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Enclosure 1

Instrument Setpoint Methodology for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor (Non-Proprietary)

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Instrument Setpoint Methodology for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor

Topical Report

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Non-Proprietary

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EXECUTIVE SUMMARY

This report describes the methodology for establishing the Kairos Power Fluoride Salt-Cooled, High Temperature Reactors (KP-FHR) safety-related instrument setpoints. This methodology is used to analyze safety-related instrument channels associated with the KP-FHRs to classify uncertainties that may be present in instrument modules, determine environmental parameters to which each instrument module may be exposed, identify module transfer functions, and establish performance intervals and acceptance criteria for testing and calibration of safety-related instrumentation.

Kairos Power is requesting NRC review and approval of the methodology described in this report for establishing safety-related instrument setpoints of KP-FHR test and power reactors for use by licensing applicants under 10 CFR 50 or 10 CFR 52.

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1 INTRODUCTION

Kairos Power LLC (Kairos Power) is pursuing the design, licensing, and deployment of the Kairos Power Fluoride Salt Cooled, High Temperature Reactor (KP-FHR) technology including a non-power test reactor and commercial power reactors. To support these objectives, Kairos Power has developed an instrument setpoint methodology to establish safety-related setpoints associated with the KP-FHRs.

This topical report describes the methodology for establishing safety-related instrument setpoints associated with KP-FHRs. The methodology described in this report ensures that the setpoints for safety-related instrumentation and control systems are consistent with the assumptions made in the safety analysis, and that they have sufficient margin provided to account for instrument uncertainties to ensure reactor trip functions are actuated in a manner that will prevent safety limits from being exceeded. The methodology is consistent with American National Standards Institute(ANSI)/International Society of Automation (ISA) standard ANSI/ISA-67.04.01-2018, "Setpoints for Nuclear Safety-Related Instrumentation," requirements (Reference 1) as endorsed by Regulatory Guide 1.105, Revision 4, "Setpoints for Safety-Related Instrumentation," (Reference 2). The methodology considers recommended practices described in ISA -RP67.04.02-2010, "Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation," (Reference 3). The methodology described in this report is applicable to KP-FHR power reactors and non-power test reactor.

Kairos Power seeks NRC review and approval for the use of the methodology described in this report for establishing instrument setpoints that control safety-related functions in a KP-FHR for use by licensing applicants under 10 CFR 50 or 10 CFR 52.

1.1 DESIGN FEATURES

1.1.1 Design Background

To facilitate NRC review and approval of this report, design features considered essential to the KP-FHR technology are provided in this section. These key features are not expected to change during the ongoing detailed design work by Kairos Power and provide the basis to support the safety review. Should fundamental changes occur to these design features or revised regulations be promulgated that affect the conclusions in this report, such changes will be reconciled and addressed in future license application submittals.

The KP-FHR is a U.S. developed Generation IV advanced reactor technology. In the last decade, U.S. national laboratories and universities have developed pre-conceptual Fluoride High-Temperature Reactor (FHR) designs with different fuel geometries, core configurations, heat transport system configurations, power cycles, and power levels. More recently, University of California at Berkeley developed the Mark 1 pebble-bed FHR, incorporating lessons learned from the previous decade of FHR pre-conceptual designs. Kairos Power has built on the foundation laid by Department of Energy (DOE)-sponsored university Integrated Research Projects (IRPs) to develop the KP-FHR.

Although not intended to support the findings necessary to approve this topical report, additional design description information is provided in the technical report "Design Overview of the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor" (Reference 4).

1.1.2 Key Design Features of the KP-FHR

The KP-FHR is a high temperature reactor with molten fluoride salt coolant operating at near-atmospheric pressure. The fuel in the KP-FHR is based on the Tri-Structural Isotropic (TRISO) high-temperature, carbonaceous-matrix coated particle fuel (originally developed for high temperature gas-cooled reactors—HTGRs) in a pebble fuel element. Coatings on the particle fuel provide retention of fission products. The reactor coolant is a chemically stable molten fluoride salt mixture, 2 LiF: BeF_2 (Flibe) which also provides retention of fission products that escape from any fuel defects. A primary coolant loop circulates the reactor coolant using pumps and transfers the heat via a heat exchanger. The design includes decay heat removal for both normal conditions and postulated event conditions. Passive decay heat removal, along with natural circulation in the reactor vessel, is used to remove decay heat in response to a postulated event. The KP-FHR does not rely on electrical power to achieve and maintain safe shutdown for postulated events.

Instead of the typical light water reactor (LWR) low-leakage, pressure retaining containment structure, the KP-FHR design relies on a functional containment approach similar to the Modular High Temperature Gas-Cooled Reactor (MHTGR). The KP-FHR functional containment safety design objective is to meet 10 CFR 50.34 (10 CFR 52.79) offsite dose requirements at the plant's exclusion area boundary with margin. A functional containment is defined in Regulatory Guide (RG) 1.232, “Guidance for Developing Principal Design Criteria for Non-Light water Reactors” as a "barrier, or set of barriers taken together, that effectively limit the physical transport and release of radionuclides to the environment across a full range of normal operating conditions, anticipated operational occurrences, and accident conditions." As also stated in RG 1.232, the NRC has reviewed the functional containment concept and found it “generally acceptable,” provided that “appropriate performance requirements and criteria” are developed. The NRC staff has developed a proposed methodology for establishing functional containment performance criteria for non-LWRs, which is presented in SECY-18-0096, “Functional Containment Performance Criteria for Non-Light-Water-Reactors”. This SECY document has been approved by the Commission.

The functional containment approach for the KP-FHR is to control radionuclides primarily at their source within the coated fuel particle under normal operations and accident conditions without requiring active design features or operator actions. The KP-FHR design relies primarily on the multiple barriers within the TRISO fuel particles to ensure that the dose at the site boundary as a consequence of postulated accidents meets regulatory limits. However, in contrast to the MHTGR, the KP-FHR molten salt coolant also serves as an additional distinct barrier providing retention of fission products that escape the fuel particle and fuel pebble barriers. This additional retention barrier is a key feature of the enhanced safety and reduced source term in the KP-FHR.

1.2 REGULATORY INFORMATION

The KP-FHR is anticipated to be licensed under Title 10 of the Code of Federal Regulations (10 CFR) using a licensing pathway provided in Part 50 or Part 52.

Applicants for operating licenses under 10 CFR 50 are required to provide a Final Safety Analysis Report (FSAR) that provides a safety assessment of the facility in accordance with 10 CFR 50.34(b). Subsections of 10 CFR 50.34(b) relevant to the requirement to establish safety-related setpoints are as follows:

- 50.34(b)(2) A description and analysis of the structures, systems, and components of the facility, with emphasis upon performance requirements, the bases, with technical justification therefor, upon which such requirements have been established, and the evaluations required to show that safety functions will be accomplished. The description shall be sufficient to permit understanding of the system designs and their relationship to safety evaluations.

Similarly, applicants for combined licenses for power reactors licensed under 10 CFR 52 are required to provide a FSAR which provides a safety assessment of the facility in accordance with 10 CFR 52.79. Subsections relevant to the requirement to establish safety-related setpoints are as follows:

- 52.79(a)(2) A description and analysis of the structures, systems, and components of the facility with emphasis upon performance requirements, the bases, with technical justification therefore, upon which these requirements have been established, and the evaluations required to show that safety functions will be accomplished. It is expected that reactors will reflect through their design, construction, and operation an extremely low probability for accidents that could result in the release of significant quantities of radioactive fission products. The descriptions shall be sufficient to permit understanding of the system designs and their relationship to safety evaluations. Items such as the reactor core, reactor coolant system, instrumentation and control systems, electrical systems, containment system, other engineered safety features, auxiliary and emergency systems, power conversion systems, radioactive waste handling systems, and fuel handling systems shall be discussed insofar as they are pertinent.

Applicants for licenses under 10 CFR Part 50 and 10 CFR Part 52 are required to include proposed technical specifications as described in 10 CFR 50.36. Subsections relevant to the requirements to establish setpoints are as follows:

- 50.36(c)(1)(ii)(A) Limiting safety system settings for nuclear reactors are settings for automatic protective devices related to those variables having significant safety functions. Where a limiting safety system setting is specified for a variable on which a safety limit has been placed, the setting must be so chosen that automatic protective action will correct the abnormal situation before a safety limit is exceeded. If, during operation, it is determined that the automatic safety system does not function as required, the licensee shall take appropriate action, which may include shutting down the reactor. The licensee shall notify the Commission, review the matter, and record the results of the review, including the cause of the condition and the basis for corrective action taken to preclude recurrence. The licensee shall retain the record of the results of each review until the Commission terminates the license for the reactor except for nuclear power reactors licensed under § 50.21(b) or § 50.22 of this part. For these reactors, the licensee shall notify the Commission as required by § 50.72 and submit a Licensee Event Report to the Commission as required by § 50.73. Licensees in these cases shall retain the records of the review for a period of three years following issuance of a Licensee Event Report.

- 50.36(c)(3) Surveillance requirements are requirements relating to test, calibration, or inspection to assure that the necessary quality of systems and components is maintained, that facility operation will be within safety limits, and that the limiting conditions for operation will be met.

Facilities licensed under 10 CFR Part 50 are also required to describe Principal Design Criteria (PDC) in their PSAR report supporting a construction permit and operating license application as described in 10 CFR 50.34(a)(3)(i). Likewise, applicants for standard design certifications, combined licenses, standard design approvals, and manufacturing licenses must include the PDC for a facility as described in 10 CFR

52.47(a)(3)(i), 10 CFR 52.79(a)(4)(i), 10 CFR 52.137(a)(3)(i), and 10 CFR 52.157(a). The PDC for the KP-FHR have been established in the Kairos Power Topical Report, "Principal Design Criteria for the Kairos Power Fluoride Salt Cooled High Temperature Reactor" (Reference 5). The specific PDC in this report, which either rely on or credit safety-related instrument setpoints include PDCs 1, 10, 15, 20, 21, 25, and 28. These PDC are discussed below.

PDC 1 requires that:
Structures, systems, and components which are safety significant shall be designed, fabricated, erected, and tested to quality standards commensurate with the safety significance of the functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of structures, systems, and components which are safety significant shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.

PDC 10 requires that:
The reactor core and associated heat removal, control, and protection systems shall be designed with appropriate margin to ensure that specified acceptable system radionuclide release design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

PDC 15 requires that:
The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to ensure that the design conditions of the safety significant elements of the reactor coolant boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

PDC 20 requires that:
The protection system shall be designed (1) to initiate automatically the operation of appropriate systems, including the reactivity control systems, to assure that specified acceptable system radionuclide release design limits are not exceeded as a result of anticipated operational occurrences and (2) to sense accident conditions and to initiate the operation of systems and components which are safety significant.

PDC 21 requires that:
The protection system shall be designed for high functional reliability and inservice testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection system shall be sufficient to assure that (1) no single failure results in loss of the protection function and (2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated. The protection system shall be designed to permit periodic testing of its functioning when the reactor is in operation, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.

PDC 25 requires that:
The protection system shall be designed to ensure that specified acceptable system radionuclide release design limits are not exceeded during any anticipated operational occurrence, accounting for a single malfunction of the reactivity control systems.

PDC 28 requires that:
The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to ensure that the effects of postulated reactivity accidents can neither

> (1) result in damage to the safety significant elements of the reactor coolant boundary greater than limited local yielding nor
> (2) sufficiently disturb the core, its support structures, or other reactor vessel internals to impair significantly the capability to cool the core.

This report provides information relevant to the content expected to be provided in a license application consistent with the regulations cited above. The process of establishing safety-related instrument setpoints describes performance requirements, documents the bases upon which the performance requirements have been established, and supports evaluations required to show that safety functions will be accomplished consistent with the assumptions made in the safety analyses. The method described in this report also ensures that limiting safety system settings for automatic protective features are chosen such that automatic protective actions will correct abnormal situations before a safety limit is exceeded. Acceptance criteria for surveillance testing and calibration of safety-related instrumentation and control systems are also established to assure that the quality of safety-related instrumentation and controls systems is maintained, and facility operation will be within safety limits. The methodology described in this report provides the necessary information to demonstrate that safety-related instrument setpoints are appropriate to support conformance, in part, to PDCs 1, 10, 15, 20, 21, 25, and 28.

1.3 REGULATORY GUIDANCE

The methodology for determining the safety-related instrument channel uncertainties is based on NRC Regulatory Guide 1.105, Revision 4, “Setpoints for Safety-Related Instrumentation.” This RG describes an approach that is acceptable to meet regulatory requirements to ensure that setpoints for safety-related instrumentation are established to protect safety and analytical limits, and to ensure that the maintenance of the instrument channels implementing these setpoints ensures that they are functioning as required, consistent with plant technical specifications. Regulatory Guide 1.105, Revision 4, endorses ANSI/ISA-67.04.01-2018, “Setpoints for Nuclear Safety-Related Instrumentation.”

1.4 INDUSTRY STANDARDS AND GUIDANCE

ANSI/ISA-67.04.01-2018, “Setpoints for Nuclear Safety-Related Instrumentation,” provides bases for establishing setpoints for safety-related instrumentation associated with nuclear power plants and nuclear reactor facilities.

ISA-RP67.04.02-2010, “Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation,” contains additional guidance for establishing safety-related setpoints but is not endorsed by the NRC in Regulatory Guide 1.105, Revision 4.

1.5 DEFINITIONS

Term	Definition
Analytical Limit (AL)	Limit of a measured or calculated variable established by the safety analysis to ensure that a safety limit is not exceeded.
As-found	The condition in which a channel, or portion of a channel, is found after a period of operation and before recalibration (without preconditioning of the instrumentation, if necessary).
As-left	The condition in which a channel, or portion of a channel, is left after calibration or final actuation device setpoint verification.
As-found Tolerance (AFT)	The maximum amount above and below the desired output by which the measured setpoint or desired calibration point is expected to change over the course of a calibration interval and still be considered to be performing normally.
As-left Tolerance (ALT)	The maximum amount above and below the desired output that is considered acceptable for the as-left value during the calibration of an instrument or instrument channel. This is the acceptance tolerance on the as-left values of the setpoint or desired calibration points of instrumentation, used for performance monitoring.
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. KP-FHR licensees may use other terms equivalent to channel.
Drift	A variation in sensor or instrument channel output that may occur between calibrations that cannot be related to changes in the process variable or environmental conditions.
Error	The arithmetic difference between the indicated and the ideal value of the measured signal.
Final Actuation Device	The portion of the instrument channel that compares the converted process value of the sensor to the trip value and produces a trip signal. The final actuation device may be digital or analog. Examples of final actuation devices are bistables, relays, digital processor or logic solver outputs, pressure switches, and level switches.
Limiting Safety System Setting (LSSS)	LSSSs for nuclear reactors are settings for automatic protective devices related to those variables having significant safety functions. Where an LSSS is specified for a variable on which a safety limit has been placed, the setting must be so chosen that automatic protective action will correct the abnormal situation before a safety limit is exceeded.
Limiting Trip Setpoint (LTSP)	The limiting value for the nominal trip setpoint so that the trip or actuation will occur at or before the analytical limit is reached. The setpoint considers all credible instrument errors associated with the instrument channel, not inclusive of additional margin for conservatism.
Measuring and Test Equipment (M&TE)	M&TE includes all devices or systems used to calibrate, certify, measure, gauge, troubleshoot, test, or inspect in order to control data or to acquire data to verify conformance to specified requirements.

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Term	Definition
Measuring and Test Equipment Uncertainty (MTEU)	The amount to which M&TE measurements are in doubt (or the allowance made for such doubt) due to possible errors, either random or systematic, for the calibration of a device or combination of devices. The uncertainty is generally identified within a probability and confidence level. The total MTEU for a calibration consists of the combined uncertainties of the M&TE device(s) reading the input(s) and the uncertainties of the M&TE device reading the output. The uncertainty generally considers, as necessary, the reference accuracy of the M&TE, temperature effects, readability and the reference accuracy of the standard used to calibrate the M&TE.
Nominal Trip Setpoint (NTSP)	A predetermined value for actuation of a final actuation device to initiate a protective action. The NTSP is the trip setpoint value used for plant operations. The NTSP must be equal to or more conservative than the LTSP.
Nuclear Safety-Related Instrumentation	Instrumentation which is essential to a) Provide emergency reactor shutdown b) Provide reactor core cooling c) Provide for reactor heat removal d) Prevent or mitigate a significant release of radioactive material to the environment or instrumentation that is otherwise essential to provide reasonable assurance that a nuclear reactor facility can be operated without undue risk to the health and safety of the public.
Performance Test	A test that evaluates the performance of equipment against a set of criteria. The results of the test are used to support an operability determination.
Reference Accuracy (RA)	A number or quantity that defines a limit that errors will not exceed when a device is used under specified operating conditions.
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.
Sensor	The portion of a channel that responds to changes in a process variable and converts the measured process variable into an instrument signal.
Tolerance Interval	A statistical statement of probability that a certain portion of the population is contained within a defined interval. The tolerance interval includes an assessment of the level of confidence in the statement of probability.
Tolerance Limit	An endpoint of a tolerance interval.
Total Loop Uncertainty (TLU)	An allowance between the LTSP and the AL to accommodate the expected performance of the instrumentation under any applicable process and environmental conditions.
Uncertainty	The amount to which an instrument channel's output is in doubt (or the allowance made for such doubt) due to possible errors, either random or systematic. The uncertainty is generally identified within a probability and confidence level.

2 UNCERTAINTIES

The actual value of measured process parameters can never be known due to errors associated with the instrumentation used to measure the parameters. Since the actual values of these instrument errors cannot be known, the errors are discussed in terms of probabilities. For the methodology described in this report, the term “uncertainty” will be used to reflect the distribution of possible errors.

This methodology characterizes uncertainties in instrumentation measurement as random, bias, or abnormally distributed. These categories of uncertainty are described in Sections 2.1 and 2.2. Sources of uncertainty are considered in Section 2.3. Guidance for combining categories of uncertainty to determine instrument channel uncertainty is provided in Section 2.4.

2.1 RANDOM UNCERTAINTIES

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

It is expected that the instrument uncertainties that a manufacturer specifies as having a ± magnitude are random uncertainties. However, the uncertainty must be zero-centered and approximately normally distributed to be considered random. Section 2.4 addresses the concern of assuming that the ± in vendor data implies that the instrument's performance represents a normal statistical distribution. After uncertainties have been categorized as random, any dependencies between the random uncertainties are identified.

2.1.1 Independent Uncertainties

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

The uncertainty tolerance interval for random, independent uncertainty terms is estimated using a statistical and bounding method such that the tolerance interval estimate bounds the uncertainty of interest with a 95% probability, at a 95% confidence level (95/95). The methodology described in this report uses this 95/95 tolerance limit as an acceptance criterion consistent with Regulatory Guide 1.105. Equation 1 provides the method for determining the tolerance limit (TL) for a random normal distribution of data.

$$TL_{(P\,\%/\gamma\,\%)} = x \pm ks \qquad \text{Equation 1}$$

where:

TL = Tolerance Limit
x = sample mean
k = tolerance interval factor (TIF, function of P & γ)
s = sample standard deviation
γ = desired confidence level
P = proportion of population contained within the tolerance interval (probability)

If there is not sufficient data to justify a statistical estimate of the uncertainty tolerance interval at the 95/95 level, then a bounding uncertainty term shall be determined, and the basis for determining the bounds of the uncertainty shall be documented in the setpoint determination calculation. The bounding estimates shall be treated as a 95/95 term in the uncertainty analysis.

2.1.2 Dependent Uncertainties

Dependent uncertainties are those for which a common root cause exists that influences two or more of the uncertainties with a known relationship. If two or more uncertainties are determined to be dependent, these uncertainties are combined algebraically to create a new, larger independent uncertainty.

2.2 NON-RANDOM UNCERTAINTIES

2.2.1 Bias (known sign)

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

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

2.2.2 Abnormally Distributed Uncertainties

Some uncertainties are not normally distributed. Such uncertainties are not eligible for SRSS combinations and are categorized as abnormally distributed uncertainties. Such uncertainties may be random (equally likely to be positive or negative with respect to some value) but extremely non-normal.

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

2.2.3 Bias (unknown sign)

Some bias effects may not have a known sign. Their unpredictable signs are conservatively treated by algebraically adding the bias in the worse direction.

2.2.4 Correction

For KP-FHRs, errors or offsets that are of a known direction and magnitude are corrected for in the calibration of the module and are not included in the setpoint calculation. The fact that these corrections are made during calibration is identified in the setpoint uncertainty calculation.

2.3 SOURCES OF UNCERTAINTIES

Potential sources of uncertainty that are considered when developing instrument uncertainty calculations are described below. These potential sources are intended to be illustrative of the sources of uncertainties that may affect instrumentation and are not intended to be all-inclusive. Each potential source of uncertainty will not be applicable to every instrument. The specific sources of uncertainty that are applicable to an instrument, instrument module, or instrument loop must be determined by analyzing the specific equipment and the conditions under which it is expected to function.

2.3.1 Process Measurement Effects

Process measurement effects are sources of uncertainty that are not directly caused by equipment. These uncertainties are induced by the physical characteristics or properties of the process that is being measured.

Process measurement uncertainty accounts for variations in the actual process conditions that influence the measurement, such as temperature stratification, density variations, pressure variations, etc. The applicability of all possible process measurement effects is considered when preparing uncertainty calculations.

2.3.2 Primary Element Accuracy

The primary element is the system element that quantitatively converts the measured variable energy into a form suitable for measurement. Primary element accuracy is the accuracy of the component, piece of equipment, or installation used as a PE to obtain a given process measurement. Primary elements include devices such as flow nozzles, venturies, and orifice plates.

2.3.3 Reference Accuracy

Reference accuracy is a number or quantity that defines a limit that errors will not exceed when a device is used under specified operating conditions and is typically provided by the device manufacturer. Reference accuracy includes four attributes: linearity, hysteresis, deadband, and repeatability.

2.3.4 Drift

Drift is a variation in sensor or instrument channel output that occurs between calibrations that cannot be related to changes in the process variable or environmental conditions. Drift values are typically provided by vendors as a value for a given period of time. In most applications, vendor provided drift values must be adjusted to cover the actual instrument calibration interval selected. This calibration interval is the limiting case time between calibrations, including both the nominal calibration frequency and any allowable grace period used for maintenance planning. For KP-FHRs, calibration intervals are established in the plant technical specifications. Adjustments to vendor provided drift values are made by combining enough time periods to envelop the time interval of interest using a square-root-sum-of-squares (SRSS) technique. Drift values may also be determined by analysis of actual as-found and as-left instrument calibration data once a sufficient population of KP-FHR performance data has been accrued.

2.3.5 Measuring and Testing Equipment Uncertainty

Establishing measuring and testing equipment (M&TE) uncertainty includes consideration of effects including reference accuracy of the M&TE, the uncertainty associated with the calibration of the M&TE, and the readability of the M&TE. The M&TE uncertainty for a module includes the uncertainty of both the input and the output test equipment. The input and output calibration test equipment are considered independent. M&TE uncertainty is considered for each separate calibration in a channel. If an entire channel (loop) is calibrated at one time, only one M&TE uncertainty value is included. If each individual module in a channel is calibrated separately without channel verification, an M&TE uncertainty is associated with each module. A bounding M&TE uncertainty value for the channel or module being calibrated is calculated for use in this methodology. To ensure that M&TE uncertainty remains bounded by the value used in the methodology, M&TE is periodically calibrated to controlled standards to maintain its accuracy in accordance with the applicable quality assurance program requirements. If the overall uncertainty of the M&TE used in a calibration of a channel or module is less than 1/10th of the reference accuracy of the channel or module being tested, the uncertainty associated with the M&TE is negligible and may be disregarded.

2.3.6 Calibration Accuracy

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

2.3.7 Temperature Effects

Most instruments exhibit a change in output as the ambient temperature to which they are exposed varies during normal plant operation above or below the temperature at which they were last calibrated. The normal temperature effect accounts for variations in ambient temperatures during normal operations from the temperature at which an instrument is calibrated. To estimate the magnitude of the normal temperature effect, the ambient operating temperature range and the calibration temperature are defined. For this methodology, the calibration temperature is an assumed value based on the ambient conditions in which the instrument is expected to operate. Bounding temperature change limits are established in the setpoint calculations based on the differences between the assumed calibration temperature and the maximum and minimum ambient operating temperature values. The normal temperature effect is calculated using the bounding temperature change limits and vendor-supplied temperature effect specifications (typically provided as ± X% span per Y°F).

2.3.8 Pressure Effects

Some instrumentation exhibits a change in output based on changes in process or ambient pressure. This effect can occur when an instrument measuring differential pressure is calibrated at low-static pressure conditions but operated at high-static pressure conditions. KP-FHRs are designed to operate at low pressure conditions, where pressure effects between calibration conditions and operating conditions are not expected to be significant. For KP-FHR instrumentation, pressure effects are corrected for in the calibration of the module and are not included in the setpoint calculation.

2.3.9 Accident Environmental Effects

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

2.3.10 Insulation Resistance Effects

Under conditions of high humidity and temperature, cables, splices, connectors, terminal blocks, and penetrations can experience a reduction in insulation resistance. Reduction in insulation resistance causes an increase in leakage currents between conductors and from individual conductors to ground. Leakage currents are negligibly small under normal conditions and are essentially calibrated out during instrument

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calibrations. However, under certain accident conditions, the leakage currents may increase to a level that causes significant error in measurement. The effect is particularly a concern for sensitive, low-level circuits such as current transmitters, RTDs, and thermocouples.

2.3.11 Power Supply Variations

Most electronic instruments exhibit a change in output because of variations in power supply voltage. To calculate uncertainty associated with the power supply effect, a normal operating voltage and voltage variation are determined. Typically, this uncertainty is very small in comparison to other instrument uncertainties.

2.3.12 Digital Signal Processing Considerations

When digital processing equipment is used, uncertainties are introduced by hardware for conversions between analog and digital domains and by the algorithms for digital arithmetic operations. Values for analog-to-digital and digital-to-analog conversion uncertainties are obtained from the module manufacturers or through testing. Sources of uncertainty may include precision of computation, rounding or truncation uncertainties, process variable changes during the deadband between data acquisition sampling scans, and inaccuracies of algorithms for transcendental functions or empirical curve fitting. The nature of the uncertainties contributed by the software (statistical or arithmetic) are identified by the software designer.

2.4 CALCULATING INSTRUMENT UNCERTAINTIES

Individual uncertainty terms are calculated in terms of percent calibrated span and combined using square-root-sum-of-squares (SRSS) and algebraic summation techniques to develop an uncertainty value for the instrument, instrument module, and/or instrument loop being analyzed. Uncertainty tolerance intervals are combined at the same number of standard deviations. The result of the combination is a value that represents the performance of the instrumentation with a 95/95 level.

The SRSS technique for combining uncertainty terms that are random and independent is an established and accepted analytical technique. The SRSS methodology is a direct application of the central limit theorem, providing a method for determining the limits of a combination of independent and random terms. The probability that all the independent processes under consideration would simultaneously be at their maximum value in the same direction (i.e., + or -) is very small. The SRSS technique provides a means to combine individual random uncertainty terms to establish a resultant net uncertainty term with the same level of probability as the individual terms. If an individual uncertainty term is known to consist of both random and bias components, the components are separated to allow subsequent combination of like components.

Resultant net uncertainty terms are determined from individual uncertainty terms based on a common probability level. Consistent with RG 1.105, this methodology uses the 95/95 tolerance interval as an acceptance criterion. Using probability levels that correspond to three or more standard deviations is unnecessarily conservative, and results in reduced operating margin. Most industry vendors supply instrument uncertainty terms at 2 sigma probability levels. In cases where uncertainty terms are provided at levels other than 2 sigma (1 sigma or 3 sigma), the values will be appropriately adjusted within the calculation. For example, if a reference accuracy for a 99% probability level (3 sigma) is given as ±6 psig, the 95% probability level corresponds to ±4 psig (= 2/3 x 6).

The algebraic summation technique is used to combine uncertainties that are not random, not normally distributed, or are dependent.

The equation for uncertainty is provided in Equation 2:

$$Z = \pm [(A^2 + B^2 + C^2)]^{1/2} \pm |F| + L - M \qquad \text{Equation 2}$$

where:

A, B, C = random and independent terms. The terms are zero-centered, approximately normally distributed, and indicated by a ± sign. Each term is determined at the tolerance interval, defined above or justification provided that the value bounds the variation in the term.

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

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

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

The addition of F, L, and M terms to the A, B, C uncertainty terms allows the formula to account for influences on total uncertainty that are not random or independent. For biases with known direction, represented by L and M, the terms are combined with only the applicable portion (+ or -) of the random uncertainty. For the uncertainty represented by F, the terms are combined with both portions of the random uncertainty. Since these terms are uncertainties themselves, the positive and negative components of the terms cannot be algebraically combined into a single term. The positive terms of the nonrandom uncertainties are summed separately from the negative terms, and then each is individually combined with the random uncertainty to yield a final value. Individual nonrandom uncertainties are independent probabilities and may not be present simultaneously. Therefore, the individual terms cannot be assumed to offset each other.

Equation 3 provides the maximum positive uncertainty:

$$Z^+ = +[(A^2 + B^2 + C^2)]^{1/2} + |F| + L \qquad \text{Equation 3}$$

The maximum negative uncertainty is provided in Equation 4:

$$Z^- = -[(A^2 + B^2 + C^2)]^{\frac{1}{2}} - |F| - M \qquad \text{Equation 4}$$

In the determination of the random portion of the uncertainty, situations may arise where two or more random terms are not totally independent of each other but are independent of the other random terms. This dependent relationship is accommodated within the SRSS technique by algebraically summing the dependent random terms prior to performing the SRSS determination. The treatment of dependent random terms within the SRSS technique is shown in Equation 5.

$$Z = \pm\left[\left(A^2 + B^2 + C^2 + (D + E)^2\right)\right]^{1/2} \pm |F| + L - M \qquad \text{Equation 5}$$

where:

D and E = random and dependent terms that are independent of terms A, B, and C.

3 ESTABLISHMENT OF SETPOINTS

3.1 LIMIT AND SETPOINT RELATIONSHIPS

To establish setpoints, it is necessary to understand the relationship between the safety limit (SL), analytical limit (AL), limiting trip setpoint (LTSP), and nominal trip setpoint (NTSP). The relative relationships between these terms are shown in Figure 1 below.

3.1.1 Safety Limits

SLs are limits upon important process variables that are necessary to maintain the integrity of physical barriers that are designed to prevent the uncontrolled release of radioactivity. SLs are identified in the technical specifications in accordance with 10 CFR 50.36(c)(1)(i)(A). SLs may be directly measured process variables or may be defined in terms of a calculated variable involving two or more process variables.

3.1.2 Analytical Limits

ALs are the values of process variables at which the safety analyses model the initiation of protective actions. For KP-FHRs, ALs are obtained from the safety analyses calculations. ALs are chosen to ensure that the safety limits are not exceeded. ALs are developed with consideration for parameters such as process delays, rod insertion times, reactivity changes, and instrument response times. The development of ALs is outside the scope of this methodology.

3.1.3 Trip Setpoints

Trip setpoints are chosen to ensure that a trip or safety actuation occurs before the process reaches the AL. Trip setpoints are also chosen to ensure that the plant can operate and experience expected operational transients without unnecessary trips or engineered safety feature actuations.

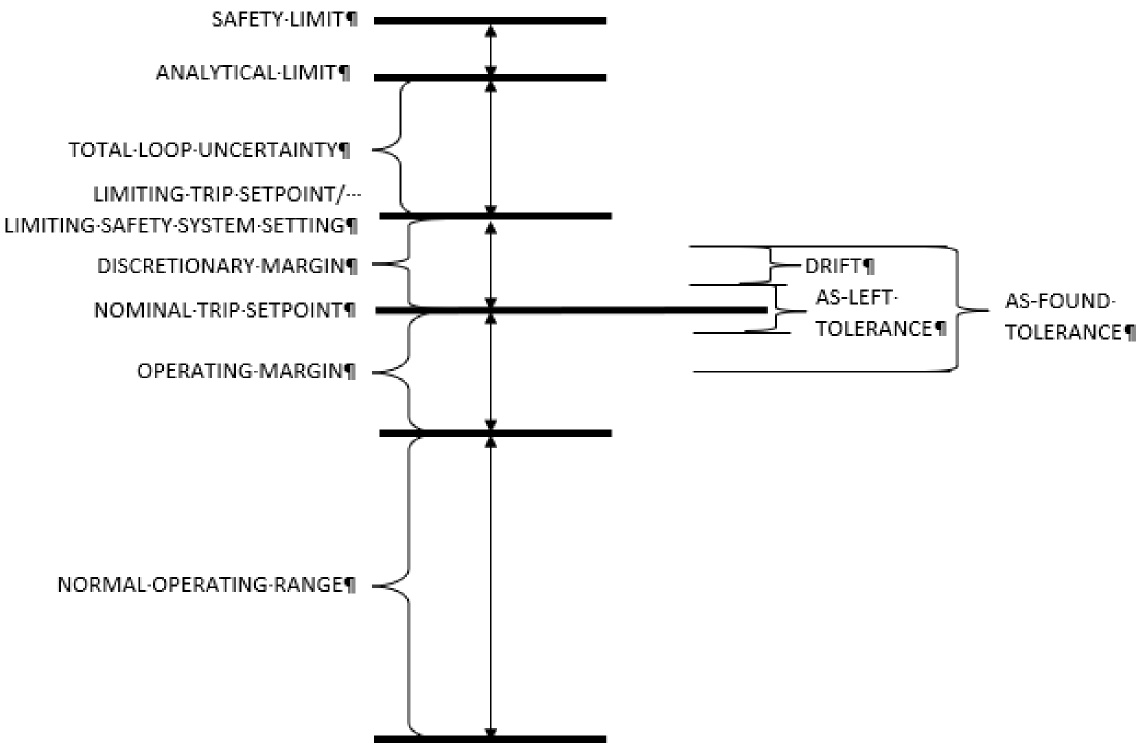
3.1.3.1 Limiting Trip Setpoints

The LTSP is the least conservative value of the NTSP that still protects the AL. The LTSP is derived by instrument channel uncertainty calculations that define the total channel uncertainty, including process, environmental, and M&TE effects. For KP-FHRs, the LTSP are the LSSSs specified in accordance with 10 CFR 50.36(c)(1)(ii)(A).

3.1.3.2 Nominal Trip Setpoints

The NTSP is the predetermined value where a final actuation device changes state. The NTSP is derived by scaling calculations and is implemented by plant calibration procedures. The NTSP should not result in spurious trips or actuations due to transients that may occur during normal operations. The channel setpoint is reset to a value that is within the as-left tolerance around the NTSP at the completion of calibration. The NTSP can be more conservative than the LTSP due to plant conditions or as a compensatory action.

Figure 1: Setpoint Parameter Relationships



Note:
This figure provides the relative positions of setpoint parameters and is not drawn to scale.

The example depicted in this figure illustrates the relationship of parameters for a setpoint that trips in the increasing direction. The relationships for a setpoint that trips in the decreasing direction would be similar, but in the opposite direction.

3.2 DETERMINING INSTRUMENT CHANNEL SETPOINTS

A flowchart depicting the general process for determining total loop uncertainty and instrument loop setpoints is provided in Figure 2 at the end of this subsection.

3.2.1 Instrument Loop Analysis

3.2.1.1 Development of an Instrument Loop Diagram

Instrument loop diagrams are generated to aid in developing the analysis of the instrument loop, classifying uncertainties that may be present in each portion of the instrument loop, determining the environmental parameters to which each portion of the instrument loop may be exposed, and identifying the appropriate module transfer functions. A typical instrument loop diagram (depicting interfaces, functions, sources of uncertainty, and different operating environments) is shown in Figure 3 below.

A typical instrument loop consists of the following major sections:

- Process
- Process Interface
- Process Measurement
- Signal Interface
- Signal Conditioning
- Actuation

3.2.1.2 Identifying Design Parameters and Sources of Uncertainty

The functional requirements, actuation functions, and operating times of the instrument loop (as well as the postulated environments that the instrument could be exposed to concurrent with these actuations) are identified. In many cases, instrument channel uncertainty is dependent on a particular system operating mode, operating point, or a particular sequence of events. In cases where a setpoint is used for more than one actuation function, each with potentially different environmental assumptions, the most limiting environmental conditions are used. In cases where a single instrument has several setpoints, either the most limiting set of conditions is used, or individual calculations for each setpoint are performed, each with the appropriate set of conditions.

Environmental boundaries can then be drawn for the instrument channel as shown in Figure 3. For simplicity, two sets of environmental conditions are shown in the figure, with conditions in Environment A normally more harsh than conditions in Environment B.

After the environmental conditions are determined, the potential sources of uncertainties affecting each portion of the instrument channel are determined. For example, the process interface portion is normally affected only by process measurement effects and not by equipment calibration or other uncertainties. Also, cables in the mild conditions of Environment B would not be appreciably affected by insulation resistance effects. Figure 3 also shows where each major class of uncertainty will typically be present. Each major class is listed below along with a further breakdown into particular types. This list is not meant to be all-inclusive.

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- Process Measurement Effects
    - Process temperature effects
    - Fluid density effects
    - System configuration effects
    - Line pressure loss/head pressure effects
- Instrument Uncertainty
    - Primary element accuracy
    - Reference accuracy
    - Temperature effects
    - Pressure effects
    - Drift
    - Module power supply variations
    - Digital signal processing
    - Environmental effects — Accident conditions
    - Calibration uncertainty
- Other
    - Insulation resistance effects

The uncertainty allowances must then be identified. These allowances are obtained from sources such as analyses of process measurement effects, manufacturer's product specifications and test reports, or operating experience data. For initial KP-FHR operations, uncertainty allowances are established using analyses, manufacturer's product specifications and test reports. KP-FHR operating experience data may be used to refine uncertainty allowances when a sufficient sample size is available to support 95/95 level values. The sources of uncertainty allowances shall be documented and justified in the setpoint calculation.

3.2.2 Calculating Total Loop Uncertainty

The total loop uncertainty (TLU) is calculated once the instrument loop modules have been identified, the sources of uncertainty applicable to each module identified and classified, and the uncertainty allowances identified. Data used to calculate the TLU is obtained from appropriate sources, which may include any of the following: operating experience, equipment qualification tests, equipment specifications, engineering analysis, laboratory tests, and engineering drawings. KP-FHR operating experience data may be used to refine uncertainty values when sufficient sample sizes are available to support uncertainty calculations that yield 95/95 level values.

Based on Equation 2 and Equation 3, the maximum positive TLU is calculated using Equation 6 and the maximum negative uncertainty is calculated using Equation 7.

Maximum positive TLU:

$$TLU^{+} = +[PM^2 + PE^2 + Module_1{}^2 + Module_2{}^2 + Module_n{}^2]^{1/2} + B_t{}^{+}$$ Equation 6

Maximum negative TLU:

$$TLU^{-} = -\left[PM^2 + PE^2 + Module_1{}^2 + Module_2{}^2 + Module_n{}^2\right]^{1/2} - B_t{}^{-}$$ Equation 7

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where:

PM = process measurement uncertainty. PM accounts for the variation in actual process conditions that influence the measurement, such as temperature stratification, density variations, and pressure variations.

PE = primary element accuracy. PE is the accuracy of a component, piece of equipment, or installation used as a primary element to obtain a given process measurement. The PE includes the accuracy of flow nozzle and/or the accuracy achievable in a specific flow metering run.

Module_n = total random uncertainty of each module that makes up the loop from module 1 through module n. The modules may include field sensors and transmitters, signal process circuits, and rack-mounted circuits.

B_t^+ = total of all positive biases associated with an instrument channel, including any uncertainties from PM, PE, or the modules that could not be combined as a random term.

B_t^- = total of all negative biases associated with an instrument channel, including any uncertainties from PM, PE, or the modules that could not be combined as a random term (biases and abnormally distributed uncertainties as discussed in Reference 1).

The individual module random uncertainties are themselves a statistical combination of uncertainties. Depending on the type of module, its location, and the specific factors that can affect its accuracy, the determination of the module uncertainty will vary. For example, the maximum positive uncertainty for an individual module is calculated using Equation 8 and the maximum negative uncertainty for the module is calculated using Equation 9.

$$Module_n^{\;+} = +[RA^2 + DR^2 + TE^2 + RE^2 + SE^2 + HE^2 + SP^2 + DSE^2 + MTE^2]^{1/2} + B^+ \qquad \text{Equation 8}$$

$$Module_n^{\;-} = -[RA^2 + DR^2 + TE^2 + RE^2 + SE^2 + HE^2 + SP^2 + DSE^2 + MTE^2]^{1/2} - B^- \qquad \text{Equation 9}$$

where:

RA = module reference accuracy (usually specified by the manufacturer)
DR = drift of the module over a specific period
TE = temperature effect for the module; the effect of ambient temperature variations on module accuracy; the TE may be a normal operating TE or an accident TE, as required
RE = radiation effect for the module; the effect of radiation exposure on module accuracy; the RE may be a normal operating RE, an accident RE, or time-of-trip RE as required
SE = seismic effect or vibration effect for the module; the effect of seismic or operational vibration on the module accuracy
HE = humidity effect for the module; the effect of changes in ambient humidity on module accuracy, if any
SP = static pressure effects for the module; the effect of changes in process static pressure on module accuracy
DSE = digital signal processing effects
MTE = measurement and test equipment effect for the module; this accounts for the uncertainties in the equipment utilized for calibration of the module
B = biases associated with the module, if any, including consideration for insulation resistance effects

For the purposes of this example, most of the uncertainties have been considered as random and independent. However, the actual characteristics of each uncertainty term must be determined and combined based on the criteria discussed in Sections 2.1 through 2.4. Additional terms may have to be included for a particular application. The terms shown are common ones encountered for a module. The individual module uncertainty calculations contain all appropriate terms for a specific module including any bias terms. The final instrument channel formula bias terms are combined according to their direction with B^+ representing positive biases and B^- representing negative bias. For example, for a total instrument channel, if PM contained a +3.0%, -0.0% bias, module 1 contained a ±0.5% calibration abnormally distributed uncertainty, and the instrument channel could experience a +1.0% insulation resistance (IR) degradation effect, then the positive and negative biases are calculated as shown in Equation 10 and Equation 11.

$$B^+ = {B_{PM}}^+ + {B_{IR}}^+ + {B_1}^+ = 3.0\% + 1.0\% + 0.5\% = +4.5\% \qquad \text{Equation 10}$$

and

$$B^- = {B_1}^- = -0.5\% \qquad \text{Equation 11}$$

Figure 2: Setpoint Calculation Flowchart

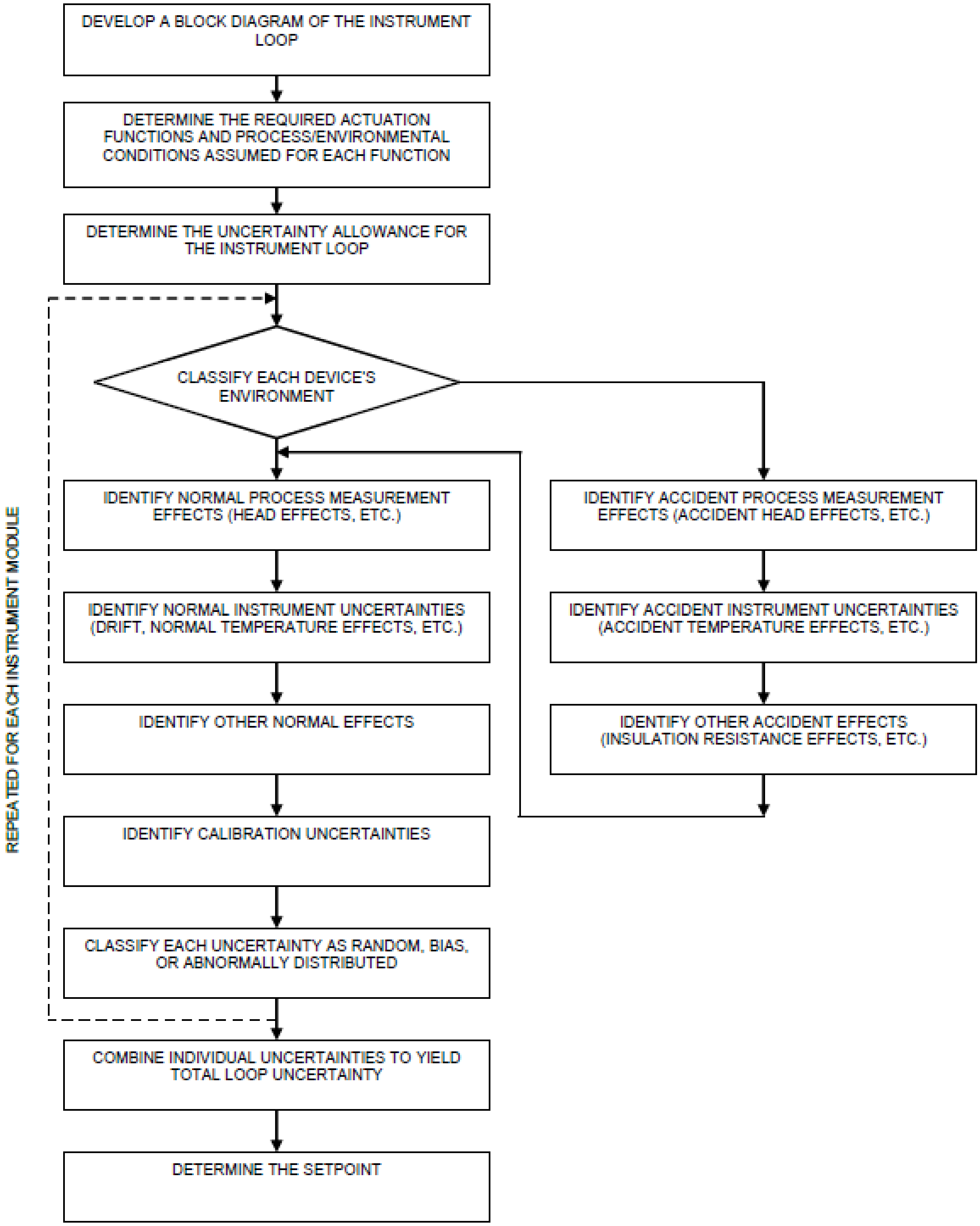
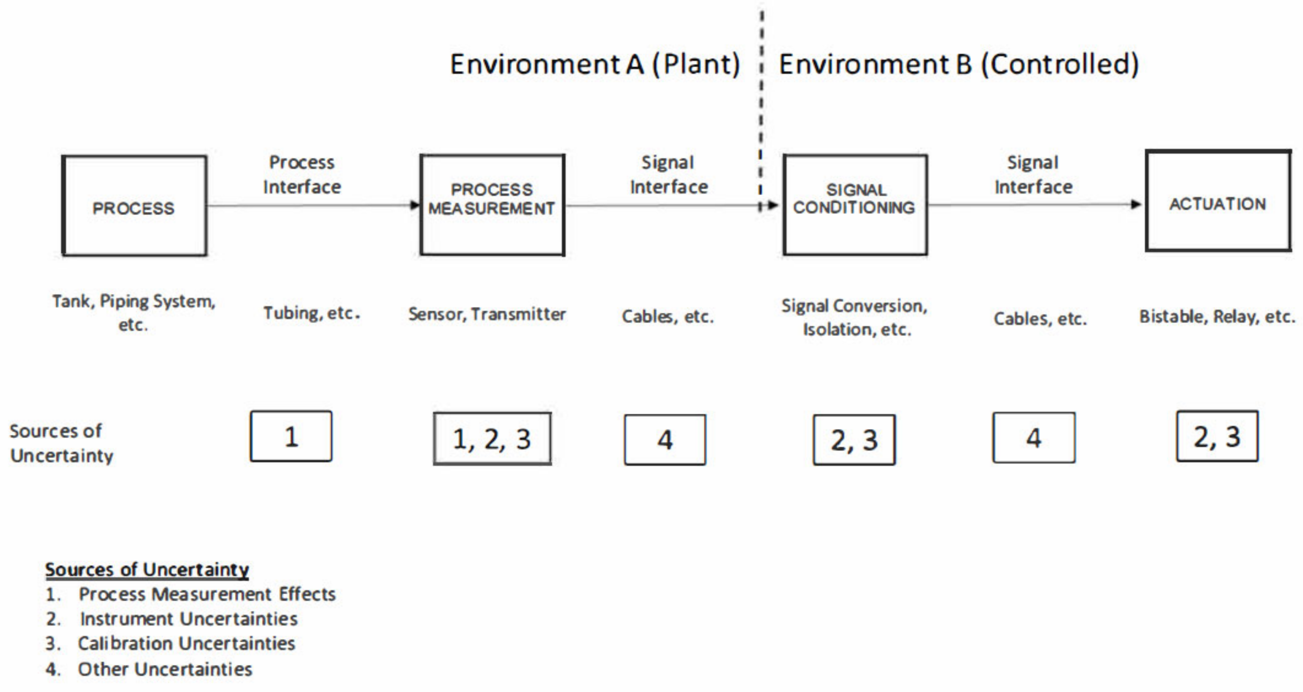


Figure 3: Typical Instrument Loop Diagram



3.3 CALCULATING TRIP SETPOINTS

After the TLU for an instrument loop has been determined, the LTSP and NTSP are calculated. The TLU represents an allowance between the LTSP and the AL to accommodate expected performance of the instrumentation under applicable process and environmental conditions.

The determination of setpoints is derived on a per channel basis. The chosen setpoints for each channel shall have values that represent the performance of the instrumentation, with a 95% probability of channel trip at or before the analytical limit is reached at a 95% confidence level. A single setpoint determination calculation may be applied to multiple equivalent channels. The basis for determining that the channels are equivalent shall be included in the setpoint determination calculation.

The LTSP and NTSP for a trip or actuation on an increasing process are calculated using Equation 12 and Equation 13, respectively.

$$LTSP = AL - TLU \qquad \text{Equation 12}$$

$$NTSP = AL - TLU - Margin \qquad \text{Equation 13}$$

The LTSP and NTSP for a trip or actuation on a decreasing process are calculated using Equations 14 and 15, respectively.

$$LTSP = AL + TLU \qquad \text{Equation 14}$$

$$NTSP = AL + TLU + Margin \qquad \text{Equation 15}$$

Margin, as used in Equations 13 and 15, is discretionary and chosen for conservatism of the trip setpoint. A standard value for discretionary margin is not applied by this methodology. Discretionary margin is established based on engineering judgment, justified, and documented in the setpoint calculation. Discretionary margin applied must be greater than or equal to the AFT to ensure the LSSS specified in the plant technical specifications is not exceeded. The NTSP is evaluated with respect to normal operational limits and margin, if any, is established to protect against inadvertent trip actuations.

3.4 PERFORMANCE TESTING

Performance testing and calibration of instrumentation that performs safety-related trip and actuation functions are required periodically by the plant technical specification surveillance requirements to verify that the equipment performs as expected and to provide early detection of equipment degradation.

The performance testing acceptance criteria (PTAC) that verify setpoint performance are based on a calculation of the expected performance of the tested instrument modules under the test conditions. The acceptance criteria are determined such that it represents expected equipment performance and avoids masking equipment degradation. For KP-FHRs, the PTAC is calculated by applying an as-found tolerance (AFT) to the NTSP. Only those effects known to be present during the test are included in the calculation of the AFT. The uncertainties included in the AFT calculation are typically limited to reference accuracy, instrument drift, and M&TE effects. Inclusion of additional uncertainties may be appropriate if it can be justified that these effects exist at the time of test, and including these additional uncertainties will not mask equipment degradation. The use of an overly conservative estimation of the M&TE effects and drift values for TLU purposes is non-conservative for equipment performance evaluation and should be avoided. The general equation for calculating the AFT is provided in Equation 16.

$$AFT \leq \pm (RA^2 + MTE^2 + DR^2)^{1/2} \qquad \text{Equation 16}$$

The PTAC is then calculated using Equation 17 by applying the AFT in both directions around the NTSP:

$$PTAC \leq NTSP \pm AFT \qquad \text{Equation 17}$$

Excessive deviation in either direction indicates equipment problems, requiring appropriate corrective action to be taken. Based on the results of performance testing and calibration, the operability of the instrument loop is determined. The potential as-found results and the required actions are summarized in the Table 1 below.

The performance testing also requires that the equipment being tested be left within an as-left tolerance (ALT). The ALT is an allowance within which the calibrated instrumentation must perform at the conclusion of a calibration or similar surveillance activity and is equal to reference accuracy of the equipment under test. The magnitude of the ALT is included in the TLU such that leaving the equipment anywhere in the ALT will ensure a trip at or before the AL is reached.

The ALT is applied in both directions around the NTSP and implemented in the surveillance and calibration procedures.

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Table 1: Operability Evaluations for Performance Testing Results

As-found Performance Testing Results	**Channel Operability Status and Required Actions**
As-found performance testing result within ALT	Instrument channel is declared Operable by on-shift Senior Reactor Operator, no additional action is required. Document results in accordance with plant procedures.
As-found performance testing result outside ALT, but within AFT	Instrument channel is declared Operable by on-shift Senior Reactor Operator, but recalibration is required to return the instrument being tested to within the ALT. Document results in accordance with plant procedures.
As-found performance testing result outside PTAC	Instrument channel is declared Inoperable by on-shift Senior Reactor Operator, applicable Technical Specification LCO conditions are entered, and the testing results are documented in the corrective action program. Recalibration is necessary to return the instrument being tested to within the ALT. An engineering evaluation of the channel functionality and additional corrective actions, as determined by the corrective action program, are required to return the channel to an operable status.

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4 DOCUMENTATION

Uncertainty analyses, setpoint determinations, performance test acceptance criteria, and as-found and as-left tolerances for safety-related instrumentation trip and actuation functions are performed and documented in accordance with the applicable nuclear quality assurance and design control programs.

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5 CONCLUSIONS

This topical report describes the methodology used to establish safety-related instrumentation setpoints for KP-FHRs. The methodology ensures that the safety-related setpoints are consistent with the assumptions made in the safety analyses and conform to the requirements of ANSI/ISA-67.04.01-2018 as endorsed by Regulatory Guide 1.105, Revision 4. The methodology accounts for total instrument loop uncertainties in the determination of safety-related setpoints to ensure that safety-related protective actions are initiated such that safety limits are not exceeded. The methodology also determines as-found and as-left tolerances to be used to establish performance testing acceptance criteria for use in technical specification surveillance testing and calibration procedures.

6 REFERENCES

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