UNITED STATES
NUCLEAR REGULATORY COMMISSION
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KAIROS POWER LLC – FINAL SAFETY EVALUATION OF TOPICAL REPORT KP-TR-021-NP, "INSTRUMENT SETPOINT METHODOLOGY FOR THE KAIROS POWER FLUORIDE SALT-COOLED HIGH-TEMPERATURE REACTOR," REVISION 1 (CAC NO. 000431 / EPID L-2023-TOP-0033)

SPONSOR INFORMATION

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Project No.: 99902069

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Correspondence Dates and ADAMS Accession Nos:

- U.S. Nuclear Regulatory Commission (NRC) Staff Topical Report (TR) Completeness Determination for Kairos Instrument Setpoint Methodology, dated July 17, 2023, (ML23194A231)
- Email Transmitting NRC Staff Clarification Questions Regarding Kairos's Instrument Setpoint Methodology TR, dated September 25, 2023, (ML23268A410)
- Public Meeting Notice Regarding the NRC Staff's Review of Kairos Instrument Setpoint Methodology TR, dated September 22, 2023, (ML23268A335)
- Summary of September 28, 2023, Public Meeting to Discuss the Kairos Instrument Setpoint Methodology TR, dated April 1, 2024, (ML24089A217)
- Kairos Power, KP-TR-021-NP, Instrument Setpoint Methodology for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor, Revision 1, dated October 4, 2023, (ML23277A313)

Brief Description of the Topical Report: The TR provides the methodology for establishing the safety-related instrument setpoints for Kairos Power Fluoride Salt-Cooled, High Temperature Reactors (KP-FHR) power and test reactors. 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.

Enclosure

EVALUATION CRITERIA

Regulatory Requirements

The following regulatory requirements are applicable to the NRC staff's review of KP-TR-021-NP, Revision 1.

Title 10 of the *Code of Federal Regulations* (10 CFR) 50.36(c)(1)(ii)(A) requires, in part, that if a limiting safety system setting (LSSS) is specified for a variable on which a safety limit (SL) has been placed, the setting will be chosen so that automatic protective action will correct the abnormal situation before a safety level is exceeded. The LSSSs are settings for automatic protective devices related to variables with significant safety functions. Additionally, 10 CFR 50.36(c)(1)(ii)(A) requires that a licensee take appropriate action if it is determined that the automatic safety system does not function as required.

10 CFR 50.36(c)(3), "Surveillance Requirements," states that 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 SLs, and that the limiting conditions for operation will be met.

American National Standards Institute (ANSI)/American Nuclear Society (ANS)15.8–1995, Quality Assurance Program Requirements for Research Reactors, reaffirmed in 2005 (Reference 2), provide requirements for tests and test equipment used in maintaining instrument setpoints.

Principal Design Criteria

The topical report KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 1, dated June 12, 2020, (ML20167A174), (Reference 3) provides principal design criteria (PDC) for the KP-FHR design that were reviewed and approved by the NRC staff. The PDCs below are applicable to the NRC staff's review of KP-TR-021-NP, Revision 1.

KP-FHR PDC 13, "Instrumentation and Control," states, in part, that "[i]nstrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions, as appropriate, to ensure adequate safety, […]," and that "[a]ppropriate controls […] be provided to maintain these variables and systems within prescribed operating ranges."

KP-FHR PDC 20, "Protection System Functions," states, that "[t]he protection system shall be designed (1) to initiate automatically the operation of appropriate systems, including the reactivity control systems, to ensure that specified acceptable 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."

TECHNICAL EVALUATION

In evaluating the adequacy of the KP-FHR Instrument Setpoint Methodology, the NRC staff utilized the following guidance:

- Regulatory Guide (RG) 1.105, "Setpoints for Nuclear Safety-Related Instrumentation," Revision 4 (Reference 4), which endorses ANSI/International Society of Automation (ISA) Standard ANSI/ISA-67.04.01-2018, "Setpoints for Nuclear Safety-Related Instrumentation," (Reference 5)
- Design Specific Review Standard (DSRS) for NuScale Small Modular Reactor Design, Chapter 7, "Instrumentation and Controls – System Characteristics," Section 7.2.7, "Setpoints," (Reference 6)
- Regulatory Issue Summary (RIS) 2006-17, "NRC Staff Position on the Requirements of 10 CFR 50.36, 'Technical Specifications,' Regarding Limiting Safety System Settings During Periodic Testing and Calibration of Instrument Channels," (Reference 7) which provides guidance to the NRC staff for the review of a setpoint methodology
- ISA-RP67.04.02-2010, "Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation," (Reference 8) contains additional guidance for establishing safety-related setpoints but is not endorsed by the NRC staff in RG 1.105, Revision 4

The objectives of the NRC staff's review of KP-TR-021-NP, Revision 1 are to (1) verify that setpoint calculation methods are adequate to ensure that protective actions are initiated before the associated plant process parameters exceed their analytical limits (ALs), (2) verify that setpoint calculation methods are adequate to ensure that control and monitoring setpoints are consistent with their requirements, and (3) confirm that the established calibration intervals and methods are consistent with safety analysis assumptions.

The establishment of setpoints and the relationships between nominal trip setpoints (NTSPs), limiting trip setpoints (LTSPs)/LSSS, as-left and as-found values, as-left tolerance (ALT), as-found tolerance (AFT), AL, and SL are discussed in this TR. A thorough understanding of these terms is important to properly utilize the total instrument channel uncertainty in the establishment of setpoints. The setpoints of concern in this review include (1) setpoints specified for process variables on which SLs have been placed, or a process variable that functions as a surrogate for one on which a SL has been placed; and (2) setpoints related to process variables that are associated with safety functions but do not protect any SLs.

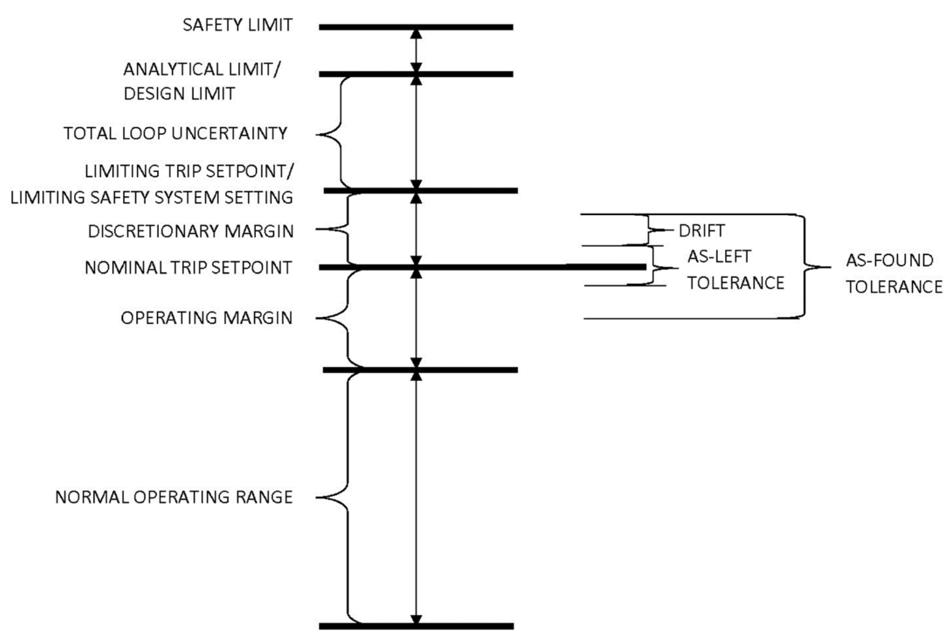
Establishing setpoints involves determination of the proper allowance for uncertainties between the device setpoint and the process AL or documented design limit. The calculation of device uncertainties is documented and the device setpoint determined using a documented methodology. The setpoint analysis set forth in the setpoint methodology confirms that an adequate margin exists between setpoints and ALs or design limits. Furthermore, the analysis should confirm that an adequate margin exists between operating limits and setpoints to avoid inadvertent actuation of the system.

A setpoint methodology developed in accordance with RG 1.105, Revision 4, and ANSI/ISA-67.04.01-2018, provides a method acceptable to the NRC staff for complying with the NRC's regulations for ensuring that setpoints for safety-related instrumentation are initially within and remain within the technical specification (TS) limits.

While DSRS was developed as a pilot for the NuScale design, it contains updated guidance applicable to other new and advanced reactor designs. For the review of Chapter 7, “Instrumentation and Control Systems,” for both the Hermes 1 and 2 construction permit applications, the staff used additional guidance from the DSRS, which incorporated important lessons the staff learned from its review of new large light-water reactor designs. Consistent with this approach, the NRC staff evaluated the setpoint methodology using DSRS Section 7.2.7, which defines the following twelve review areas, to verify conformance with the previously cited regulatory bases and standards for instrument setpoints.

1. <u>Relationships between the SL, the AL, the limiting trip setpoint, the allowable value, the setpoint, the acceptable as-found band, the acceptable as-left band, and the setting tolerance</u>.

The NRC staff reviewed TR Figure 1, “Setpoint Parameter Relationships,” shown below in Figure 1, and compared it to Figure 1, “Relation Between Setpoint Parameters,” of ANSI/ISA-67.04.01-2018 (ANSI Figure 1) which depict relationships between various setpoints, margins, limits and other setpoint parameters. RG 1.105, Revision 4, states that “Figure 1 of ANSI/ISA 67.04.01-2008 [(ANSI Figure 1)] illustrates setpoint relationships for nuclear safety-related setpoints.” The NRC staff determined that the TR Figure 1 is comparable to ANSI Figure 1 in that the types of setpoints parameters (e.g. setpoints, margin, limits, etc.) and relative relationships are represented similarly. For these reasons, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to relationships between setpoint parameters for safety-related instrumentation.



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.

Figure 1 Setpoint Parameter Relationships (TR Figure 1)

2. Setpoint TS meeting the requirements of 10 CFR 50.36, with RIS 2006-17 providing additional information related to setpoint TS.

Applicants for licenses under 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities,” are required to include proposed TS as described in 10 CFR 50.36, “Technical Specifications.” The Kairos methodology in the TR provides an overview of the information that the Kairos TS will provide to develop setpoints for safety-related instrumentation. The NRC staff reviewed TR Sections 1.3, “Regulatory Guidance,” 2.3.4, “Drift,” 3.1, “Limit and Setpoint Relationships,” and 3.4, “Performance Testing,” Figure 2, “Setpoint Calculation Flowchart,” and Table 1, “Operability Evaluations for Performance Testing Results.” Based on its review, the NRC staff confirmed that the methodology describes the information needed to:

1. Ensure that the maintenance of the instrument channels implementing these setpoints are functioning, as required with appropriate calibration intervals established;
2. Ensure SLs are identified 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. Ensure operability evaluations for performance of testing results that confirm the equipment performs as expected to provide early detection of equipment degradation, and actions to address testing results.

Based on the above discussion, the NRC staff finds that the Kairos setpoint methodology meets the requirements of 10 CFR 50.36.

3. Basis for selection of the trip setpoint.

The NRC staff reviewed TR Section 3, “Establishment of Setpoints,” Figure 1, “Setpoint Parameter Relationships,” Figure 2, “Setpoint Calculation Flowchart,” and Equations 12 through 15. In the Kairos methodology, the AL is provided by the plant’s safety analysis, to ensure that a trip occurs before the SL is reached. The purpose of an LTSP is to ensure that a protective action is initiated before the process conditions reach the AL. NTSPs are calculated using the LTSP and discretionary margin as shown in TR Equations 12 through 15. Discretionary margin applied must be greater than or equal to the AFT to ensure the LSSS specified in the plant TS is not exceeded. The NTSP is evaluated with respect to normal operational limits and margin, if any, and is established to protect against inadvertent trip actuations, which is consistent with ANSI/ISA-67.04.01-2018. For this reason, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to calculating and selection of a trip setpoint.

4. Uncertainty terms that are addressed.

The NRC staff reviewed TR Section 3.2.1.2, “Identifying Design Parameters and Sources of Uncertainty,” which provides a minimum list of uncertainties for calculating the total loop uncertainty (TLU) that are considered typical, but not inclusive, and found the list consistent with ANSI/ISA-67.04.01-2018. Other considerations that contribute to the uncertainty, such as environmental conditions and installation details of the components, are also factored into the TLU as described in TR Section 3.2.1.2 and Equations 6, 7, 8, and 9 in TR Section 3.2.2, “Calculating Total Loop Uncertainty,” which are consistent with equations in Section 4.5.3, “Formulas and Methodology Discussion,” of ANSI/ISA-67.04.01-2018. For this reason, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to uncertainty terms, bias values, and correction factors used when calculating trip setpoints.

5. Method used to combine uncertainty terms.

The NRC staff reviewed TR Section 2, "Uncertainties," which states that the Kairos "…methodology characterizes uncertainties in instrumentation measurement as random, bias, or abnormally distributed." Additionally, TR Section 2.4, "Calculating Instrument Uncertainties," states that "[i]ndividual 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 NRC staff notes that the methods for combining uncertainties are consistent with ANSI/ISA-67.04.01-2018, and for this reason, the NRC staff finds that the Kairos setpoint conforms to RG 1.105, Revision 4, with respect to combining uncertainty terms when calculating a trip setpoint.

6. Justification of statistical combination.

The NRC staff reviewed TR Section 3.2.1.2 which states that "[t]he sources of uncertainty allowances shall be documented and justified in the setpoint calculation." The NRC staff notes that this is consistent with the documentation requirements of ANSI/ISA-67.04.01-2018. For this reason, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to documenting justifications within a trip setpoint calculation.

7. Relationship between instrument and process measurement units.

The NRC staff reviewed TR Section 2.4 and noted that although it states that "[i]ndividual uncertainty terms are calculated in terms of percent calibrated span…," it does not describe the relationship between instrument and process measurement units. However, the methodology references ISA-RP67.04.02-2010, which describes this relationship by stating that trip setpoint values usually require transformation from process parameters to voltage or current values. For example, an analog pressure transmitter loop may contain an electronic comparator whose trip setting is measured and set in milliamperes of current. This conversion or scaling process can typically be described as a simple linear equation that relates process variable units to measurement signal units. This scaling process would also apply to ALT and AFT. Although ISA-RP67.04.02-2010 is not endorsed by the NRC, based on its review, the NRC staff determined that the methodology referenced in ISA-RP67.04.02-2010 provides applicable guidance for the implementation of ANSI/ISA-67.04.01-2018.

Using the methodology described in ISA-RP67.04.02-2010, a setpoint provided in percent span is calibrated at the sensor in process units [e.g., sensor input is 0-100 inches of water column (inWC), output is 4-20 milliamp direct current (mA DC), the computer input card input is 4-20 mA DC, output is 0-10 volts (V) DC]. The software converts 0-10 V DC to 0-100 percent span. Thus, a 70 percent span setpoint indication at main control room equates to 70 inWC at the process and is represented below in Figure 2. Additional discussion on the scaling or conversion process is described in ISA-RP67.04.02-2010, Section 9. Based on the above, the NRC staff finds that the Kairos setpoint methodology is consistent with ISA-RP67.04-0210, and therefore conforms to RG 1.105, Revision 4, with respect to converting percent calibrated span into process measurement units within a trip setpoint calculation.

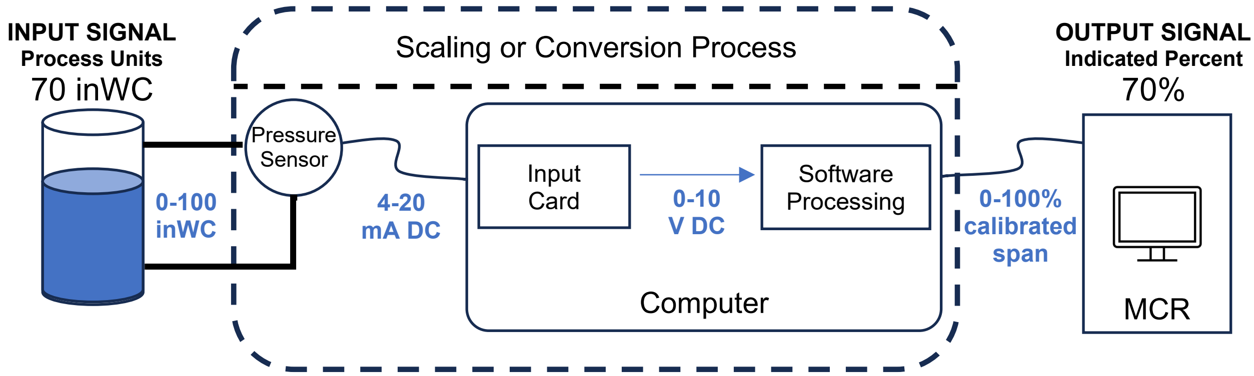


Figure 2 Scaling or Conversion Process

8. Data used to select the trip setpoint, including the source of the data.

The NRC staff reviewed TR Section 3.2.1.2, which states that “[t]he 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.” Section 3.3, “Calculating Trip Setpoints,” states that “[t]he chosen setpoints for each channel shall have values that represent the performance of the instrumentation, with a 95 [percent] probability of channel trip at or before the [AL] is reached at a 95 [percent] confidence level.” Section 2.1.1, “Independent Uncertainties,” states that “[i]f 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.” The NRC staff notes that the discussion above is consistent with ANSI/ISA-67.04.01-2018 for the data and the source of data used in calculating setpoints. For this reason, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to data used for a trip setpoint calculation.

9. Assumptions used to select the trip setpoint (e.g., ambient temperature limits for equipment calibration and operation, potential for harsh accident environment).

The NRC staff reviewed TR Section 2.3, “Sources of Uncertainties,” which describes various assumptions used to select the trip setpoint including those related to measurement and test equipment, temperature, and power supply variations. Additionally, TR Sections 1, “Introduction,” and 5, “Conclusions,” both make declarative statements that the methodology described in the TR ensures that the safety-related setpoints are consistent with the assumptions made in the safety analyses. For this reason, the NRC staff finds that the Kairos setpoint methodology is consistent with ANSI/ISA-67.04.01-2018 and conforms to RG 1.105, Revision 4, with respect to assumptions for a trip setpoint calculation.

10. Instrument installation details and bias values that could affect the setpoint.

The NRC staff reviewed TR Sections 2.2.1, "Bias (Known Sign)," through 2.2.3, “Bias (Unknown Sign),” Section 2.4, “Calculating Instrument Uncertainties,” and Equation 2. The NRC staff notes that the Kairos methodology generally describes and provides examples of the different types of bias that may be encountered and how they are addressed in the calculation of TLU. Based on its review, the NRC staff determined that the identification of the different types of bias and how they are used in the setpoint calculation, is consistent with ANSI/ISA-67.04.01-2018. The staff evaluated TR Section 2.2.4 concerning corrections related to installation details in review area 11 of this safety evaluation. For this reason and the finding in review area 11 below, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to installation details and bias.

11. Correction factors used to determine the setpoint (e.g., pressure compensation to account for elevation difference between the trip measurement point and the sensor physical location).

The NRC staff reviewed TR Section 2.2.4, "Corrections," which states "[f]or KP-FHRs, errors or offsets associated with instrument installation and service (i.e., static head effects) that are of a known direction and magnitude are corrected for in the calibration of the module when possible and are not included in the setpoint calculation. The fact that these corrections are made during calibration is identified in the setpoint uncertainty calculation." The NRC staff reviewed the discussion of corrections and how they are dealt with concerning setpoint calculation in ISA-RP67.04.02-2010, Sections 6.2.1.2.4, "Correction," and 6.2.6, "Calibration Uncertainty (CU)." Based on this review, the NRC staff finds the Kairos setpoint methodology dealing with instrument installation and service corrections acceptable because the approach of either calibrating out the effects or accounting for it in the setpoint calculation is consistent with ANSI/ISA-67.04.01-2018 and ISA-RP67.04.02-2010. For this reason, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to corrections factors during calibration.

12. Instrument testing, calibration or vendor data, as-found and as-left; where each instrument should be demonstrated to have random drift by empirical and field data. Evaluation results should be reflected appropriately in the uncertainty terms, including the setpoint methodology.

Review area 8 above describes the data used to select the trip setpoint, including the source of the data. The NRC staff reviewed TR Section 2.3.4, "Drift," which states 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. The NRC staff reviewed the discussion of drift and the different ways it is established, either by vendor specification, extrapolating the vendor drift to meet the need surveillance interval, or drift analysis of the AFT and ALT calculated in the setpoint calculation. ISA-RP67.04.02-2010, Annex E, "As-found and as-left data – collection and interpretation," provides a means for collection and interpretation of the as-found and as-left values acquired during calibration. Based on the above discussion, the NRC staff finds the Kairos setpoint methodology dealing with obtaining, evaluating, and validating drift acceptable because the approach is consistent with ANSI/ISA-67.04.01-2018 and ISA-RP67.04.02-2010. For this reason, the NRC staff finds that the Kairos setpoint methodology conforms to RG 1.105, Revision 4, with respect to corrections factors during calibration.

CONCLUSION

The NRC staff concludes that the Kairos TR KP-TR-021-NP, Revision 1, provides information sufficient to (1) demonstrate that the setpoint calculation methods are adequate to ensure that protective actions are initiated before the associated plant process variables exceed their ALs, (2) demonstrate that the setpoint calculation methods are adequate to ensure that control and monitoring setpoints are consistent with their system specifications, and (3) show that the established calibration intervals and methods are consistent with safety analysis assumptions. The NRC staff also confirmed that the applicant's approach is consistent with ANSI/ISA-67.04.01-2018 and conforms to the guidance in RG 1.105, Revision 4.

Based on the above discussion, the NRC staff finds that the setpoint methodology in TR KP-TR-021-NP, Revision 1, is sufficient to allow the applicant to create setpoint calculations to meet PDCs 13 and 20, and the requirements of 10 CFR 50.36(c)(1)(ii)(A), and 10 CFR 50.36(c)(3), once the instruments are specified, procured, and installed, and the TS and safety analysis are available.

REFERENCES

1. Kairos Power LLC, “Instrument Setpoint Methodology for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” KP-TR-021-NP, Revision 1, dated, October 4, 2023, (ML23277A313)

2. ANSI/ANS-15.8-1995, “Quality Assurance Program Requirements for Research Reactors,” American Nuclear Society, La Grange Park, IL, dated September 2005.

3. Kairos Power LLC, “Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor,” KP-TR-003-NP-A, dated June 12, 2020, (ML20167A174)

4. United States Nuclear Regulatory Commission, Regulatory Guide 1.105, “Setpoints for Safety-Related Instrumentation,” Revision 4, dated February 2021, (ML20330A329)

5. ANSI/ISA- 67.04.01-2018, “Setpoints for Nuclear Safety-Related Instrumentation,” dated December 2018, Research Triangle Park, NC

6. Design Specific Review Standard for NuScale Small Modular Reactor Design, Chapter 7, “Instrumentation and Controls – System Characteristics,” dated July 2016, (ML15363A347)

7. Regulatory Issue Summary 2006-17, “NRC Staff Position on the Requirements of 10 CFR 50.36, ‘Technical Specifications,’” dated August 2006, (ML051810077)

8. ISA-RP67.04.02-2010, “Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation,” dated December 2010, Research Triangle Park, NC

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