error. This is true because the effective solid angle subtended by the detector and the sample self-absorption may not be constant with energy.

Data interpretation can be error prone for noble gas primary calibrations. ^{133}Xe has an average photon energy of 30 keV, however most calibration reports show the measurement plotted at 80 keV, arguing that it is "obvious" that the detector does not respond in the 30-35 keV region. If this assumption is unwarranted, then the low energy portion of the response curve is shifted. ^{85}Kr measurements for gamma detectors are complicated by the possibility that bremsstrahlung from beta emissions may contribute significantly to measured sensitivity, because the gamma abundance is very low.

When the supplemental sources differ substantially in composition from the process sample (i.e., solid for gas), then solid angle and scattering differences may result in both sensitivity errors and an apparent shift in energy.

Often, the primary calibration will attempt to cover the three-decade (0.03 to 3 MeV) energy range with one source in the first decade and one in the last. This lack of data contributes to sometimes severe extrapolation error.

Recognizing that noble gas calibrations using only ^{133}Xe and ^{85}Kr do not provide sufficient data concerning the overall shape of the energy response, some studies have been done using shielding codes such as ISOSHLD or QAD-CG to predict the response of the monitor. Due to a variety of effects, these codes are not accurate below 200 keV. This form of modeling contributes
an additional component to the extrapolation error.

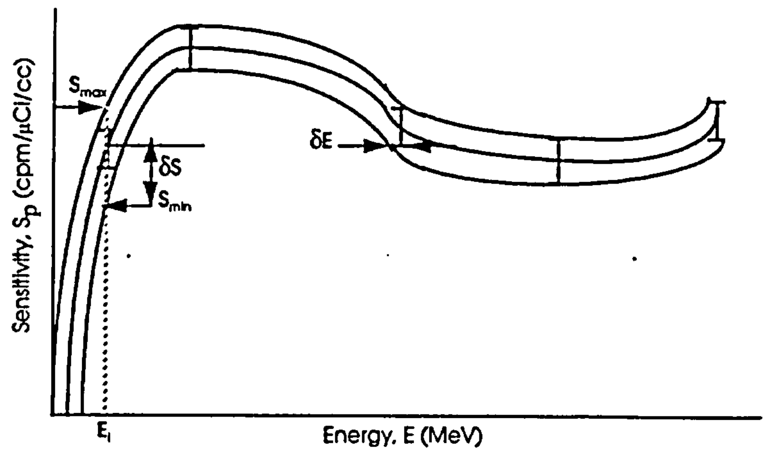


Figure 1: Hypothetical Primary Calibration Results

All measurements may have been performed on a single "prototype" monitor. As a consequence, the user has no measure of reproducibility and may be basing the monitor calibration upon an atypical sample. This, plus the fact that the calibration for all monitors will reflect any uncertainties in the primary calibration, indicates that those uncertainties be included in the setpoint calculation as additional terms.

The source concentration uncertainty and the counting uncertainty are normally evaluated explicitly in the primary calibration report. However, many of the other factors may only be inferred. As can be seen from **Figure 1**, the factors which cause an apparent energy shift are significant only when the sensitivity is rapidly changing usually at low energies. A method which is consistent with the uncertainties involved, is to estimate the magnitude of the effects at each energy of interest and graphically combine them as shown in **Figure 1**.

Much of this uncertainty may be avoided for normal effluents by routinely calibrating the monitor with dilute samples from primary coolant or waste gas holdup tanks. Under those conditions, the source term sensitivity is found by direct comparison to laboratory analysis, and the primary/transfer calibration uncertainties may be neglected. Since an accident source term would bear no simple relationship to normal effluents, NUREG-737 high range monitors must be calibrated using data from the primary calibration.

- **Transfer Calibration**

  In order to avoid the complexity of liquid or gaseous calibrations, most sites use a secondary or tertiary set of solid sources. The source uncertainty and counting uncertainty involved in making the comparison between the prototype monitor and the final set of transfer sources are the obvious contributors. Additionally, the results for one monitor do not apply without uncertainty to any other monitor.

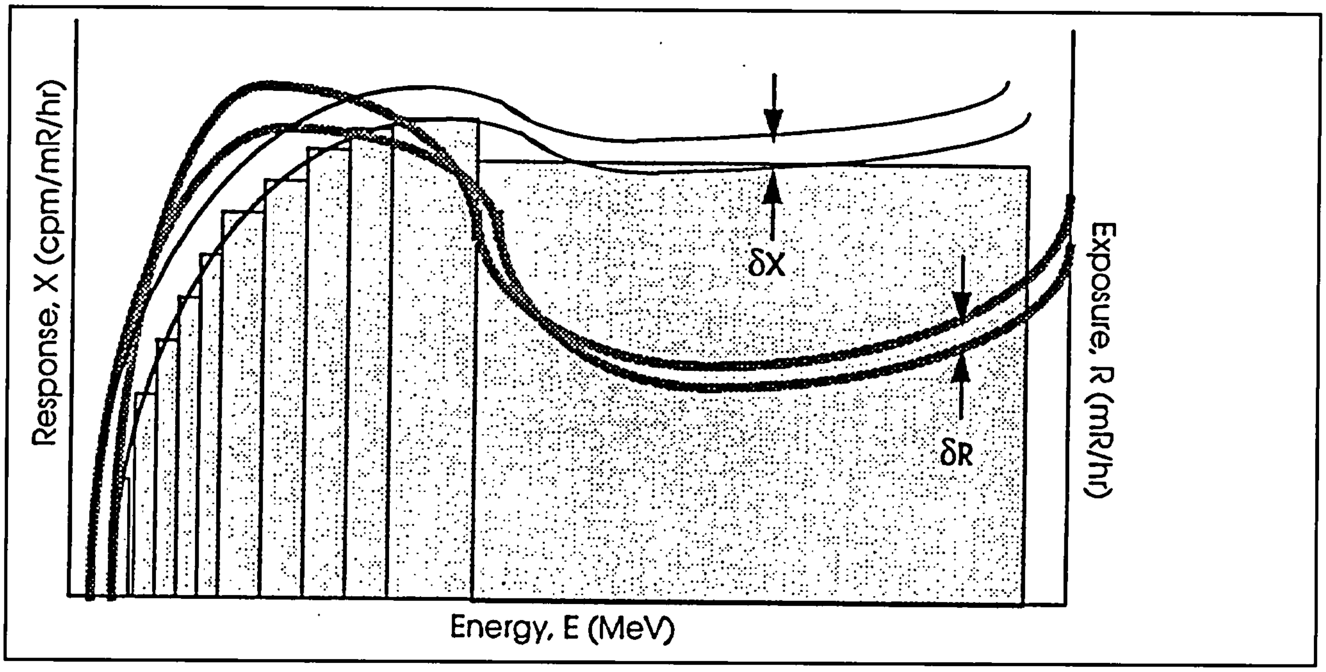
  Off-line monitors experience a variety of effects which reduce the concentration of activity at the monitor. Leakage may cause the sample to be diluted, however, except under accident conditions, this effect should be negligible. Plateout, settling, and gas adsorption may cause buildup in the sample line. These factors may be estimates or measurements for specific operating conditions. Over the expected range of operating conditions, these factors are subject to large systematic variations. If the sample chamber is operating at a vacuum, then gas expansion would cause an error in concentration (or mass flow).

4. AREA TYPE MONITORS

As noted above, the typical radiation detector responds to the flux of particles reaching it. Scintillation counters respond more or less directly to betas and photons as they are absorbed. G-M tubes on the other hand respond to the secondary emission of electrons from the tube wall so that the gamma response (cpm or current) is roughly proportional to energy fluence (MeV-cm^2/s), which makes them well suited to area monitors calibrated in mR/hr.

If the composition of the source term is unknown but the energy distribution is known, then the uncertainty in the energy of the sample may be used to calculate the energy-dependent uncertainty in the output. **Figure 2** illustrates the hypothetical response for an area detector, superimposed on 11 energy groups along with a hypothetical exposure distribution.

Figure 2: Energy Group Analysis



Unlike the process sampling monitors, the area monitors are routinely calibrated using a source which is calibrated directly in mR/hr. Consequently the conversion factor may be readjusted to compensate for systematic sample to sample variations in the sensitivity at one energy (usually 661 keV).

Another example of this case would be a G-M tube post-accident monitor, when the expected source term energy is a function of time after an accident generated by a shielding code. If such a detector is calibrated in energy adjusted units, such as µCi-MeV/cc, ^{133}Xe-Equivalent µCi/cc, or Bq-MeV/cc, then this source of error is at least partially compensated, since the sensitivity is more nearly constant at each energy.

5. INSTRUMENT UNCERTAINTIES

5.1 Dead Time Uncertainty

Modern radiation counting systems generally have dead time characteristics approximated by the so called "nonparalysable" model:

$$n = \frac{m}{1 - m\tau}$$

where:

n = true interaction rate
m = observed count rate
τ = dead time

The count rate may be thought to be reduced by a variable factor (M_τ):

$$M_\tau = \frac{m}{n} = 1 - m\tau$$

If this effect is not corrected, it is a pure negative error term, which is predictable and consequently must be treated as a bias.

5.2 Efficiency Uncertainties

Drift (DR), accuracy or calibration effect (CA), voltage effect (VE), and the environmental effects all contribute to the uncertainty in instrument efficiency (or sensitivity). Humidity, IR loss, radiation effects and atmospheric pressure may all contribute significant uncertainties; however, for most applications, these factors may be neglected for normal conditions. Efficiency should be defined in the same terms as the efficiency measured during calibration.

5.2.1 Effective Accuracy

The effective accuracy for inclusion in setpoint calculations should generally be the calibration tolerance combined with the testing uncertainties. If the conversion factor is adjusted to match the measured efficiency, the uncertainty is simply the counting uncertainty and calibration source tolerance, neglecting the calibration tolerance.

5.2.2 Drift

Few manufacturers of radiation detectors specify long-term drift (DR), consequently the recommended source for drift information is the as-found/as-left surveillance data. Such data would also include the cumulative effects of radiation and other environmental factors.

5.2.3 Gain Uncertainty

For scintillation detectors, the discriminator threshold and amplifier gain may not be set to match the prototype monitor. This error (δG) may cause significant uncertainties at low energies, unless the calibration procedure includes verification of the threshold setting energy. The system gain is also a predictable function of temperature and high voltage fluctuations.

Scintillation detectors typically have a negative temperature effect, bounded by roughly -10 to -20% per 50°F.

Typically, the detector high voltage is adjusted at one energy such that the counting efficiency is on a "plateau", with a positive slope of from 5 to 10% per 100 V. At lower energies, the slope may be much more severe, and a change in voltage will cause a proportionally larger change in efficiency.

The temperature (TE) and voltage effects (VE) are complex functions, depending upon scintillation material, PM tube construction, and preamplifier design. Both factors are related to the threshold setting and gain error (δG).

For G-M tube detectors, the threshold has negligible effect on efficiency and the voltage effect may be estimated directly from the plateau slope. Temperature effect may be calculated directly from the resulting specific ionization changes inside the G-M tube[6]; however, for temperature swings normally encountered, the total effect is approximately 1% and may be estimated.

Preferably, the overall stability of the detector system should be obtained from vendor testing. Alternately, the effects may be calculated from published data[7]. Unless the detector is servo gain stabilized, these effects are biases or abnormally distributed.

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[6] W. J. Price, *Nuclear Radiation Detection*, 2nd Edition, McGraw-Hill, 1958.

[7] J. B. Birks, *The Theory and Practice of Scintillation Counting*, Pergamon Press, 1964.

6. TOTAL UNCERTAINTY

There is no single expression for total uncertainty that applies to all radiation monitors. The preceding equations are suggestive of how the individual effects may be evaluated. The specific form of the total uncertainty equation depends upon the analyst's evaluation of which effects are bias terms and which are random. If the effects are large (more typical), then the most reliable method available would be to evaluate the random effects using SRSS, and propagate random and bias uncertainties together using the response function.

For the typical monitor which is set as close to background as practical, a statistical evaluation of actual response may be all that is necessary.

Particular mention should be made of the Vermont Yankee main steam line monitors, which have been assigned in an allowable value of 3.6 times background, and a nominal setpoint of 3.0 times background by most BWR plants, entirely by precedent and regulatory approval, since there is no analytical limit associated with this channel in the safety analysis.

ATTACHMENT F: Statistical Considerations

There are two terms that will be used extensively in statistical discussion, these are confidence and proportion. The proportion of an occurrence is based on the frequency distribution. The frequency distribution defines how often a given event will have a specific outcome. Given a coin toss how often will the coin land heads up? The second term is confidence. The level of confidence is based on the size of the sample used to determine the frequency distribution. There is less confidence in the measurement if 5 coin tosses are used instead of 500 to determine a frequency distribution. For the purposes of the design guide a short hand term will be used for the discussion of statistical characteristics. This short hand is confidence/ proportion. The short hand 95/75 means we have a 95 percent confidence that at least 75 percent of the events will fall within our projected distribution. Proportion can be picked from a histogram or frequency distribution, confidence is based on the size of the sample set compared to the total population. The term confidence interval as used in this Attachment refers to the confidence and proportion as an integral value (e.g. 95/95) is a confidence interval.

1. COMBINING UNCERTAINTIES WITH DIFFERENT LEVELS OF CONFIDENCE INTERVAL

Equipment vendors usually provide uncertainty data that may be assumed to reflect at least a 95% confidence interval or a two standard deviation (2-sigma or 2σ) value. The uncertainty estimate resulting from combining the random terms by SRSS will reflect the least conservative statistical characteristics of the included terms. In other words, if all the terms except one are 3σ values (99.7% confidence interval) and that one is a 2σ value (~95% confidence interval), then the uncertainty estimate will be a 2σ value. For conservatism, it shall be assumed that published vendor specifications are no better than 2σ values unless specific information is available to indicate otherwise.

If there is **very strong evidence** that a particular error specification represents a higher confidence level, the individual preparing an uncertainty calculation may adjust that specification to be consistent with other uncertainty elements. This evidence should be equivalent to one or more of the following:

1. Manufacturer's testing data, demonstrating the statistical distribution and confidence interval.

2. Documented vendor statement of the confidence interval.

3. Third party or plant data demonstrating a minimum tolerance interval corresponding to the specification, which is at least 99/95 (see next section).

Table 1 in the following section, shows the K multipliers for a two-sided distribution for various proportions of the population. If the uncertainty is being determined using confidence interval values for a normal distribution, then a 99% confidence interval (2.58σ) uncertainty value may be multiplied by $1.96/2.58 = 0.760$ to approximate the 95% (1.96σ) confidence interval value. The combination with other error limits would yield an overall uncertainty calculation with a 95% confidence interval.

2. SINGLE SIDED DISTRIBUTIONS

For nearly all setpoints, interest is only in the possibility that a single value of the process parameter is not exceeded, and the single value is approached only from one direction. A good example of such a process parameter is reactor vessel low-low level. The analytical limit is a single value near the top of active fuel. It is approached only from the direction of decreasing level. In this case, the uncertainty of particular interest is unidirectional, and is the largest positive limit for errors that encompasses 95% of the population of instruments.

As generally calculated here and in ISA-RP67.04 Part II uncertainty is bidirectional, describing the limits in either direction, which encompass a particular confidence interval, for instance, 95% of a population of instruments, **around the mean**. In situations where it can be proven that the protection point is only approached from one side, accounting for a one-sided area of interest may reduce the magnitude of the random uncertainty component. In such a case, the random uncertainty may be reduced by a factor J/K, where the quantities J and K are distances from the mean, in standard deviations, for one- and two-tailed tests, respectively, to insure that a particular portion of the proportion is included. Values of J and K are shown in **Table 1** for representative confidence intervals [Ref. 6.1].

Nearly all-single input, bistable setpoints could fit into this category; however, for general indication and measurement, the two-tailed limits are appropriate. To avoid confusion among the users of uncertainty information, this adjustment generally should not be made unless needed to prevent operational impact.

Table 1: Proportion Factors for One and Two Sided Uncertainties

Proportion	One-Sided (J)	Two-Sided (K)
75%	0.68	1.15
90%	1.29	1.65
95%	1.65	1.96
99%	2.33	2.58

3. DEPENDENCY

Dependent errors can exist when there is an interaction between two or more effects. Those interactions could be intradevice (multiple effects acting on one instrument) or inter-device (an effect causing an interaction between devices). A combination of dependent effects is generally assumed to have greater uncertainty than independent effects; though, theoretically the uncertainty could be smaller. Dependency is only a consideration when errors are not random and normally distributed.

3.1 Intra-device Dependency

Intra-device dependency exists when the effect of multiple external factors applied simultaneously is different from when the factors are applied individually and then combined analytically without consideration of any interaction.

An example of where an intra-device dependency might exist is that between temperature and pressure for a pressure transmitter using a bellows with a fill fluid. For a given plant event the pressure and temperature increase in a dependent manner (i.e. due to the single initiating event both pressure and temperature increase). The increased pressure caused a force on the outside of the measuring bellows. The increased temperature causes a change in the density of the fluid used to fill the bellows. In this case both errors are directional and possible have a specific linear relationship between the change and the error. Since a single event causes the increase in pressure and temperature and these changes both cause non-random changes in the device output, a dependency exists between the errors. Where non-normally distributed random errors are present dependency must be evaluated.

3.2 Inter-device Dependency

Inter-device dependency is of concern when a given change in some external factor, which affects two or more instruments (e.g., power supply voltage or temperature), may results in a larger error than when they were tested individually and then combined without concern for a common interaction. In general, there are only three mechanisms by which interaction can occur. The first is via the intended signal between the instruments. The second is via a common environment. And the third is via a common power supply.

As an example two switches are used to measure the difference in inlet and outlet pressure for a pump and display a pump differential pressure. If each switch has a temperature error which is a bias, then any temperature change would create a dependent error for the differential pressure measurement based on the bias change for each switch. Dependent errors will be treated, as bias or error combination by other than SRSS will be used.

4. DRIFT EVALUATIONS

A detailed summary is provided in each drift calculation describing the results of that analysis. The summary provided in the associated drift analysis should be included (all or in part) within the setpoint calculation. The Vermont Yankee drift calculations provide two-sided and one-sided tolerance intervals where appropriate. The drift calculation values may be reduce to lesser confidence interval values in accordance with Table 1. For all other conditions values should be selected directly from the drift calculation. There shall be no interpretation of time dependence or drift value outside of the drift calculation with the exception of confidence interval adjustment.

ATTACHMENT G: Abnormal and Uniform Uncertainty Distributions

Not all random uncertainties are described by the gaussian or normal distribution. Possible theoretical distributions include the poisson, binomial, lagrangian, bi-modal, and the subject of this discussion, the uniform or rectangular distribution.

The uniform distribution is important because many uncertainty terms may be recognizably random but not understood in sufficient detail to rigorously establish 95/95 tolerance intervals using an underlying assumption of normality. In particular, for estimated uncertainties, only the upper bound for the magnitude of uncertainty is known, the frequency distribution remains unknown. However, it is often reasonable to assume that any uncertainty between the assumed plus and minus limits is equally probable, which describes the uniform distribution.

All the discussion which follows is based upon Chapter 4 of Uncertainty, Calibration and Probability, Second Edition, by C. F. Dietrich. **Figure 1** illustrates the proportion density function of a uniform distribution with a semi-range of ±h about the mean value (μ_x) of the random variable, x.

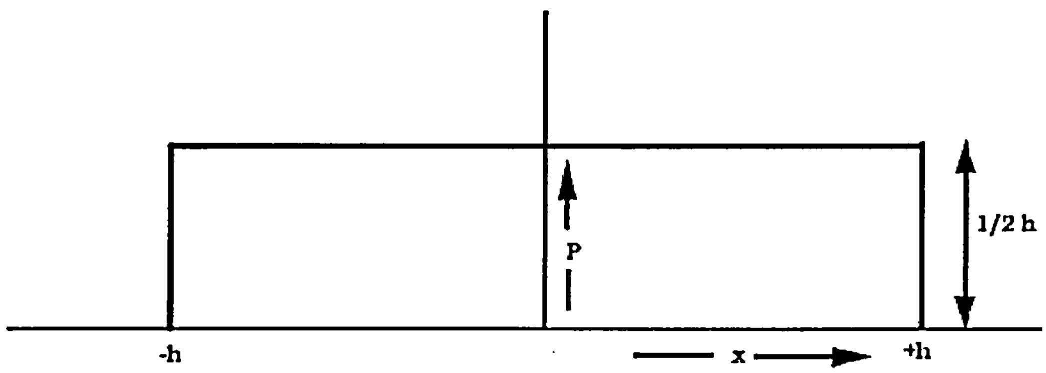

Figure 1: Uniform Distribution, Range = ±h

Since the area under a proportion distribution must be unity (1), the height of the rectangle must be equal to $\frac{1}{2h}$. For the uniform distribution, the standard deviation (σ_u) is:

$$\sigma_u^2 = \int_{-h}^{h} x^2 P dx = \frac{h^2}{3}$$

$$\sigma_u = \frac{h}{\sqrt{3}}$$

The proportion of an uncertainty lying between the limits of $\pm\ \sigma_u$, for the uniform distribution, is $1/\sqrt{3}$ = 0.5770, which means that the interval $\pm 2\sigma_u$ exceeds the range of the entire distribution and the chance that the uncertainty lies outside the range of $-2\sigma_u$ to $+2\sigma_u$ is zero. Dietrich has exhaustively evaluated the combination of uniform (rectangular) distributions with other uniform distributions and with normal distributions. The results of these evaluations are summarized below (from Table 4.68, Uncertainty, Calibration and Probability).

Type of Distribution	Probability of an Error Outside 2σ or 3σ	
	-2σ to $+2\sigma$	-3σ to $+3\sigma$
Uniform (rectangular)	0.00%	0.00%
Combination of 2 similar uniform distributions	3.37%	0.00%
Combination of 3 similar uniform distributions	4.17%	0.00%
Combination of 3 uniform distributions, standard deviations in ratio 3:2:1	3.29%	0.00%
Combination of 3 uniform distributions, standard deviations in ratio 3:1.5:1	2.87%	0.00%
Combination of 4 equal uniform distributions	4.20%	0.07%
Combination of 1 uniform distribution with 1 normal distribution of equal standard deviation	4.01%	
Combination of 1 uniform distribution with 1 normal distribution of 1/5 the standard deviation of the uniform distribution	0.36%	
Normal (Gaussian) distribution	4.55%	0.27%

Quoting from Dietrich:

> "The most important point to notice about the results is that the probabilities of an uncertainty outside either $\pm 2\sigma$ or $\pm 3\sigma$ are greater for a Gaussian distribution than for any of the combinations. This is a highly important point since it means that if we combine rectangular distributions both with themselves or with Gaussian distributions, we can always be sure that the probability of an uncertainty greater than $\pm 2\sigma$, $\pm 3\sigma$, etc., is always less than in the corresponding Gaussian case, and that the true probability will in general not be much less than the Gaussian one."

For the purposes of this guide, any random uncertainty, which is bounded by a uniform distribution of semi-range, h, may be combined with normally distributed uncertainties using SRSS and a uncertainty value (u_u) equal to:

$$u_u = \pm 2\sigma_u = \pm \frac{2h}{\sqrt{3}}$$

The principal caution to applying this rule is that the distribution cannot be bi-modal, that is the errors cannot cluster around the limits with very few cases near the mean, such as would be the case if the system were operated in one of two modes, with neither predominating, but the errors being mostly positive in one mode and mostly negative in the other.

1. UNCERTAINTIES WITH ESTIMATED LIMITS, DISTRIBUTION UNKNOWN

In many cases, for environmental error influences particularly, the uncertainty distribution is not known, only the upper and lower limits are available either by design or estimate. The ISA-RP67.04 Part II position is that in these cases, the resulting uncertainties are to be treated as biases. The methodology described by this guide generally follows this recommendation, which is intended to avoid underestimating the contribution of estimated uncertainties to the total loop uncertainty, by inappropriately combining non-normally distributed errors with normally distributed terms using the SRSS method. However, this approach may be overly conservative for some cases. This guide allows treatment of certain estimated uncertainties as uniform distributions, which satisfy the following criteria:

1.1. The uncertainty is a random effect or a systematic effect of an influence which is itself a random variable.

1.2. For the random influence variable under the specific operating conditions considered, either:

1.2.1. Is equally likely to assume any value within certain known limits or,

1.2.2. Is typically found near a single nominal operating point.

1.3. The random influence variable is symmetrically distributed around its mean value.

An example of such a case would be the process measurement uncertainty (PM) for reactor vessel level under normal operating conditions, as described in Attachment C. This effect is systematically related to liquid density, which is in turn dependent upon vessel pressure, vessel temperature, drywell temperature, and Reactor Building temperature. Since the vessel is at saturation, vessel density follows pressure, which during normal operations is held very close to 1020 psia. The drywell and Reactor Building temperatures fluctuate daily, seasonally and also in response to varying heat loads in the buildings. The net result is that fluid densities in the measurement system fluctuate randomly around the mean, but not demonstrably according to a normal distribution. In this case, it would be appropriate to assume the PM_n uncertainty is a uniformly distributed, random variable.

Such is not the case for the same system during an accident. For a LOCA, reactor pressure falls predictably in response to the loss of coolant, eventually stabilizing at a new value depending upon the size of the break. Consequently, the vessel and sense line liquid densities would all decrease, at the limit resulting in a predictable error. In this case, the criteria for randomness are not satisfied and PM_a should be treated as a bias.

2. UNCERTAINTIES WITH KNOWN ABNORMAL DISTRIBUTION

For uncertainties which, as a result of statistical analysis, such as a drift study, are found to be abnormally distributed, but bounded by a uniform distribution, then the uncertainty may be treated as a uniform distribution and combined with other uncertainties using the SRSS method. The bounding distribution is not that which has the same sample standard deviation as the sample studied, but rather has the same semi-range from the mean as the most extreme (non-outlier) measurement.

Example

In a transmitter drift study, the mean analyzed drift is found to be 0.1% CS, the most positive drift value in the study sample is +1.4% CS, most negative is -0.9%. The sample distribution is not covered by a normal distribution of the same standard deviation. Neglecting the 0.1% mean offset from zero, the bounding rectangular distribution has a semi-range of ±1.4% and the effective uncertainty is:

ATTACHMENT H: IST Accuracy Calculation and Calibration Requirements.

In-Service Testing (IST) is intended to monitor degradation of components. The ASME Code does not require that pumps be tested at design basis conditions. Many plants use the ASME test to verify compliance with the ASME Code and the pump design basis requirements contained in the plant design basis documentation such as the FSAR. In this case, additional plant design basis accuracy considerations need to be properly integrated into surveillance test procedure acceptance criteria.

Instrument accuracy and full scale range limits are important to ensure that pump in-service testing obtains measurements that permits the detection of pump degradation. It is important to detect pump degradation during in-service testing so a pump with significant degradation can be repaired prior to the pump degrading to the point where there is the likelihood that it will not be capable of performing its safety function if called upon to do so to mitigate the consequences of an accident.

Instrument inaccuracy results in uncertainty in the test measurements. This uncertainty could result in a scatter of data which could be sufficient to mask changes in pump capability that is indicative of degradation. This could result in false positive results. To minimize the potential for false positive results ASME Section XI established criteria for testing instrumentation.

ASME Section XI (1989 Edition, OM-1987/OMa-1988 Addenda) requires testing to assess the operational readiness of selected centrifugal and positive displacement pumps. Testing criteria uses reference values established at points of operation readily duplicated during subsequent tests. All subsequent tests are compared to the initial reference values to monitor degradation. Deviations detected are symptoms of changes and, depending upon the degree of deviation, indicate need for further tests or corrective action. The instrumentation relied on to evaluate degradation is intended to be good commercial grade quality that are repeatable from one test to the next. The ASME OMa-1988 Addenda to the OM-1987 Code (Part 6) provides the acceptance criteria for instrumentation to be used in this application.

1. Accuracy: Per Section 4.6.1, "Instrumentation" refers to station instruments used to trend and predict pump degradation and must have an accuracy as stipulated in Table 1 as noted below:

Parameter	Accuracy - Percent Full Scale[8]
Pressure	±2%
Flow Rate	±2%
Speed	±2%
Vibration	±5%
Differential Pressure	±2%

8 Percent full scale for individual analog, percent total loop accuracy for a combination of instruments, or the calibrated range for digital instruments. Flow elements are not included in the flow rate accuracy determination.

2. Range:

   a. The full scale range of each analog device shall be ≤3-times the reference value. Reference values are established from the preservice testing or the first inservice test.

   b. When digital instrumentation is used, the reference value shall be ≤70% of the calibrated range.

3. Measurement:

   a. Static head based on a filled sensing line (or based on a voided sensing line) where the absence or presence of fluid could impact a pressure reading by more than 0.25% must be considered. The consideration could be that verification of the appropriate static head be made.

   b. A differential pressure sensor should be used when monitoring pressure difference across a pump (although this is not specifically required by the Code). If two separate pressure gauges are used instead (one at the suction side and one at the discharge side) to determine differential pressure, the accuracy of each gauge should be Root-Sum-Squared (RSS) to determine "loop" accuracy (the Code implies that only the individual pressure gauge accuracy needs to be considered; the RSS approach is a more conservative position and viewed as appropriate).

The criteria established assumes that conditions are repeatable from one test and the next. As such, applying a full instrument uncertainty analysis in accordance with ISA SP67.04 does not apply. OMa-1988, Part 6, Table 1 only considers instrument accuracy and does not take into account attributes such as orifice plate tolerance, tap locations, and process temperature (also refer to NUREG 1482 Section 5.5.4). ASME/ANSI OMa -1988, Part 6, Section 1.3 defines instrument accuracy as the allowable inaccuracy of an instrument loop based on the square root of the sum of the square of the inaccuracies of each instrument or component in the loop. Alternatively, the allowable inaccuracy of an instrument loop may be based on the output for a known input into the instrument loop. Accuracy is based on full scale range. Note that if the surveillance test includes the design basis criteria, than additional instrument uncertainty needs to be applied; design basis surveillance will be addressed as a separate subject.

Per Section 4.6.1.4, instruments shall be calibrated in accordance with the Owner's QA program. New or repaired instruments shall be calibrated before test use. Based on this, a calibration of test instruments is not required prior to each test (unless repaired or replaced) and instrument drift is not a required consideration.

It is anticipated that there will be gradual differences from one test and the next due to changes in performance. The differences are anticipated to be within predicted bounds. If there are deviations in the direction of degradation (or in the opposite direction) which are higher than predicted, then an evaluation of the instrumentation and the parameter being measured is warranted before determining operability.

Unless the cause of the excessive deviation is obvious, a calibration of the instrumentation loop should be performed. A comparison of the "as left" with the "as found" calibration data will determine instrument drift. If large enough, the instrument drift could be the major contributor to the excessive results. A successful retest would validate this conclusion. Other parameters which could cause the measurement system to provide excessive results are extreme differences from one test and the next of:

- Ambient temperature (electronic instrumentation)
- Process temperature (flow)

Example:

Pump differential pressure (DP) is monitored in the control room. An analog DP transmitter and an analog indicator are used. Reference value is 120 psid. IST on pump DP is performed quarterly; this is the third quarter test. The transmitter is connected to the process via filled impulse lines. The transmitter is located 10-feet below the process taps. The process taps are located at the pump discharge and suction along the horizontal plane. Instrument loop calibrations are performed yearly. The instrument component accuracy specifications are as follows:

Full scale range:	200 psid
Transmitter:	±0.5% of full scale range (Manufacturer's published data)
Indicator:	±2.0% of full scale range (Manufacturer's published data)
RSS Method:	$\pm(0.5\%^2 + 2.0\%^2)^{1/2} = \pm 2.06\%$ of full scale
Loop cal method:	Input pressure using highly accurate M&TE and reading output from board indicator. If an input pressure of 120 psid reads at the indictor 122 psid, then the full scale loop accuracy is 1%.

Evaluation:

1. The criteria of Table 1 is 2% of full scale. The calculated loop accuracy is ±2.05% of full scale. Therefore, the primary method of determining accuracy criteria is not satisfied. However, an alternative approach yields an acceptable full scale accuracy of 1%.

2. The transmitter is located below the process line and the tap is center of the pipe. It is maintained filled by gravity. Therefore, no additional considerations are needed.

3. A single pressure differential monitoring device is used.

4. Calibration has been performed within the past year.

5. The reference value is 120 psid. The full scale range is 200 psig. The full scale range is <3 times reference.

Therefore, use of this loop is acceptable for IST.

If a loop calibration is not available, an evaluation of component drift can be applied. In this case, the accuracy component would be considered to be fully representative by the drift evaluation results. When drift is used, it should be evaluated as a Class 3 setpoint and apply the 95%/75% criteria (95% probability with a 75% confidence level). This applies providing the calibration is performed in the direction of interest. Specifically, if the degradation is anticipated to trend in the decreasing direction, then the calibration must include a verification in the decreasing direction. However, it is preferable that the calibration be both in the increasing and decreasing direction.

ATTACHMENT I: Instrument Cross Comparison Averaging Methodology

The difference between a parameters actual (true) value and the value indicated to the operator is the instrument uncertainty associated with the loop. When the same parameter is being monitored by multiple loops, the outputs can be combined together to provide an average reading of the parameter.

It stands to reason that the more independent readings provided for a given parameter that are averaged together the averaged loop uncertainty will diminish, For example:

> Taken to an extreme, a thousand instrument loops monitor the same temperature parameter. Each instrument loop exhibits and uncertainty of $\pm 4°$ F. This uncertainty is random in nature and at any time can be positive (+) or negative (-). Taken alone, each loop would be considered to be accurate to within $\pm 4°$F. However, when the accuracy component of all 1000 instrument loops are average together, the random nature of this variation will essentially result in a negligible uncertainty.

This approach can be applied anytime a variable has multiple readings that are averaged to provide a single value. It must be recognized that as the number of independent readings decreases, the value of the uncertainty increases. The uncertainties are not averaged together in a true Average nor is the uncertainty halved as the monitoring points double. Instead, a nonlinear approach is applied. A comparison of the techniques discussed follows:

Two temperature readings of the same variable; each loop has an uncertainty of $\pm 5°$F:

1. Adding uncertainties arithmetically:
   Total uncertainty = $\pm$ (5°F+5°F) = $\pm$ 10°F

2. Averaging uncertainties linearly:
   Total uncertainty = $\pm$ (5°F+5°F)/2 = $\pm$ 5°F

3. Averaging uncertainties linearly then dividing the square of the number of loops:
   Total uncertainty = $\pm$ (5°F+5°F)/2^2 = $\pm$ 2.5°F

4. Averaging uncertainties non-linearly:
   Total uncertainty = $\pm (5^{2}°F+5^{2}°F)^{1/2}/2 = \pm 3.54°F$

Extending the above example to include three temperature readings of the same variable; each again with an uncertainties of $\pm 5°$F:

1. Adding uncertainties arithmetically:
   Total uncertainty = $\pm$ (5°F+5°F+5°F) = $\pm$ 15°F

2. Averaging uncertainties linearly:
   Total uncertainty = $\pm$ (5°F+5°F+5°F)/3 = $\pm$ 5°F

3. Averaging uncertainties linearly then dividing the square of the number of loops:
Total uncertainty = $\pm$ (5°F+5°F+5°F)/3^2 = $\pm$ 1.7°F

4. Averaging uncertainties non-linearly:
Total uncertainty = $\pm$ (5^2°F+5^2°F+5^2°F)$^{1/2}$/3 = $\pm$ 2.3°F

Options 3 & 4 both provide a method that supports the premise that as the sampling points increase the uncertainty contribution decreases. Option 3 is basically obtaining the average of the uncertainty of all the loops and then dividing the averaged uncertainty by the number of loops, or:

Total Uncertainty =$\pm$ (5°F+5°F+5°F)/3 = $\pm$ 5°F/3 = $\pm$ 1.7°F

However, the non-linear averaging technique (option 4) is a more conservative method. Taken to an extreme, the non-linear averaging performs as follows:

- 1 Sampling Point: Total Uncertainty = $\pm$ (1 * 5^2°F)$^{1/2}$/1 = $\pm$ 5°F
- 2 Sampling Points: Total Uncertainty = $\pm$ (2 * 5^2°F)$^{1/2}$/2 = $\pm$ 3.54°F
- 5 Sampling Points: Total Uncertainty = $\pm$ (5 * 5^2°F)$^{1/2}$/5 = $\pm$ 2.2°F
- 10 Sampling Points: Total Uncertainty = $\pm$ (10 * 5^2°F)$^{1/2}$/10 = $\pm$ 1.6°F
- 25 Sampling Points: Total Uncertainty = $\pm$ (25 * 5^2°F)$^{1/2}$/25 = $\pm$ 1.0°F
- 50 Sampling Points: Total Uncertainty = $\pm$ (50 * 5^2°F)$^{1/2}$/50 = $\pm$ 0.71°F
- 100 Sampling Points: Total Uncertainty = $\pm$ (100 * 5^2°F)$^{1/2}$/100 = $\pm$ 0.5°F
- 500 Sampling Points: Total Uncertainty = $\pm$ (500 * 5^2°F)$^{1/2}$/500 = $\pm$ 0..22°F
- 1000 Sampling Points: Total Uncertainty = $\pm$ (1000 * 5^2°F)$^{1/2}$/1000 = $\pm$ 0.16°F
- 10000 Sampling Points: Total Uncertainty = $\pm$ (10000 * 5^2°F)$^{1/2}$/10000 = $\pm$ 0.05°F

As is evident, the uncertainty approaches zero but can never reach it. The mathematical model for non-linear averaging is:

Non-linear Average = $\pm$ ($A1^2 + A2^2 + AN^2$)$^{1/2}$ /BN = $\pm$ C

Where: A1, A2, AN	=	Individual loop uncertainty
BN	=	Total number of loops monitoring the parameter
C	=	Average uncertainty

This same non-linear average would also be used to perform channel checks. For comparison of two different channels the two sample point calculation would be used to determine the maximum value of the difference between the two indications or recordings. The total loop uncertainty associated with the indications should be used. Where channel checks between multiple channels will be performed the difference between any two readings is defined as above, however the difference between multiple channels would be calculated based on the total number of channels evaluated.

ATTACHMENT J: Instrument Uncertainty and Performance Monitoring

There are several considerations when analyzing instrument uncertainty in regards performance monitoring.

1. Technical Specifications: Surveillance tests are required to validate operability of selected components.

2. Component Protection: Limiting conditions are identified which must be satisfied to ensure damage does not occur to components.

3. Analysis: Values (analytical limits) that are used in safety related analysis.

   Unless stipulated otherwise, the values are absolute limits, i.e., "not to be exceeded". These limits are not nominal values. The limits apply to both manual and automatic functions. Automatic functions are evaluated as setpoints and are addresses in detail in the Vermont Yankee Setpoint and Uncertainty Design Guide.

   Manual functions, such as Core Spray pump flow surveillance, rely on monitoring instrumentation to determine performance characteristics. The monitoring instrumentation inherently includes an accuracy component, which can cause the information presented to the operator to be erroneous, i.e., instrument uncertainty. To ensure limits are not exceeded, the acceptable value must consider instrument uncertainty.

   The following guidance will apply:

   1. Custom Technical Specifications (CTS): Limits identified in CTS apply during normal plant operation. Therefore, only normal operating parameters need to be considered. These limits fall into two categories:

      a. Limits associated with parameters used in safety related analysis, and
      b. Limits that are not associated with safety related analysis.

      When a parameter is used in a safety related analysis, the CTS operability test (surveillance test) verifies that the component will perform in a manner that will support assumptions of the analysis. However, the bases for the CTS values is that as long as the plant operates within those limits during normal operation, the components will perform as required when exposed to abnormal conditions.

      If a CTS parameter limit is also used in a safety related analysis, the instrument uncertainty evaluation will require a high degree of rigor. In this case, the uncertainty analysis would be evaluated as a Class 1 setpoint (95% probability that the true parameter value is validated by the surveillance test wit a 95% confidence).

If the CTS parameter limit is *not* used in a safety related analysis, the instrument uncertaintyevaluation does not require as high a degree of rigor. In this case, the uncertainty analysis would be evaluated as a Class 3 setpoint (75% probability that the true parameter value is validated by the surveillance test with a confidence of 95%).

When not sure, the higher level of rigor should be applied. In addition, manufacturer's data is typically provided as 2 sigma (95%) probability. If only manufacturer's data is available, the 95%/95% criteria would have to be applied in either case. In all cases, the uncertainty analysis is to be prepared in accordance with ISA S67.04.

Example #1:

CTS require Core Spray pump surveillance. The CTS limit is 22700 gpm flow at a discharge pressure of ≤90 psig. Core Spray flow is a parameter used in a safety related analysis. The Analytical Limit is 2300 gpm at a discharge pressure of 80 psig.

a. A 95%/95% uncertainty analysis is required. Assume an indicated flow uncertainty of +200 gpm and an indicated pressure uncertainty of +7.5 psig.

b. To ensure an actual flow of 22700 gpm, the surveillance criteria must account for the 200 gpm uncertainty in the indicated reading. Therefore, the acceptance criteria must be 22900 gpm.

c. To ensure an actual pressure ≤90 psig, the surveillance criteria must account for the 7.5 psig uncertainty in the indicated reading. Therefore, the acceptance criteria must be ≤82.5 psig.

This approach ensures the Analytical Limit is not compromised. By proving the pump is operable during normal plant conditions, the pumps will be capable of providing the flow assumed in the analysis.

Example #2:

CTS require Core Spray pump surveillance. The CTS limit is 22700 gpm flow at a discharge pressure of ≤90 psig. Core Spray flow is *not* a parameter used in a safety related analysis.

a. A 95%/75% uncertainty analysis is required. Assume an indicated flow uncertainty of ±150 gpm and an indicated pressure uncertainty of ±5.0 psig.

b. To ensure an actual flow of 22700 gpm, the surveillance criteria must account for the 150 gpm uncertainty in the indicated reading. Therefore, the acceptance criteria must be 2850 gpm.

c. To ensure an actual pressure $\leq$90 psig, the surveillance criteria must account for the 5.0 psig uncertainty in the indicated reading. Therefore, the acceptance criteria must be <85.0 psig.

This approach ensures the CTS Limit is not compromised. The pump is operable during normal plant conditions. It would be expected to perform when called upon to do so.

2. Improved Technical Specifications (ITS): Values identified in ITS are Allowable Values. They are not limits, but are developed from the analytical limits used in safety related analysis. ITS includes only the parameters assumed in safety related analysis.

The ITS operability test (surveillance test) verifies that the component will perform in a manner which will support assumptions of the analysis. The Allowable Value takes into account the instrument uncertainty associated with the performance monitoring instrumentation. The uncertainty analysis would be evaluated as a Class 1 setpoint (95% probability that the true parameter value is validated by the surveillance test 95% of the time) and is prepared in accordance with ISA S67.04.

In the case of Allowable Value, there is no additional instrument uncertainty to be considered.

Example:

ITS requires Core Spray pump surveillance. The ITS Allowable Value is >2900 gpm flow at a discharge pressure of <80 psig. The surveillance test only needs to consider the Allowable Value as the final acceptance criteria for operability determination. This approach ensures the Analytical Limit is not compromised. By proving the pump is operable in within the Allowable Value during normal plant conditions, the pumps will be capable of providing the flow assumed in the analysis.

3. Component Protection: Limits are imposed on selected equipment to prevent component damage. These limits are imposed via Operator training and procedures. These limits are typically mandated by the equipment manufacturer but can also have been determined from operating experience. These limits are not part of any safety related analysis. However, it is necessary to conform to the operating limits imposed to ensure the equipment will be available when required to perform its safety related function.

Example:

The pump vendor requires a minimum Core Spray pump flow of >300 gpm for the first half hour of operation and >2000 gpm thereafter. The 300 gpm flow requirement is automatically satisfied by the design of the Core Spray pump minimum recirculation flow piping. A setpoint analysis ensures the pump minimum recirculation valve remains open until there is at least 300 gpm flow. At 2000 gpm, assume an instrument uncertainty of +250 gpm.

The 2000 gpm minimum flow is controlled by manual Operator action. The operating procedure must account for the 250 gpm instrument uncertainty. Therefore, to ensure the 2000 gpm pump minimum recirculation flow requirement is satisfied, the procedure must stipulate a minimum flow of >2500 gpm be maintained after the first half hour.

4. Safety Related Analysis: Unless otherwise noted, values applied in safety related analysis are Analytical Limits. Analytical Limits used in a safety related analysis require that the a high degree of rigor be imposed in the determination of the instrument uncertainty evaluation. In this case, the uncertainty analysis would be evaluated as a Class 1 setpoint (95% probability that the true parameter value is validated by the surveillance test 95% of the time). The uncertainty analysis is to be prepared in accordance with ISA S67.04.

Example:

Core Spray flow is an input to a safety relate analysis. The Analytical Limit is 2300 gpm based on Operator action during an accident.

a. A 95%/95% uncertainty analysis is required. Assume an indicated flow uncertainty of 200 gpm.

b. To ensure an actual flow of 22300 gpm, the Operator action must account for the 250 gpm uncertainty in the indicated reading. Therefore, the acceptance criteria must be ≥2550 gpm.

This approach ensures the Analytical Limit is not compromised. The Operator will provide the flow required to perform the required safety related function and there is assurance that the safety analysis remains valid.

5. In general, linear instrument loops will have a fixed uncertainty that will apply at any given reading (such as temperature or pressure). However, non-linear instrument loops will have a varying uncertainty dependent on where along the scale the reading is taken. To address flow loop performance operability a series of flow curves should be developed. The flow curve should consist of:

   a. The pump curve associated with the analytical or performance limit. This curve is the minimum (or maximum) acceptable set of pump flow and head conditions. These conditions must be met or exceeded for pump operation. The Technical Specification limiting Condition for Operation condition. This condition is the Technical Specification limitations for pressure and flow. The pump curve design pressure (psig") vs. design flow (gpm), also referred to as the pump head curve.

   b. The final curve to be developed is the required test curve to ensure conformance to the Technical Specification limit and the Analytical Limit. This curve is based on the the Technical Specification Limiting condition for operation and the errors associated with the flow and pressure measurement methods.

      1. Determine the error associated with the pressure measurement and flow measurement methods. These errors may be constant over the range of measurement or may vary depending on scale position.

      2. Select a point on the LCO condition curve. Determine the flow and pressure coordinates for this point on the curve. Apply the error calculated for the pressure measurement method to the pressure coordinates of the point and draw a line parallel to the x axis equivalent to this pressure plus error (assuming flow and pressure on the LCO curve are for minimum conditions. Perform the same steps for the flow coordinates. Where these two lines meet are the coordinates for the equivalent point on the required testing curve.

      3. Repeat this process for representative points on the curve until a smooth required test curve can be drawn.

      4. Table 1 shows selection of a point on the curve, the application of flow and pressure measurement errors and the resulting point on the required test curve. Note: where errors are not constant for the entire range of measurement, lines may either converge or diverge.

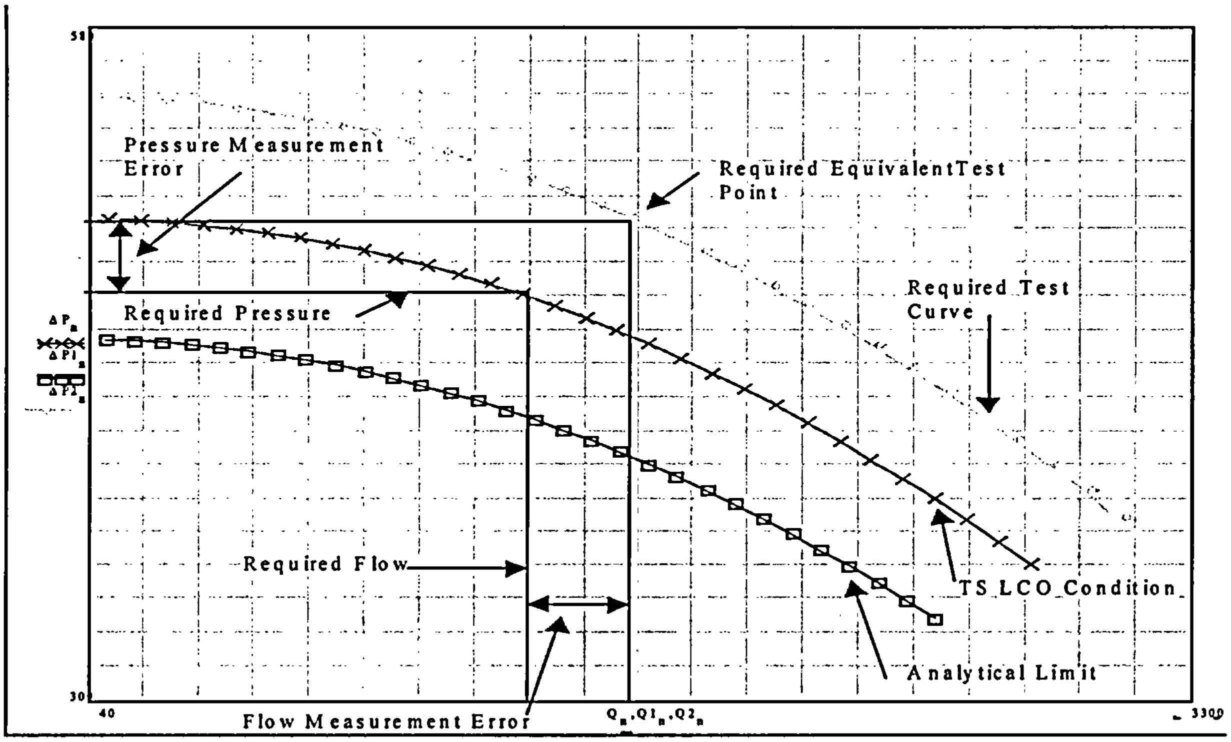

Table 1 Required Test Curve Single Limit

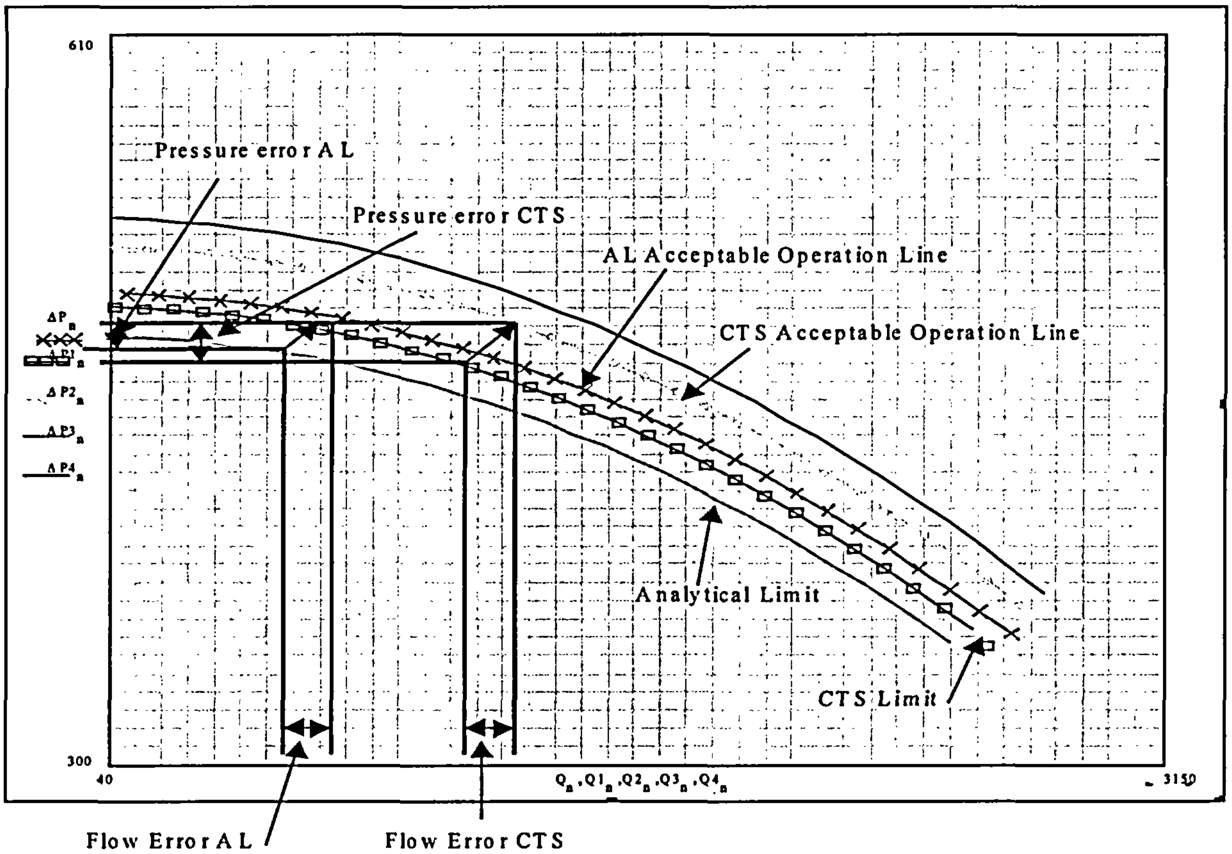

Table 2 Required Test Curve Analytical lim it and Technical Specification Limit

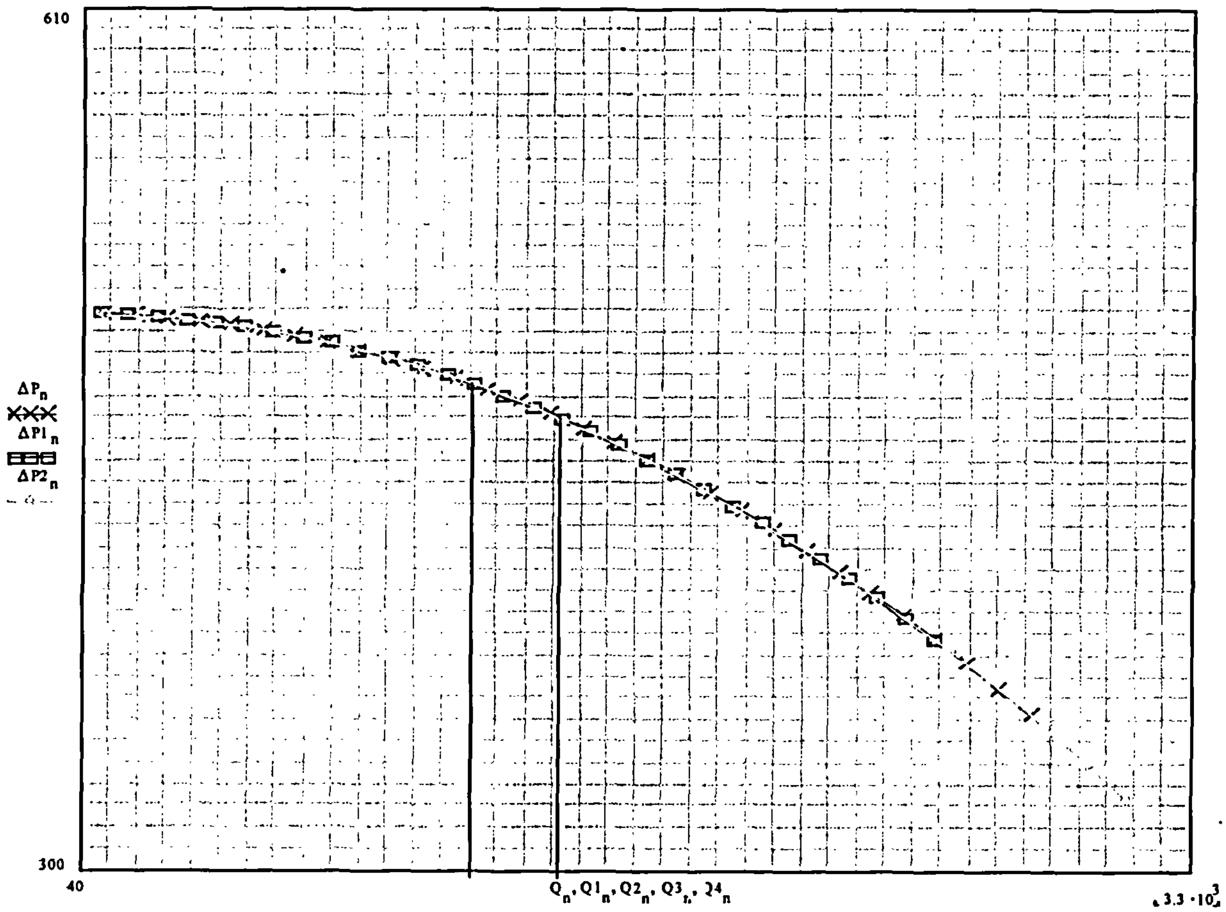

Figure 3
Gpm only adjusted results in no change in x axis only change in y axis

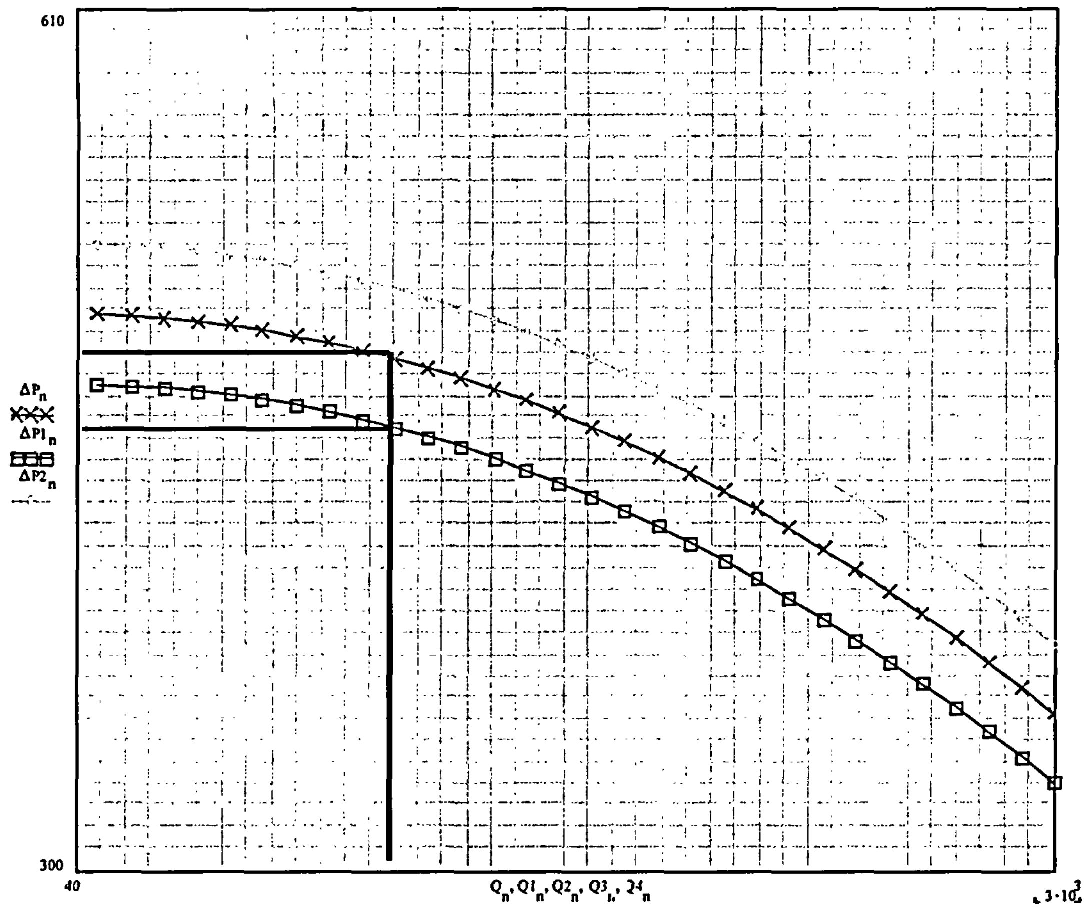

Figure 4

All errors have been converted to pressure errors. Note the the data points

6. For certain special testing conditions test personnel may be required to combine several different variables together to verify acceptability with a single performance criteria (i.e. flow, temperature, pressure and velocity to determine total developed head). When this occurs the error associated with each of the measurement methods must be considered as discussed previously. However, in these special conditions the method of combining the various inputs to provide a single acceptance criteria may also generate, significantly magnify or compress the measurement errors. One method to determine the specific contribution of the measurement and calculation errors associated with the testing method is discussed below.

a Perturbation of values to determine weighted values to be used in an SRSS error combination. This is best explained by a simple example.

Evaluating the following simplified flow formula:

$$Q = K * \sqrt{\Lambda P}$$

It is obvious from the equation that an error associated with the K value would not have the same impact as an error associated with the delta P term. To determine the actual impact of errors, evaluate the equation for normal testing conditions. For this example we will assume that both K and delta P are equal to 100.

$1000 = 100 * \sqrt{100}$

To determine the actual effect of an error for each term, we test each term with an identical error and evaluate the impact of this error on the result. First assume a 10% error for K:

$1100 = 110 * \sqrt{100}$
$900 = 90 * \sqrt{100}$ an error of 100 for a positive or negative error

Next assume a 10% error for the delta P term. Note: the error magnitude selected for the test may not be realistic for all of the different terms. However, the test must use equivalent values to provide appropriate weighting.

$1048.80 = 100 * \sqrt{110}$
$948.68 = 100 * \sqrt{90}$ or an error of 48.8 for a positive error and of 51.32 for negative errors.

Based on this evaluation if we combined the errors together using an SRSS approach the delta P error would have a 0.488 or 0.513 (depending upon the direction of interest) multiplier while the error associated with K would have a multiplier of 1.

ATTACHMENT K: Maximum Allowable Deviation Limit

The Improved Technical Specifications (ITS) NUREG 1433 requires instrument channel checks. NUREG 1433 (Standard Technical Specifications General Electric Plants, BWR/4 NUREG-1433 R1 April 1995) defines CHANNEL CHECK as:

> "... the qualitative assessment, by observation, of channel behavior during operation. This determination shall include, where possible, comparison of the channel indication and status to the other indications or status derived from independent instrument channels measuring the same parameter".

The Standard Technical Specification Bases for the Channel Check Surveillance Requirement states,

> "Performance of the CHANNEL CHECK once every XXX hours ensures that a gross failure of the instrumentation has no occurred".

A Channel Check is normally a comparison of the parameter indicated on one calibrated channel to a similar parameter on other calibrated channels. It is based on the assumption that instrument channels monitoring the same parameter will read approximately the same value. Significant deviations between instrument channels could be indicative of excess instrument drift in one of the channels or a prelude to a more serious failure. A Channel Check will detect gross channel failure; thus, it is a key to verifying the instrumentation continues to operate properly between each channel calibration.

Channel Check acceptance criteria are determined by the plant staff based on a combination of the channel instrument uncertainties, including indication and readability. If a channel is outside the established criteria, it could be an indication that the instrument is performing outside its intended functional use.

For Vermont Yankee, the Maximum Allowable Deviation Limit (MADL) defines the allowable difference between readings of a common parameter. MADL is the largest value difference between channels measuring the same parameter which can exist before the operability of the channel is questioned. The industry has not adopted a standard for determining MADL. For MADL analysis, the smaller differences are the more conservative.

MADL will be determined by combining the random uncertainties associated with an instrument loop using the Root-Sum-Square methodology. This methodology of combining random and independent uncertainties is endorsed by ISA S67.04 for setpoint and uncertainty analysis. MADL criteria is to be based on the following:

1. More than two (2) identical instrument channels monitoring the same parameter - MADL will be defined as twice the random uncertainty associated with one instrument channel. When there are more than two instrument channels random errors should be clearly defined and it should be readily apparent which channel is in question.

   $MADL = 2 * \pm(A^2 + DR^2 + CE^2 + TE_N^2)^{1/2}$ Rounded up to the nearest minor division, Where:

- A, DR, CE, & TE_N are the random uncertainties associated with one channel. Alternately, where multiple indications being verified are connected to a single transmitter, the terms should be limited to the errors associated with the unique loop components being compared. The uncertainty values are provided from manufacturers published specifications, or, where drift analysis is available,

- A, DR, CE, & TE_N (or portion thereof) is the standard deviation representing normal operating conditions associated with one channel.

2. Two (2) identical instrument channels monitoring the same parameter - MADL will be defined as the random uncertainty associated with one instrument channel. When there are only two (2) instrument channels, determining which channel is in question becomes more difficult. Additional investigation will be needed to determine which channel is not operable.

$MADL = 1 \times \pm(A^2 + DR^2 + CE^2 + TE_N^2)^{1/2}$ Rounded up to the nearest minor division,

Where:

- $A + DR + CE + TE_N$ are the random uncertainties associated with one channel. Alternately, where multiple indications being verified are connected to a single transmitter, the terms should be limited to the errors associated with the unique loop components being compared. The uncertainty values are provided from manufacturers published specifications, or, where drift analysis is available.

- A, DR, CE, & TE_N (or portion thereof) is the standard deviation representing normal operating conditions associated with one channel.

3. Two (2) or more instrument channels monitoring the same parameter that differ from each other – MADL will be defined as a combination of the two channels exhibiting the smallest and largest random uncertainties. The combination of each channel uncertainty will be by using the standard RSS methodology.

An example would be to compare eight (8) level loops; four (4) identical channels that are ranged 100-inches, two (2) identical channels that are ranged 110-inches, and two (2) identical channels that are ranged 60-inches.

Step 1: Determine the random uncertainty associated with each set of identical channels.

$MADL\text{-}100 = 1 \times \pm(A_{100}^2 + DR_{100}^2 + CE_{100}^2 + TE_{N100}^2)^{1/2} = X$
$MADL\text{-}110 = 1 \times \pm(A_{110}^2 + DR_{110}^2 + CE_{110}^2 + TE_{N110}^2)^{1/2} = Y$ (largest random uncertainty)
$MADL\text{-}60 = 1 \times \pm(A_{60}^2 + DR_{60}^2 + CE_{60}^2 + TE_{N60}^2)^{1/2} = Z$ (smallest random uncertainty)

$MADL_{all\,8} = 1 \times \pm(Y^2 + Z^2)^{1/2}$ Rounded up to the nearest one-half of a minor division where possible. In some cases, an adjustment might be required due to scaling differences. This adjustment should be based on engineering judgement keeping the MADL as close as practical to the value determined above yet providing a value that can be read from all scales.

Where:

- A, DR, CE, & TE_N are the random uncertainties associated with one channel. The uncertainty values are provided from manufacturers published specifications, or, where drift analysis is available,
- A, DR, CE, & TE_N (or portion thereof) is the standard deviation representing normal operating conditions associated with one channel.
- X, Y, & Z are the RSS values associated with the random uncertainties associated with each identical channel.
- $MADL_{all\,8}$ is the RSS value associated with the channels exhibiting the smallest and largest random uncertainty.