U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Clean. Reliable. Nuclear.

ASI Technology Qualification Process

Advanced Sensors and Instrumentation Annual Webinar

October 29, 2020

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INL

Project Overview

- Objective
  - Develop a guideline for qualifying new sensors and Instrumentation Systems for Nuclear Applications that are being developed at INL in an R&D environment
  - Guidelines based on established standards (ASME NQA-1, NASA, ISO), especially pertinent is the Graded Approach defined in NQA-1 subpart 4.2 for sensors developed in an R&D environment
  - Guideline QA procedures based on established practices in Nuclear Industry
  - Use Guideline to Qualify New Sensors developed at INL

- INL Participants
  - Developers: Yogi Dayal, Colby Jensen,
  - Reviewers: Pattrick Calderoni, Troy Unruh, Joe Palmer, Richard Skifton, Austin Fleming, Nicolas Woolstenhulme

- Schedule
  - Formal document Completed, Reviewed and Issued in 2020

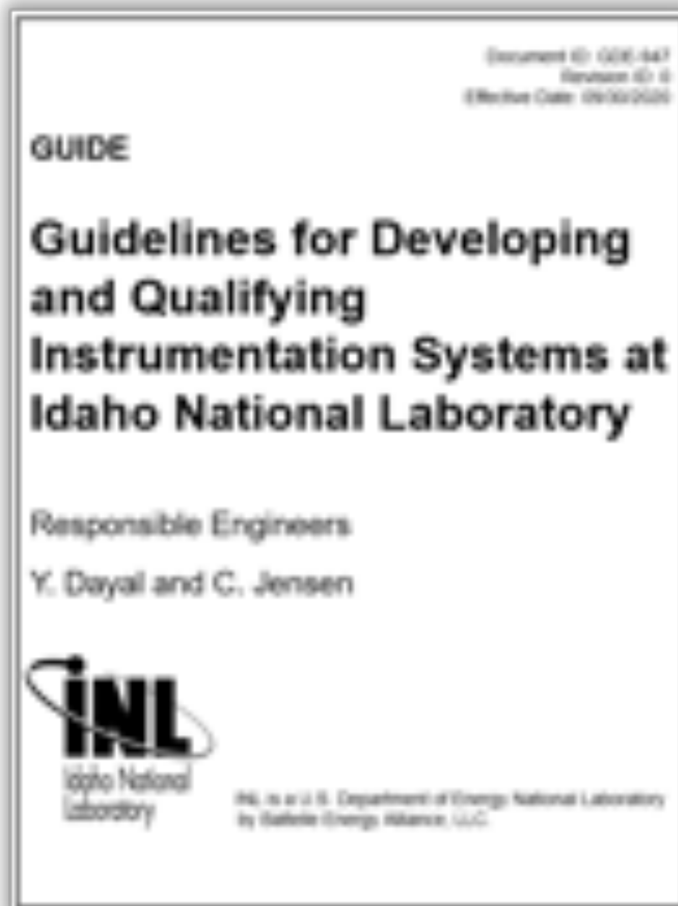
Summary of Accomplishments

- Guidelines for developing and qualifying new sensors and instrumentation systems has been completed

- A report has been written and has gone through a critical INL review and acceptance process

- Report is in the final stages of the document technical editing and release process

  INL Report: GDE-947



GUIDE

Guidelines for Developing and Qualifying Instrumentation Systems at Idaho National Laboratory

Responsible Engineers

Y. Dayal and C. Jensen

Technology Impact

- This QA guideline provides a formal step by step method for new Instrumentation and Control products and data developed in an R&D environment to get qualified for nuclear application

- Provides pedigree to new product design and data that is acceptable to the NRC and the new product stakeholders

- Supports the DOE-NE research mission and provides a positive impact to the nuclear industry by providing a method of obtaining qualified new products and test data

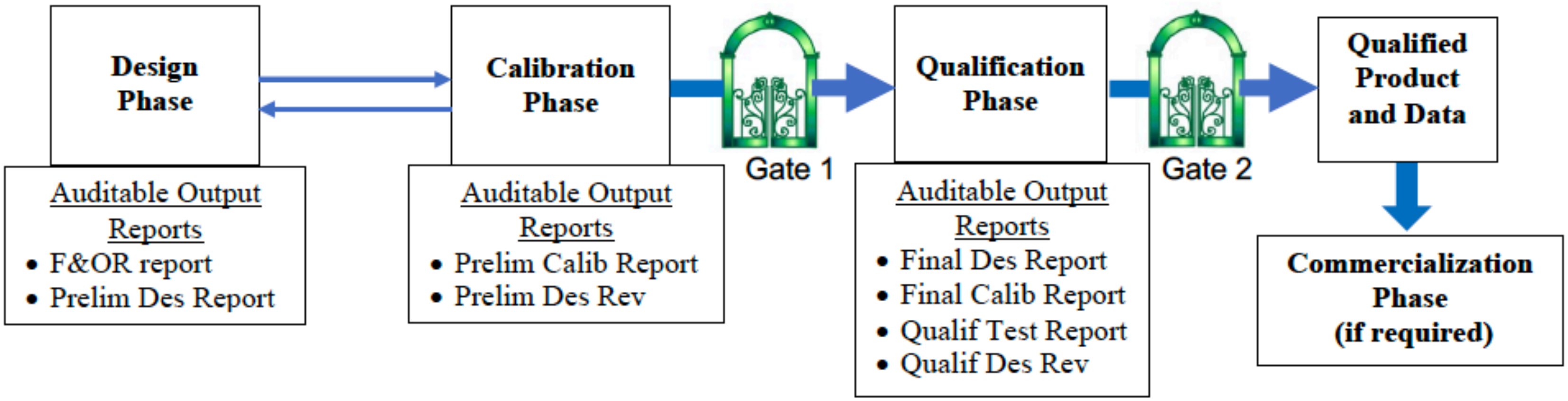
- Products qualified according this methodology can readily be commercialized. This qualification methodology focuses on critical technical and performance features such as Requirements, Design, Calibration, Accuracy and Test Results in a prototypic nuclear environment. Details, such as Class 1E qualification which are application specific would be performed later by or in coordination with the commercial party.

Technology Impact (Continued)

- This QA Guidelines will support
  - New Sensors for in-pile experiments for testing properties (such as temperature, growth etc) of new fuels and materials
  - New Sensors will be needed for monitoring critical parameters in new advanced Small modular reactors with their small core and lack of penetrations for monitoring sensors. New sensors will also be needed for the corrosive environment of advanced Molten Salt reactors, and for high temperature operation in the advanced High Temperature Gas Reactor. Critical parameters include:
    - in-core neutron flux
    - primary flow
    - core inlet and outlet temperatures
    - Pressure, Level, etc
    - Fuel Temperature in case of loss-of-flow

Technical Content

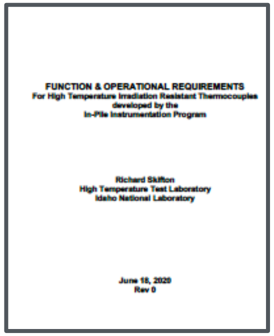
- Overall Product Development and QA Process has targeted Engineering Output Reports which are auditable
- Activities to Pass Qualification Gate 1
  - Functional and Operational Requirements Report
  - Preliminary Design Report
  - Preliminary Design Review
- Activities to Pass Qualification Gate 2
  - Final Design and Calibration Reports
  - Reactor Qualification Test Report
  - Qualification Design Review
- Qualified Product – Potential Commercialization Phase



Example

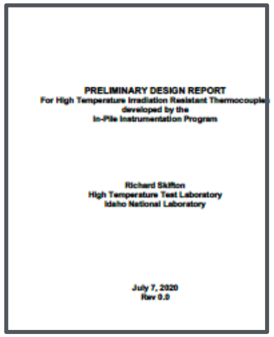
- New High Temperature Irradiation Resistant Thermocouple (HTIR-TC)

- Completed F&OR, Preliminary Design Report, Preliminary Calibration Report and Preliminary Design Review


FUNCTION & OPERATIONAL REQUIREMENTS
For High Temperature Irradiation Resistant Thermocouples
developed by the
In-Pile Instrumentation Program

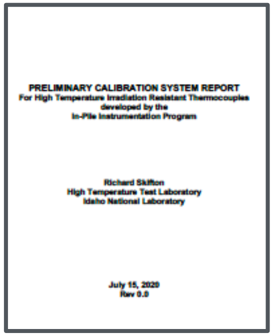
Richard Skifton
High Temperature Test Laboratory
Idaho National Laboratory

June 18, 2020
Rev 0


PRELIMINARY DESIGN REPORT
For High Temperature Irradiation Resistant Thermocouples
developed by the
In-Pile Instrumentation Program

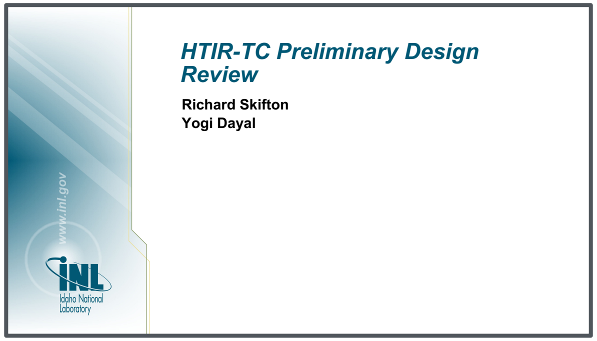
Richard Skifton
High Temperature Test Laboratory
Idaho National Laboratory

July 7, 2020
Rev 0.0


PRELIMINARY CALIBRATION SYSTEM REPORT
For High Temperature Irradiation Resistant Thermocouples
developed by the
In-Pile Instrumentation Program

Richard Skifton
High Temperature Test Laboratory
Idaho National Laboratory

July 15, 2020
Rev 0.0



- Currently incorporating Design Review Comments into Reports. All reports are auditable

- Next Pass thru Gate 1 and enter the Qualification Phase

Example – HTIR-TC Requirements

- Capable Temperature Measurement in Experimental Rig to Evaluate New Fuel Designs
- Capable of Stand-alone Temperature Measurements in Power Reactors
- Measure up to 1600 degrees C in Reactor Environment at Neutron Flux of 10^{14} nv – Suitable for In-Core Fuel Temperature Measurements in Case of Loss-of-Flow Accidents
- Accuracy: < 1% at High Temperature
- Sensitivity Change < -5% over 1.2 x10^{21} nvt equivalent to typical year Refueling Interval in Power Reactors
- Mechanically Rugged with Low Sensitivity to damage from Fast Neutrons

Example – HTIR-TC Material Basis

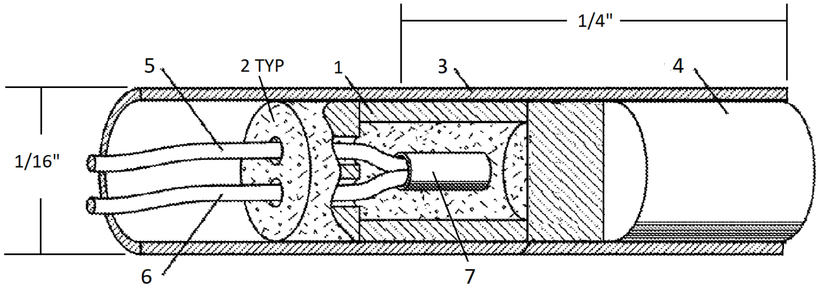
	Element	Atomic No.	Atomic Wt.	Density [kg/m3] x 10^{-3}	Melting Temperature [°C]	Absorption Cross Section [barns], σ_A[1]
HTIR	Niobium	41	92.906	8.57	2477	1.15
	Molybdenum	42	95.94	10.2	2623	*2.48
OTHERS	Nickel	28	58.71	8.90	1455	*4.49
	Tungsten	74	183.84	19.3	3422	*18.43
	Rhenium	75	186.207	21.02	3186	*89.7
	Platinum	78	195.09	21.45	1768	*10.3
	Rhodium	45	102.905	12.41	1964	144.8

[1]2200 m/sec Cross Sections (based on neutron velocity of 2200 m/sec and thermal neutron energy 0.0253-eV)

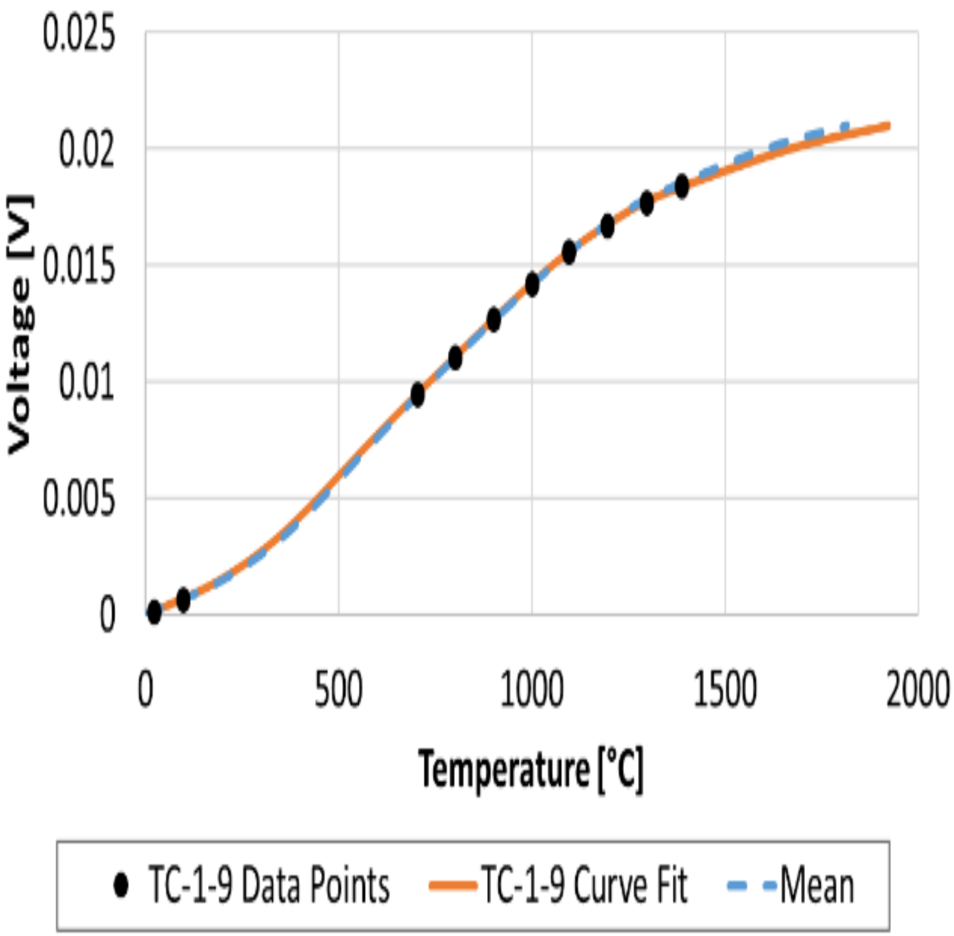
* Average values of individual isotope cross sections

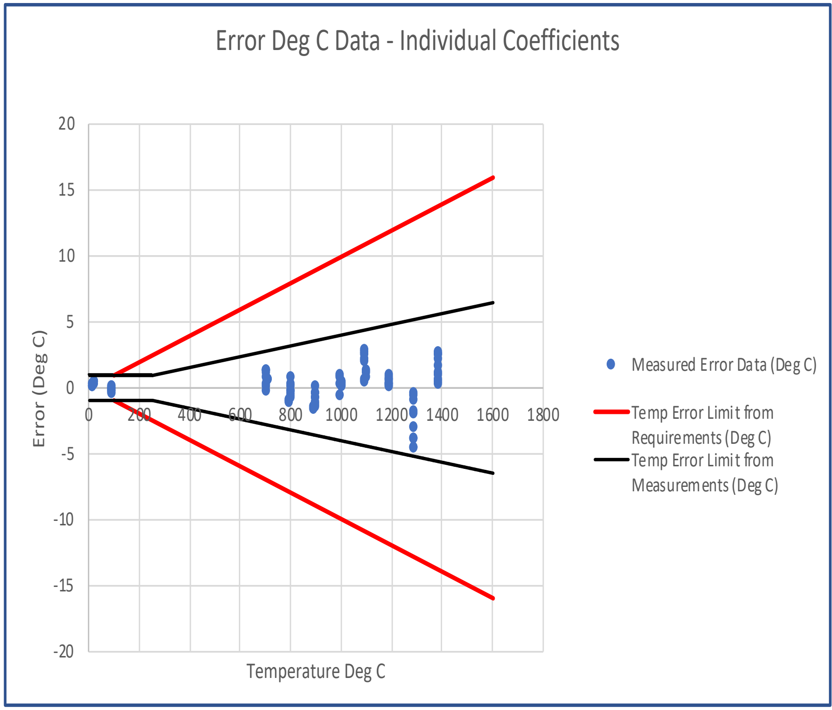
Example – HTIR-TC Preliminary Design

- The HTIR-TC junction between Niobium and Molybdenum is formed by a small tantalum band/bushing
- No weld utilized in the forming of the thermocouple junction
- The mechanical junction outperforms a weld in the harsh high temperature environment of the reactor



Example – HTIR-TC Calibration Data

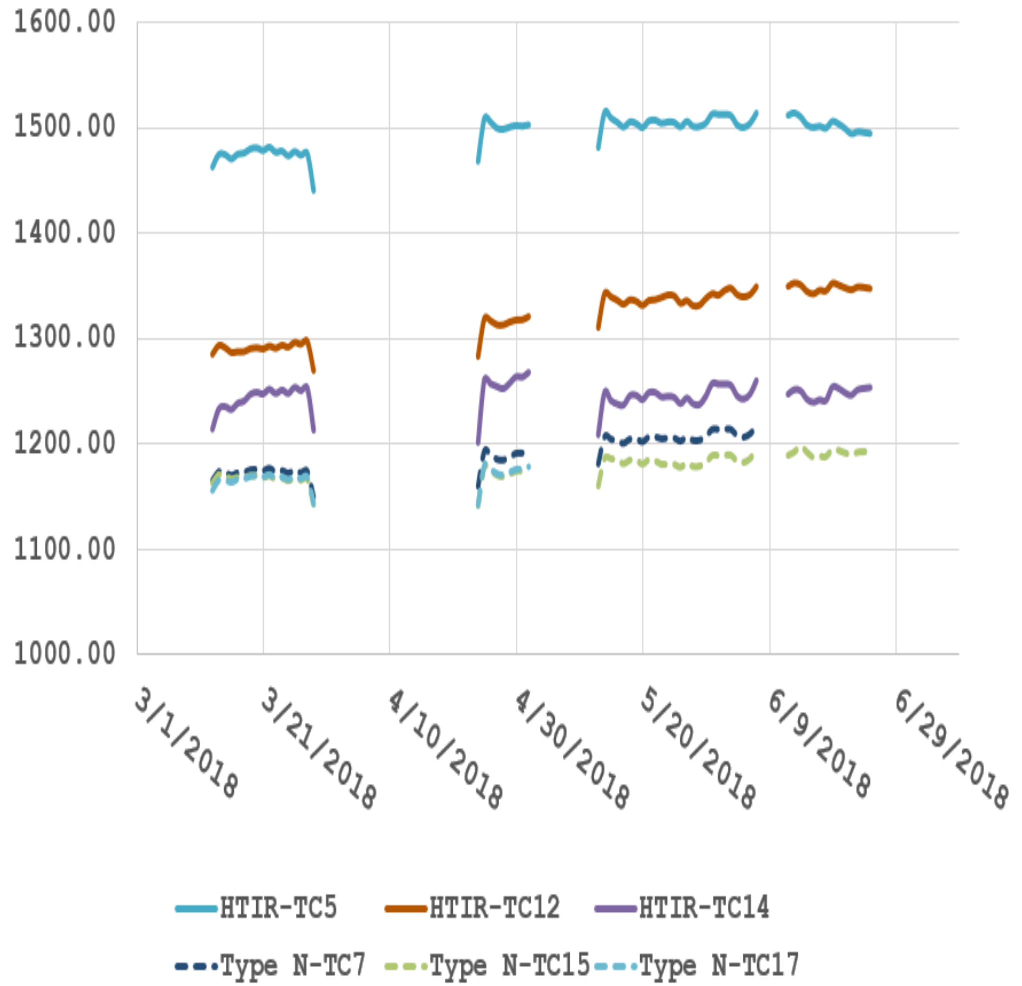




Error Requirement:	**1% (16 Deg C at 1600 Deg C),**
Error Measured:	**< 0.4% (6.4 Deg C at 1600 Deg C**

Example – HTIR-TC Reactor Test Results

- Results show HTIR-TC can reliably measure temperatures up to 1500 °C over 5 months in ATR test reactor.
- The HTIR-TCs recover to correct value after multiple shutdown/restarts.



Conclusion

- Summary
  - An INL QA Guidelines Document based on ASME NQA-1 standards has been written to qualify new Sensors developed in an R&D environment
  - Document is currently being used to qualify newly developed HTIR-TC and Data obtained by them in Reactor Tests
  - Other products will follow including newly developed Hafnium-Gadolinium Prompt Self-Powered Detectors for advanced reactors, and LVDTs for measuring dimensional changes to evaluate performance of new fuel designs in a reactor environment
  - Qualification of new sensors is a critical part of ASI program which supports DOE-NE R&D programmatic needs
- Questions ?
- Contact: Yogi Dayal, email: Yogeshwar.dayal @inl.gov