INL/MIS-24-80593-Revision-0

Accelerated Materials Deployment

September 2024

Changing the World's Energy Future

Jason Albert Christensen, Todd Michael Anselmi

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

INL/MIS-24-80593-Revision-0

Accelerated Materials Deployment

Jason Albert Christensen, Todd Michael Anselmi

September 2024

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Accelerated Materials Deployment

USNRC Standards Forum

September 25, 2024

Todd Anselmi / Scott Ferrara – Idaho National Laboratory

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

INL Idaho National Laboratory

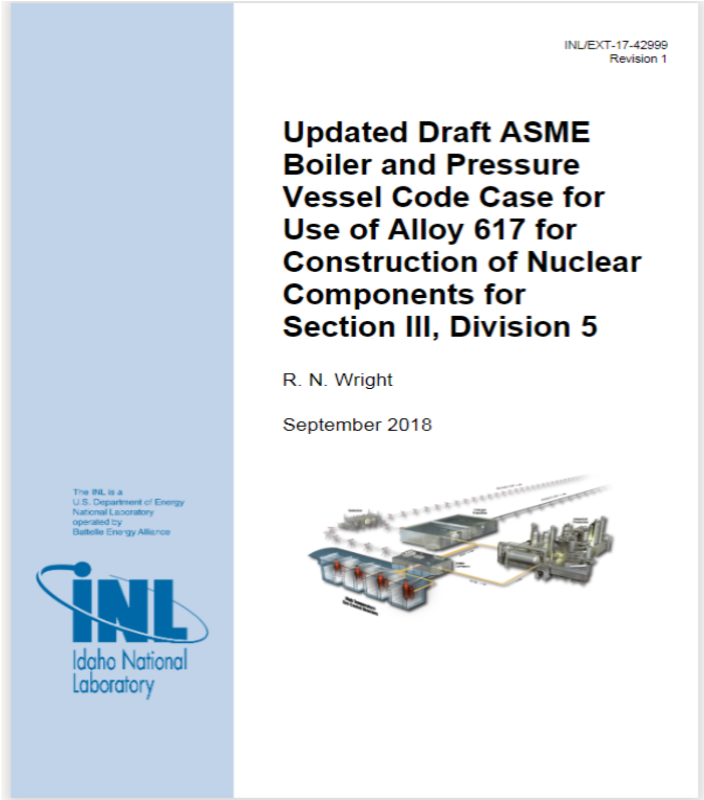
Project Scope and Objectives

Overall Project Objective

- Research and identify a regulatory approach that provides a process for early use and deployment of an existing or novel material in a reactor application that does not have an existing code case for licensing

The “Case” for the Research Activity and Program

- Code case development can take years of testing, data collection, and NRC approvals/acceptance
  - Alloy 617 – Commenced in 2005
- Testing of materials in a representative environment can come at great cost and schedule impacts
- Efficiencies and savings could be realized through baseline materials testing, performance modeling, and in-situ risk informed performance-based Reliability and Integrity Management (RIM) program



Project Scope and Objectives (cont.)

- Identify existing licensing pathways for early deployment of materials in novel environments where an established code case doesn't exist
- Identify regulatory areas where risk is managed through similar methods where base knowledge is available, but operating experience is not
- Evaluated safety case development attributes for potential licensing case technical support including sister agency applications such as NASA risk management processes

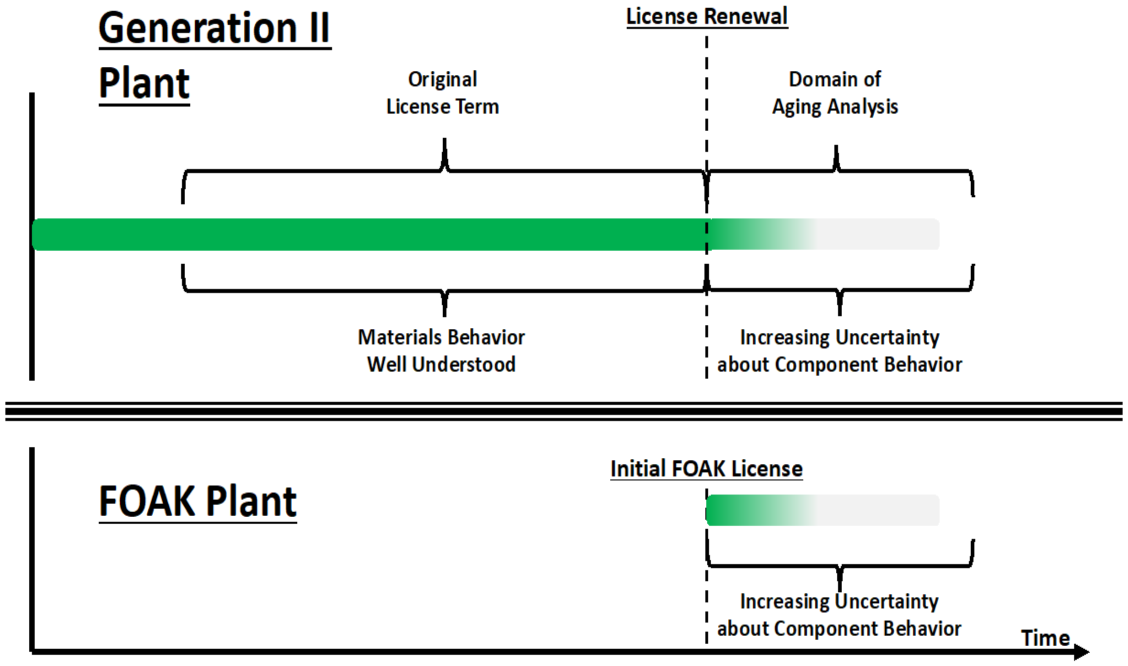
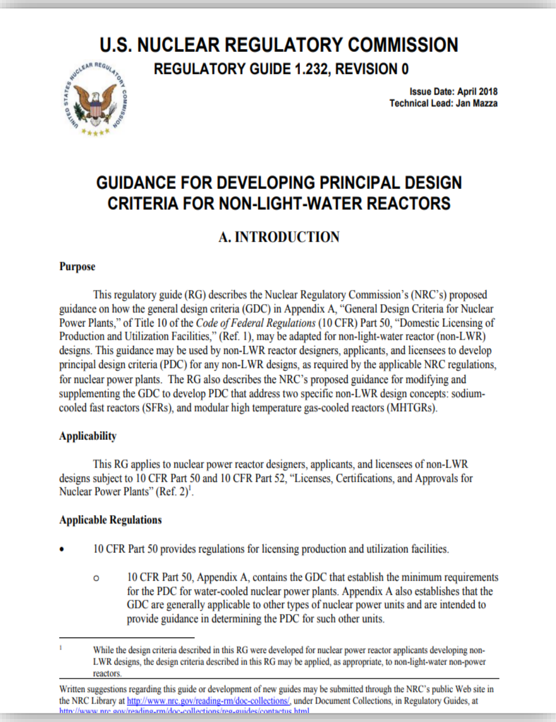


Figure 1. Time-dependent uncertainty in a Generation II Plant compared to a First of a Kind (FOAK) Plant.

Accelerated Materials Deployment Regulatory Approach – Design Criteria Evaluation

- Novel materials are evaluated for use in environments against design criteria based on technology type
  - Appendix A to 10 CFR Part 50, “General Design Criteria [GDC] for Nuclear Power Plants”
  - Regulatory Guide 1.232, “Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors”



U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE 1.232, REVISION 0

Issue Date: April 2018
Technical Lead: Jan Mazza

GUIDANCE FOR DEVELOPING PRINCIPAL DESIGN CRITERIA FOR NON-LIGHT-WATER REACTORS

A. INTRODUCTION

Purpose

This regulatory guide (RG) describes the Nuclear Regulatory Commission’s (NRC’s) proposed guidance on how the general design criteria (GDC) in Appendix A, “General Design Criteria for Nuclear Power Plants,” of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, “Domestic Licensing of Production and Utilization Facilities,” (Ref. 1), may be adapted for non-light-water reactor (non-LWR) designs. This guidance may be used by non-LWR reactor designers, applicants, and licensees to develop principal design criteria (PDC) for any non-LWR designs, as required by the applicable NRC regulations, for nuclear power plants. The RG also describes the NRC’s proposed guidance for modifying and supplementing the GDC to develop PDC that address two specific non-LWR design concepts: sodium-cooled fast reactors (SFRs), and modular high temperature gas-cooled reactors (MHTGRs).

Applicability

This RG applies to nuclear power reactor designers, applicants, and licensees of non-LWR designs subject to 10 CFR Part 50 and 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants” (Ref. 2)[1].

Applicable Regulations

- 10 CFR Part 50 provides regulations for licensing production and utilization facilities.
  - 10 CFR Part 50, Appendix A, contains the GDC that establish the minimum requirements for the PDC for water-cooled nuclear power plants. Appendix A also establishes that the GDC are generally applicable to other types of nuclear power units and are intended to provide guidance in determining the PDC for such other units.

[1] While the design criteria described in this RG were developed for nuclear power reactor applicants developing non-LWR designs, the design criteria described in this RG may be applied, as appropriate, to non-light-water non-power reactors.

Written suggestions regarding this guide or development of new guides may be submitted through the NRC’s public Web site in the NRC Library at http://www.nrc.gov/reading-rm/doc-collections/, under Document Collections, in Regulatory Guides, at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/contactus.html

- GDC 4 - Environmental and Dynamic Effects Design Bases
  - “Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents….. These SSCs shall be appropriately protected against dynamic effects…….. that may result from equipment failures and from events and conditions outside the nuclear power unit…..”

Accelerated Materials Deployment Regulatory Approach – Analysis, Appropriate Test Programs, Experience Method

§ 50.43 Additional standards and provisions affecting class 103 licenses and certifications for commercial power

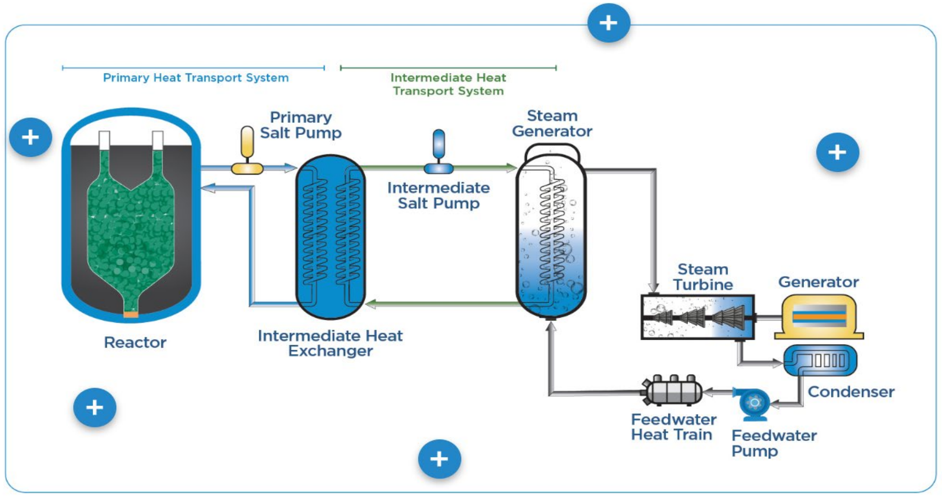
(e) Applications for a design certification, combined license, manufacturing license, operating license or standard design approval that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997. Or use simplified, inherent, passive, or other innovative means to accomplish their safety functions will be approved only if:

- (1)(i) The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof;
- (ii) Interdependent effects among the safety features of the design are acceptable, as demonstrated by analysis, appropriate test programs, experience, or a combination thereof; and
- (iii) Sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions; or

Accelerated Materials Deployment Regulatory Approach - Prototype Provision

- § 50.43 Additional standards and provisions affecting class 103 licenses and certifications for commercial power (e)
  - (2) There has been acceptable testing of a prototype plant over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions. If a prototype plant is used to comply with the testing requirements….. then the NRC may impose additional requirements …….to protect the public and the plant staff from the possible consequences of accidents during the testing period.

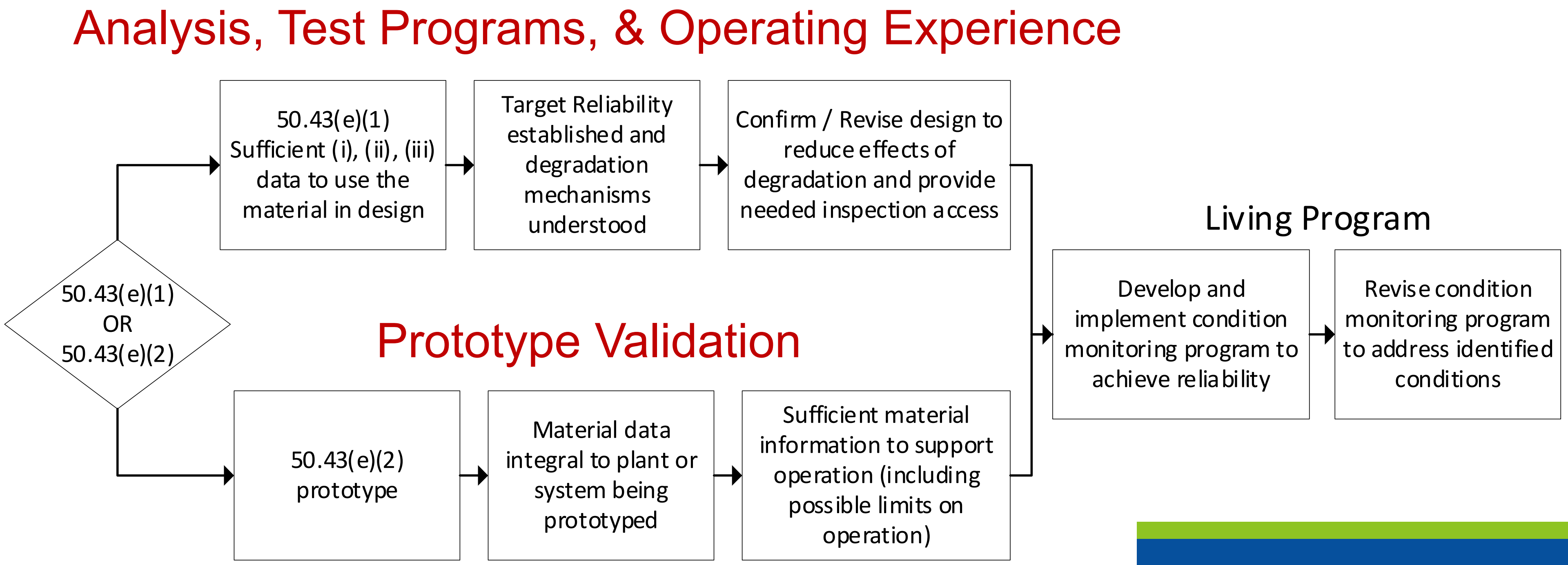
- Large scale "Plant Application" of novel materials technology deployment
- Can establish data and code case information with plant limitations that may be imposed by the regulator
- Larger scale risk vice targeted, and risk informed singular approaches in 50.43(e)(1)



Accelerated Materials Deployment Regulatory Approach - - Generic Process Flow

Methodologies for Demonstrating Materials GDC / ARDC Compliance

- Traditional methods of compliance with GDC and ARDC Criteria 4 can rely heavily on codes and standards for surety in materials performance
- If codes and standards do not exist for an existing or novel material deployed in a known or novel environment; 10 CFR 50.43 may be used:



Accelerated Materials Deployment Regulatory Approach

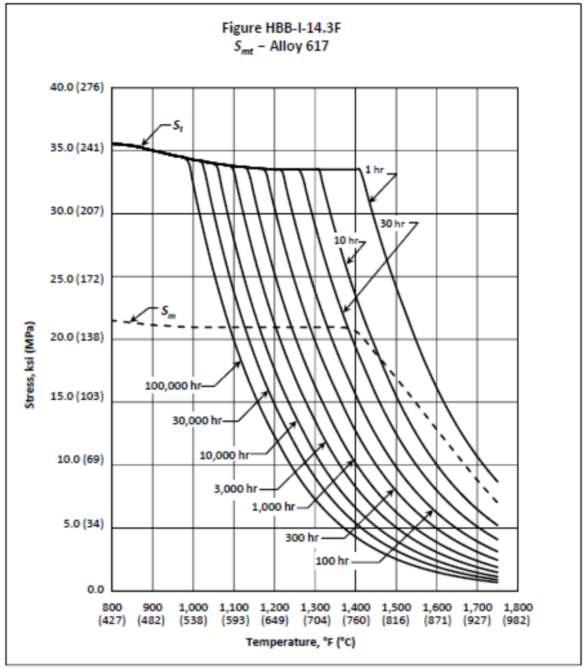
- There is currently no established and endorsed way to license a plant incorporating novel materials (or materials being deployed in novel environments): in many cases, there are no directly applicable code cases for decision-makers to rely on
  - 50.43 can provide a means to regulatory consideration of new designs deploying new materials, but does not provide a detailed roadmap for succeeding by that route

- A framework using 50.43 (e)(1) i-iii within which to manage the risks (uncertainties) associated with deployment of novel materials using
  - An establishment of baseline guidance for necessary information, testing, and modeling
  - An establishment of a condition monitoring and examination Reliability and Integrity Management (RIM) type program

Accelerated Materials Deployment Regulatory Approach

Process Entry Conditions- Material Code Adoption Status

- Materials included in ASME Section III, Div. 5 code, but design requires temperatures greater than currently approved,
  - Alloy 617 is an example where a Code Case for elevated temperature service was processed, utilizing an extension of time dependent material properties from low temperature service informed by experimental data and analysis.



- Materials listed in ASME Section II for codes other than Section III, Div. 5
  - Material properties listed in ASME Section II may need to be supplemented with extended values at elevated temperature (i.e., properties for a material may not cover all critical and time dependent mechanisms necessary to be considered for use).
- Materials not listed in ASME Section II, but which have a recognized national or international material specification.
  - Section III, Div. 5 provides guidelines for minimum design data needs for new materials

Accelerated Materials Deployment Regulatory Approach

RIM strategies may be considered to support shortened experimental data time periods while continuing baseline material property development

- The proposed framework is based on the approach of ASME Section XI, Division 2, Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Reactor Facilities and ensures applicants:
  - ✓ Assign target reliabilities to SSCs, supporting the top-level plant objectives;
  - ✓ Understand failure modes of SSCs using those materials, and the degradation mechanisms that could lead to those failure modes;
  - ✓ Develop and propose a program of surveillances that will identify degradation prior to failure of the SSC
  - ✓ Provide a means of reporting results, taking actions for anomalous or undesirable conditions, and give the regulator assurance for continued safe operations
- An applicant makes the case that applying the protocol for monitoring and examination will either show that the reliability targets are being met, or provide adequate warning that they are not

Accelerated Materials Deployment Regulatory Approach

- Risk Management – Allocation of Reliability Targets
  - How do investors and regulators determine whether certain novel material applications in advanced NPP designs are appropriate?
  - Investment protection needs and safety needs associated with particular SSCs can be addressed by applying the RIM program.
  - The RIM program calls for establishment of SSC reliability targets, informed by a plant risk model, and a process of identifying
    - component degradation mechanisms, and
    - what surveillance activities are needed in order to assure that component reliability targets are met on an ongoing basis.
  - The applicant needs to formulate an assurance case arguing that despite residual uncertainties associated with novel material applications, the problem is sufficiently well understood that the risks associated with those novel materials can be managed adequately based on the RIM program.

Accelerated Materials Deployment Regulatory Approach

- Risk Management – Allocation of Reliability Targets (Cont'd)
  - Setting reliability targets for SSCs establishes a reference point against which to judge performance relative to higher-level safety requirements.
  - The plant-level requirements do not uniquely determine the reliability targets at the component level; those targets must be consciously selected. That selection process is allocation.
  - Component-level reliability targets must:
    - combine through the plant risk model to satisfy the plant-level requirements, and
    - be feasible
      - Example of infeasibility: choosing an unachievably low value of unreliability.
  - The reliability needed in a given SSC depends, in general, on what is feasible to achieve in other SSCs

Accelerated Materials Deployment Regulatory Approach

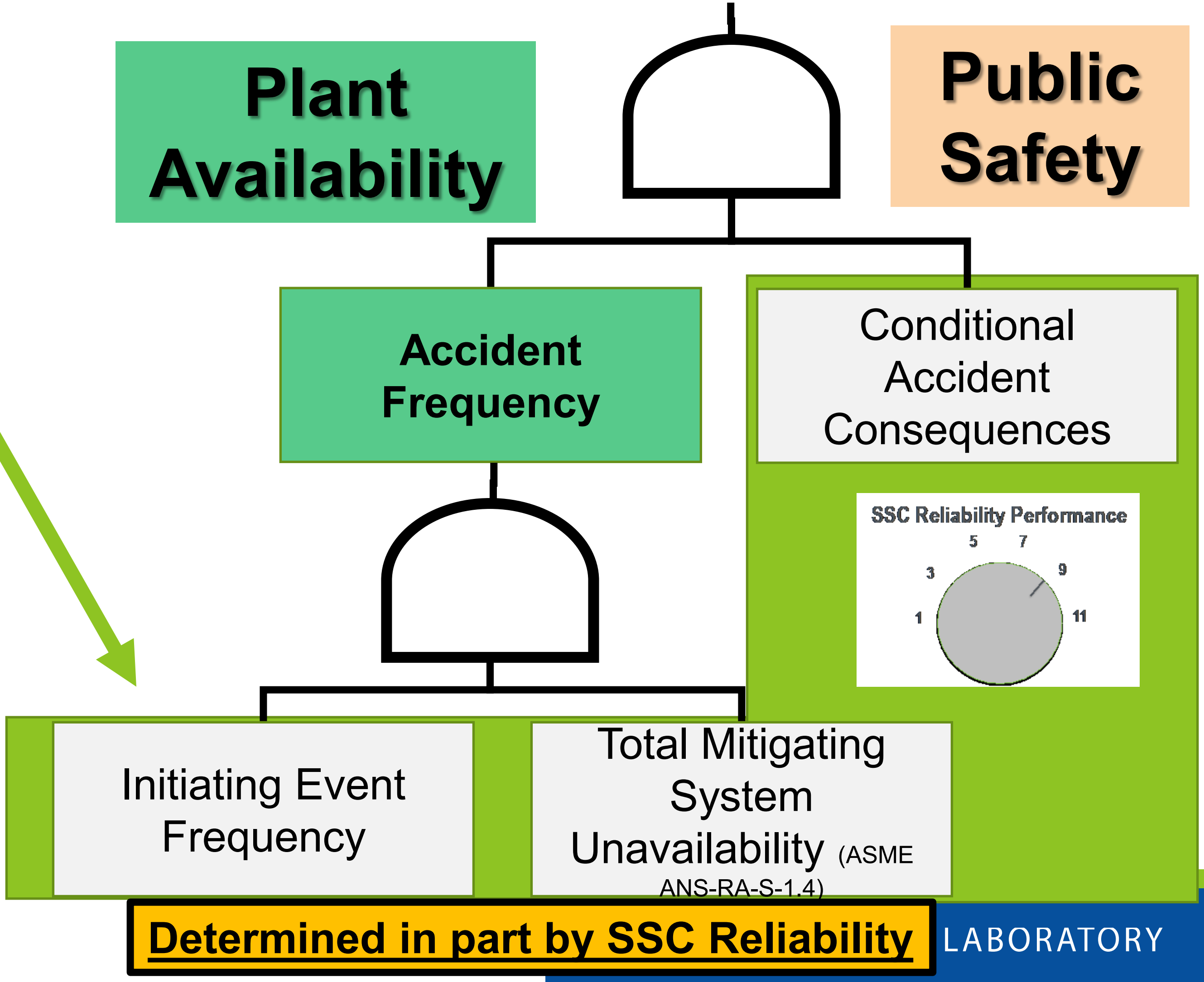
- Risk Management – Allocation of Reliability Targets* (Cont.)
  - Example: suppose that
    - We are considering allocation of reliability performance to SSCs in a particular advanced design;
    - We have two goals: one on plant unavailability, and one on the frequency of significant radiological releases;
    - The failure of a given passive SSC would constitute a breach of a reactor coolant system that, *from a safety perspective,* needs to be either mitigated or confined
    - Such an event would also have significant plant availability implications
  - The allocation task is to decide on a level of treatment for this SSC (and other SSCs) (e.g., surveillance type, surveillance interval) such that
    - the high-level goals (plant unavailability and release frequency) are both satisfied, and
    - the resource implications of the treatment allocation are bearable for the investor

*Derived from - XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Division 2 / Requirements for Reliability and Integrity

Accelerated Materials Deployment Regulatory Approach

Allocation:

- Establishing goals on SSC reliability that
(a) are feasible, and
(b) combine to efficiently achieve plant-level goals on Public Safety, Plant Availability
- … recognizing that needlessly stringent goals will be more expensive to meet



Accelerated Materials Deployment Regulatory Approach – Final Report

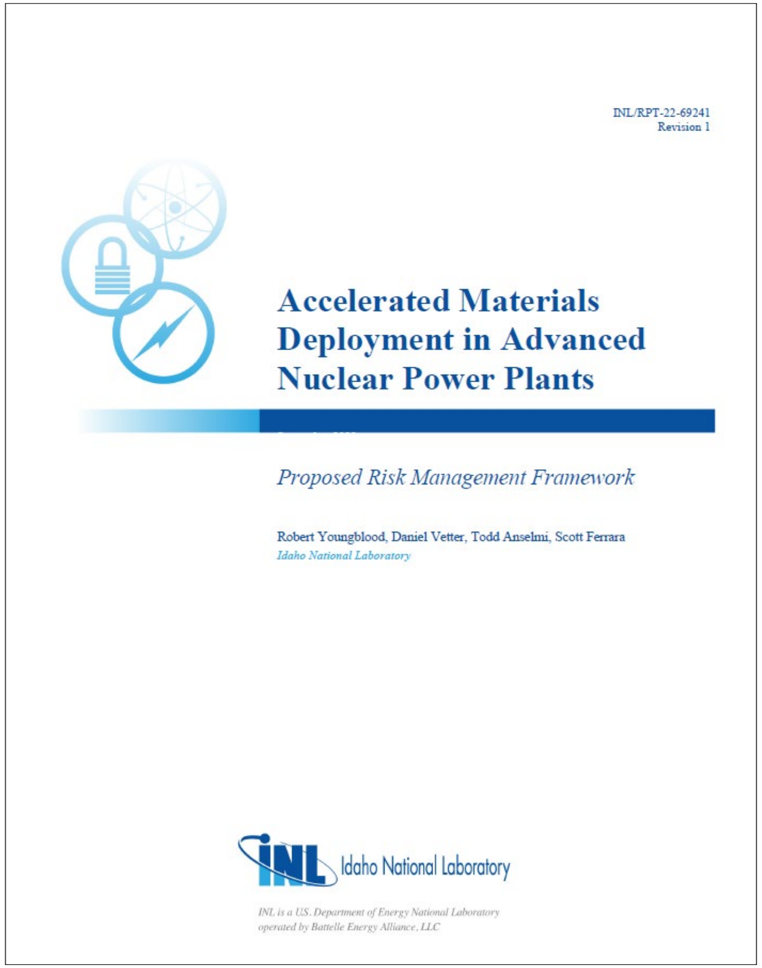
Precedence examples from both DOE / NRC and OGAs (i.e., NASA etc.)

- Aging Management Programs, License Extensions, Advanced Fuel Qualification (NUREG-2246), etc

Technical basis for safe program implementation

Regulatory pathway to success

- A report that can serve as endorsable guidance
- Notional material example with theorized RIM implementation, technical safety case probabilities, and allocations


INL/RPT-22-69241
Revision 1

Accelerated Materials Deployment in Advanced Nuclear Power Plants

Proposed Risk Management Framework

Robert Youngblood, Daniel Vetter, Todd Anselmi, Scott Ferrara
Idaho National Laboratory

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

Accelerated Materials Deployment Regulatory Approach – Possible Next Steps

- Establishing suggested minimum baseline data and information guidance for a material
  - What level of testing and analysis should be included in the applicant's safety case for deployment prior to RIM like surveillance during operations?
- What is the recommended reporting mechanism to the regulator and what does it enable (surveillance requirement or license extension through a license condition approved report etc.)
- Risk management goal recommendations based on material impact to SSC performance
- Obtain and incorporate further stakeholder feedback for refinement

IDAHO NATIONAL LABORATORY 75TH ANNIVERSARY

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.