

**Engineering Standard
ES-002**

**Instrument Error Calculation and
Setpoint Determination**

This standard addresses:

- ✓ A uniform method for establishing setpoints for instrumentation channels; factors that must be considered when establishing instrument setpoints and how these factors are combined.

Approved By: Richard J. McGoey
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1.0 PURPOSE & SCOPE

This design standard describes a uniform method for establishing setpoints for instrumentation channels. Setpoints are intended to initiate corrective or protective actions in a timely manner before the safety of people and/or equipment are endangered. Therefore, those factors that influence the accuracy of the instruments initiating the setpoint function must be considered to assure that the instrument trip signal will be generated when it is required. This standard addresses the factors that must be considered when establishing an instrument setpoint and how these factors are combined. Included are the relationships of the instrument setpoint to the various limits of normal operation, design basis event environmental conditions, and calibration and surveillance testing. The scope of this standard does not include the methods for determining equipment protective values, process safety limits, safety factors that should be utilized, or design basis event analysis that apply. Factors affecting instrument accuracy are described, along with methods for calculating their impact on overall loop accuracy, and setpoint.

2.0 APPLICABILITY

This standard shall apply to new designs, modifications of design, and for new calculations required for safety system instruments with setpoints where specific actions are either initiated, terminated or prohibited. The methods in this standard shall apply to both safety related and Balance of Plant (BOP) calculations.

Error calculations that utilize this standard shall address every item in the Requirements Section 5.0. If a requirement of this standard is evaluated as not applicable, then the calculation shall provide a statement of the reasons why it is not included.

3.0 REFERENCES

- 3.1 ISA-S51.1 (1979) Process Instrument Terminology.
- 3.2 ISA-S67.04 (1982) Setpoints for Nuclear Safety-Related Instrumentation Used In Nuclear Power Plants.
- 3.3 Regulatory Guide 1.105 revision 2 (February 1986) Instrumentation Setpoints for Safety-Related Systems.
- 3.4 NUREG/CR-3691 (September 1984) An Assessment of Terminal Blocks in the Nuclear Power Industry.

4.0 DEFINITIONS

- 4.1 Accuracy - In process instrumentation, degree of conformity of an indicated value to a recognized accepted standard value, or ideal value (Ref. 1).

- 4.2 **Accuracy, Measured** - The maximum positive and negative deviation observed in testing a device under specific conditions and by a specified procedure. (Ref.3.1)

NOTE

Note 1: It is usually measured as inaccuracy and expressed as accuracy.

Note 2: It is typically expressed in terms of the measured variable, percent of span, percent of upper range-value, percent of scale length or percent of actual output reading.

- 4.3 **Accuracy Rating** - 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. (Ref. 3.1)

NOTE

Note 1: When operating conditions are not specified, design 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 \pm sign precede the number or quantity. The absence of a sign indicates a + and a - sign.

- 4.4 **Design Basis Event Analysis** - That analysis used to determine safety system responses to design basis events.
- 4.5 **Drift** - An undesired change in the output over a period of time. This change is unrelated to the input, environment, or load. (Ref. 3.1)
- 4.6 **Error** - In process instrumentation, the algebraic difference between the indication and the ideal true value of the measured signal. It is the quantity which algebraically subtracted from the indication gives the ideal value.

NOTE

A positive error denotes that the indication of the instrument is greater than the ideal value.

$$\text{Error} = \text{Indication} - \text{Ideal value (Ref.3. 1)}$$

- 4.7 Error. Environmental - Error caused by a change in a specified operating condition from reference operating condition.
- 4.8 Error. Process Measurement (EPM) - Process errors that include those inherent in the measurement technique, for example fluid stratification effects on temperature measurements, or the effect of fluid density changes on level measurement.
- 4.9 Error. Position - The change in output resulting from mounting or setting an instrument in a position different from that at which it was calibrated. (Ref.3. 1)
- 4.10 Error Random - In this design standard, all errors that are not systematic errors. Error due to no known cause, usually the net result of a large number of small effects. The value tends to cluster about a central point with a fairly equal spread above and below the central value.
- 4.11 Error. Systematic - An error which, in the course of a number of measurements made under the same conditions of the same value of a given quantity, either remains constant in absolute value and sign or varies according to a definite law when the conditions change.
- 4.12 Instrument Channel - An arrangement of components and modules that generate a single protective action signal when required by a generating station condition. A channel loses its identity where single protective action signals are combined. (Ref. 3.2)
- 4.13 Protective Action - The initiation of a signal or operation of equipment within the protection system or protective action system to accomplish a protective function in response to a generating station condition having reached a limit specified in the design basis. (Ref.3.2)
- 4.14 Safety Limit - A limit placed on important process variables that are necessary to reasonably protect the integrity of certain physical barriers guarding against the uncontrolled release of radioactivity. (Ref. 3.3)
- 4.15 Setpoint - An input variable that sets the desired value of the controlled variable.
- 4.16 Span - The algebraic difference between the upper and lower range values.

5.0 **REQUIREMENTS**

5.1 **Determination of Setpoints**

Setpoints shall be selected to provide sufficient margin between the protective action setpoint and the system protection limits to account for all the inaccuracy inherent in the instrument loop. This inaccuracy may be due to instrument inaccuracy, loop calibration tolerance, inaccuracy of the test equipment, process measurement inaccuracy, effects of transient overshoot, effects of time response characteristics, environmental effects, instrument drift, or the effects of normal process transients/upsets. Detailed requirements for the instrument setpoint relationships are delineated in this section and illustrated by Figure 1.

5.2 **Allowable Value (Technical Specification Limit)**

The technical specification limit shall be regarded as the operational allowable value. Operation within the allowable value shall provide assurance that automatic protective action will correct the most severe abnormal situation anticipated before a safety limit is exceeded.

- [1] The allowances between the allowable value (technical specification limit) and the safety limit shall include the following items unless they are included in the determination of the process safety limit.
 - a. The effects of potential transient overshoot as determined by the design basis event analysis.
 - b. The effects of the time response characteristics of the total instrument channel, including the sensor.
 - c. Environmental effects on instrument accuracy or time response characteristics caused by anticipated operational occurrences or design basis events for those instruments required to mitigate the consequences of such events.

[2] **Setpoints and Technical Specification Allowable Limits**

The setpoint value to initiate protective action, combined with the instrument loop inaccuracies at normal operating conditions, shall not exceed the Allowable Value (Technical Specification Limit). This margin between setpoint and allowable values shall provide allowance for:

- a. The tolerance specified in the instrument loop calibration procedure. This value is considered a systematic error for conservatism.
- b. All instrument random and systematic inaccuracies and drift that occur during normal environmental operating conditions.
- c. Accuracy of the test equipment used for surveillance testing the instrument channel.
- d. Process measurement accuracy such as the effects of fluid stratification and changing fluid density.

[3] Setpoints and Operational Limits

Referring to Figure 1, the normal desired operation reference line represents the nominal value the operator desires for the process. This nominal value of the process varies slightly with operational transients that are in an acceptable range to the operator and this is represented by the Operational Limit reference line. The instrument trip setpoint specified must provide sufficient margin to assure that inaccuracy and normal drift of the instruments do not cause the instrument to trip on process values within its Operational Limit.

[4] Setpoint Upper/Lower Limits (As Left Calibration Tolerance)

This is the tolerance specified in the surveillance test procedure that is acceptable without recalibration. The band between the setpoint and its upper or lower limit shall be broad enough to minimize the need for frequent instrument adjustment. The setpoint upper and lower limit (calibration tolerance) specified on the test procedure may be derived from historical maintenance data or other engineering sources. For new designs, the test tolerance shall be calculated to include the statistical combination of the two sigma random accuracy ratings of all the instruments that comprise the loop, and the accuracy ratings of the test equipment used to calibrate those instruments. This value is expressed with a plus and minus sign that defines the upper and lower setpoint limits. For new designs, the setpoint is determined by algebraically adding the calibration procedure tolerance to the calculated loop error. This is very conservative. Historical performance of the instrument loop may permit a reduction in this conservatism and subsequent setpoint readjustment.

[5] Acceptable-as-Found Limit

The Acceptable-as-Found limit also known as the surveillance test Acceptance Criteria at TMI-1, shall be used for the evaluation of surveillance test as-found data. This band defines acceptable drift limits of the instruments included in the surveillance test, and is used to confirm that the instrument loop has not drifted beyond an acceptable predicted value.

As-found limit shall include errors due to drift, temperature effect, and power supply effect in addition to those errors used to determine the upper/lower set point limit.

For some existing instrument loops at TMI-1 the surveillance test Acceptance Criteria (acceptable as found limit) is the same value as the setpoint upper/lower limit value. For these instrument loops the values were either derived from historical instrument performance data, or were specified by the manufacturer that provided the instrument loop.

Errors that are not measurable during a surveillance test are not included in the Acceptable-as-found limit. (e.g. Transmitter error when the transmitter is not part of the surveillance test.)

Instrument Setpoint Relationship

Note

This figure provides relative position only and is not intended to imply direction.

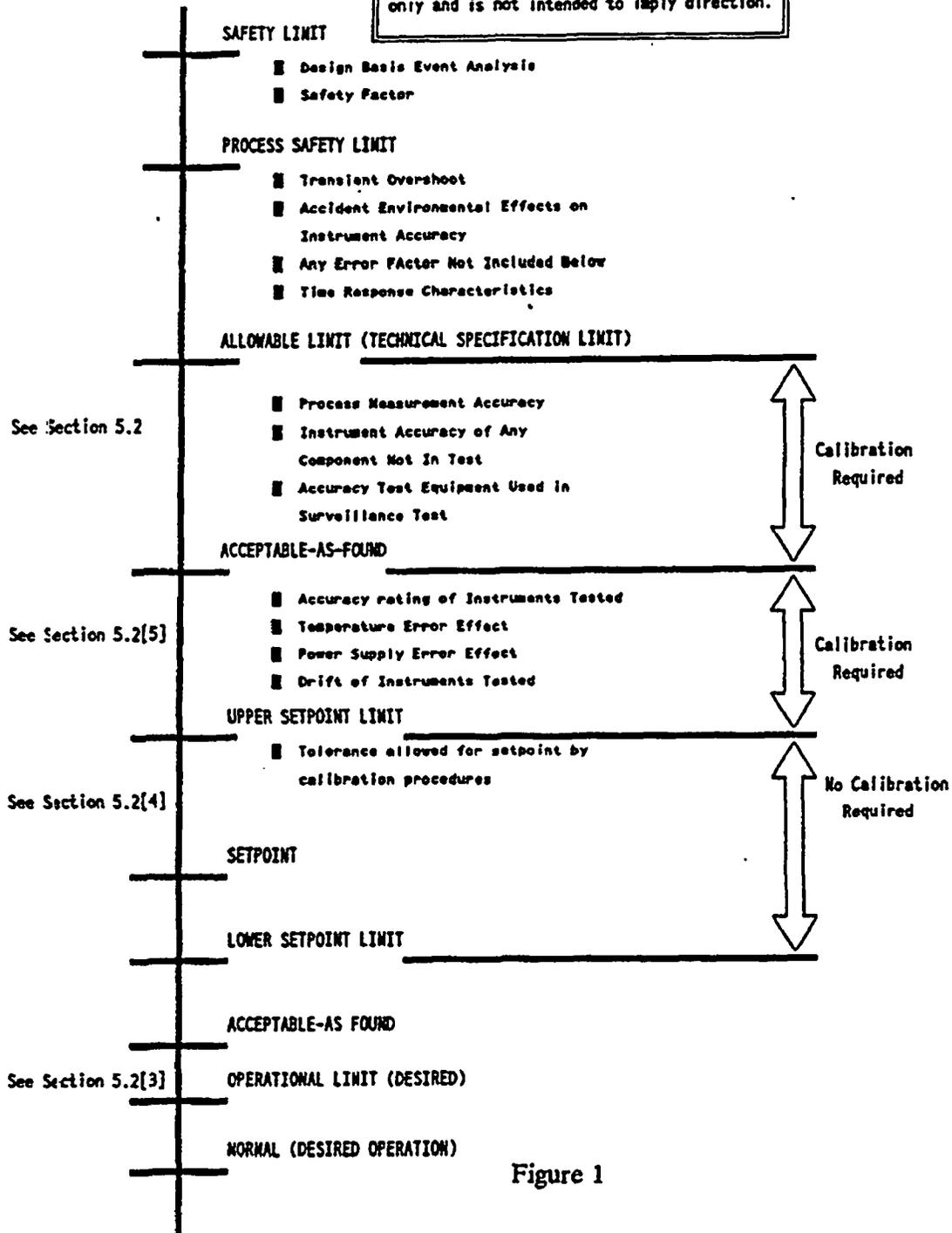


Figure 1

6.0 CALCULATIONS

6.1 Instrument Accuracy Baseline Data

- [1] Vendor product specifications and/or Environmental Qualification (EQ) files shall be used to obtain accuracy data for each instrument for normal and harsh environmental conditions. It is usual practice for instrument suppliers to express accuracy data as an upper limit based on test data inaccuracy values that none of their instruments will exceed (the confidence level is greater than 99.7%). It is conservative to assume that the vendor accuracy data unless otherwise specified, represents a probability distribution of three sigma with a confidence level of 99.7%.
- [2] For accuracy calculations the NRC staff has accepted 95.5% (two sigma value) as a probability limit for errors (Ref.3.3). Therefore all calculations shall utilize all baseline data of random values at two sigma to provide loop accuracy and set point values at a two sigma probability.
- [3] Three sigma baseline values can be converted to two sigma by multiplying by two-thirds.
- [4] In an accuracy calculation of an instrument string of two or more components convert all individual component errors into the common unit for the variable of concern. For example, a string consisting of a differential transmitter, an analytical unit and a meter may have their individual accuracies expressed as % full range (psi), % of output (mv), and % of scale (ft. of water). If the variable of concern is ft. of level, the accuracy of each component should be converted to feet of level for the calibrated range of the application.

6.2 Combining Accuracy Errors

The accuracy error values of the instrument loop are combined using the following methods:

- [1] All errors identified as random errors will be combined using the square root of the sum of the squares method.
- [2] Systematic errors will be combined by algebraic summation.
- [3] The total inaccuracy is the algebraic sum of the total random error and total systematic error.

6.3 Discussion of Accuracy Calculations

Following is a discussion of various errors to be considered.

[1] Process Measurement

Process errors in measurement are caused by process variables other than that being measured. Flow and level measurements using differential pressure transmitters are subject to errors due to changes in the temperature and the static pressure of the process fluid.

Temperature and pressure change influence the density of the fluid. This changes the output of primary flow elements. It also changes the pressure produced by a given level of fluid in a vessel or a level reference leg. Differential pressure transmitters are calibrated to measure flow or level at a particular fluid pressure and temperature. Any change from this condition produces an error. The error must be computed for the fluid pressure and temperature change of interest and expressed as a percent of the differential pressure span to which the transmitter is calibrated.

[2] Static Pressure Errors

Differential pressure transmitters can be calibrated to correct for the systematic error from zero and span shifts at a particular static pressure. Any deviation from the calibration pressure caused by either a transient or a change in operating conditions will produce a new error due to zero span shifts. When a differential pressure transmitter is operated at a pressure different from the pressure for zero systematic error over a range of static pressures then the systematic errors should be accounted for in the loop error calculation. Differential pressure transmitter manufacturers generally provide the error equations for their instruments.

Pressure instruments, absolute or gage, respond to the pressure head due to the height difference between the point-of-interest and the pressure sensor. Include a pressure head correction in both setpoint determination and accuracy calculations.

[3] Normal Accuracy

These calculations are performed taking into account normal (non-accident) conditions of humidity, temperature, etc., errors of the individual modules that comprise the loop considering the following:

- a. **Module Accuracy Rating** - The accuracy of the module under consideration include the combined effects of probable error introduced as a result of dead band, repeatability, hysteresis, etc.

- b. Calibration loop tolerance - This error is specified in the instrument loop surveillance test procedure. For new designs this error is calculated by statistically combining the two sigma values of the accuracy ratings of all the modules that comprise the surveillance test loop and the accuracies of the test equipment used during calibration.
- c. Temperature Error - This error is caused by changes in the module ambient temperature from calibration conditions over the design range.
- d. Drift - This error is caused by a change in accuracy within the design range conditions over a period of time.
- e. Power Source - These are errors introduced as a result of fluctuations in the power supply from calibration conditions over the design range.
- f. Test Instrument Error - This error is the accuracy of the test equipment used in the calibration or surveillance testing of the instrument. Where the test equipment tolerance is expressed as plus or minus % of reading a conservative (maximum) error value would be based on the upper (100%) calibrated span reading of the instrument.
- ° Calibration test equipment accuracies are used in calculating the calibration loop tolerance error (6.3[3]b).
- ° Surveillance test equipment accuracies are used in calculating the total loop error (5.2.[2]c).
- g. Miscellaneous Errors - Errors that may be peculiar to a particular module should be included, i.e., self heating.
- h. Wire Drop Errors - Errors introduced as a result of line drop, as signal current passes through dropping resistors, terminations, etc.
- i. Radiation Exposure

[4] Accident Accuracy

- a. Accident accuracy calculations are performed only for those instruments loops that have any component physically located in a harsh environment. Only those humidity, temperature, and radiation errors due to the accident environment are combined to define the Accident Accuracy.

Instruments are qualified to operate in the worst environment anticipated at its location. However, the accuracy calculations are performed for the intended function, and may utilize environmental limits that exist when the intended function is accomplished.

- b. The functional significance of the various accident errors may not be applicable when specific circuit functions and applications are reviewed. For instance, the instrument may have performed its protective function before it is exposed to maximum harsh accident environmental conditions. This is very common when considering Circuit Insulation resistance error. Good practice is to identify the error and state clearly the reasons or assumptions for not including the error in the accident calculation.

Where maximum accident temperature and radiation errors do not occur concurrently, perform two separate calculations and identify them by the time after the accident. Use the worst (greatest) error value of the two calculations to define the Accident Accuracy.

In those instances where the instrument product data sheets or EQ test reports provide error values for environmental conditions much more severe than the design basis event conditions, and the error calculations are not realistic, one of the following methods may be applicable:

- Request the instrument manufacturer provide specific accuracy values at the desired conditions and document the response with ED&CC and/or EQ files.
- Use straight line interpolation if the results will be conservative.

If the error is non-linear with the data points given, and is some unknown exponential function $e_N = e^N$, for $N > 0$ than a straight line interpolation will provide conservative error values between the extreme given values.

- c. For instruments using current loops low insulation resistance values due to condensation at terminations (e.g. terminal blocks) or due to cabling being in a high temperature ambient can cause significant instrument signal error due to current leakage. A method to derive that error is presented:

Effectively, an instrument transmitter performs as if it is a variable resistor with the resistance value proportional to the process condition.

Sandia National Laboratories, in NUREG/CR-3691 (Ref.3.4) described a reasonable basis for determining induced error due to low insulation or termination resistance. The following equivalent equation for expressing instrument error is provided:

$$e = \frac{V_s - R_e I_T}{I_T (R_{th} - R_e)}$$

Where: e = Fractional Error of Reading
 V_s = Source Voltage (Volts)
 R_s = Equivalent Series Resistance of Loop (Ohms)
 I_T = Transmitter Output Current (Amps)
 R_{in} = Insulation resistance of termination(s), cable/or splice
(Including Adjustment for Length and Circuit Configuration)
(Ohms)

[5] Time Response

Time response calculations are determined by algebraically adding together the response time of each instrument in instrument channel. Response time is provided on the manufactures product specification. Use the absolute value provided, or the value required to obtain one time constant.

The time response is analyzed to insure the integrity of the protective action is maintained by assuring that the process safety limit is not exceeded during the time required for the instrument channel to initiate the protective action signal.

**SUMMARY OF CHANGE
ORIGINAL ISSUE DATE:**

1/1/88

- Rev 1** This revision provides clarity to Setpoint and T.S. Allowable Limits (Section 5.2.2), Setpoint Upper/Lower Limits (Section 5.2.4), and Acceptable-as-Found Limit (Section 5.2.5); plus, adds Surveillance Test Tolerance Error to consider under Normal Accuracy error (Section 6.3.3), and deletes combination method requirements (Section 6.4) (5/22/89).
- Rev 2** This minor revision clarifies that the standard applies to safety related and BOP calculations.
- Rev 3** This revision satisfies a triennial review; and updates format and organizational titles. (2/17/93)
- Rev 4** Revised to clarify calibration for static pressure errors.