Advanced Materials, Manufacturing, and Construction

- **Session Chair:** Greg Oberson, Chief, Advanced Reactor Technical Branch 1, Division of Advanced Reactors and Non-power Production and Utilization Facilities, NRC Office of Nuclear Reactor Regulation

- **Speakers:**
  - Todd Anselmi (INL)
  - Luke Voss (NRIC/ACTI)
  - Amit H. Varma (Purdue University)
  - Teresa Melfi (Lincoln Electric/ASME)
  - Ralph Hill (ASME)

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

Idaho National Laboratory

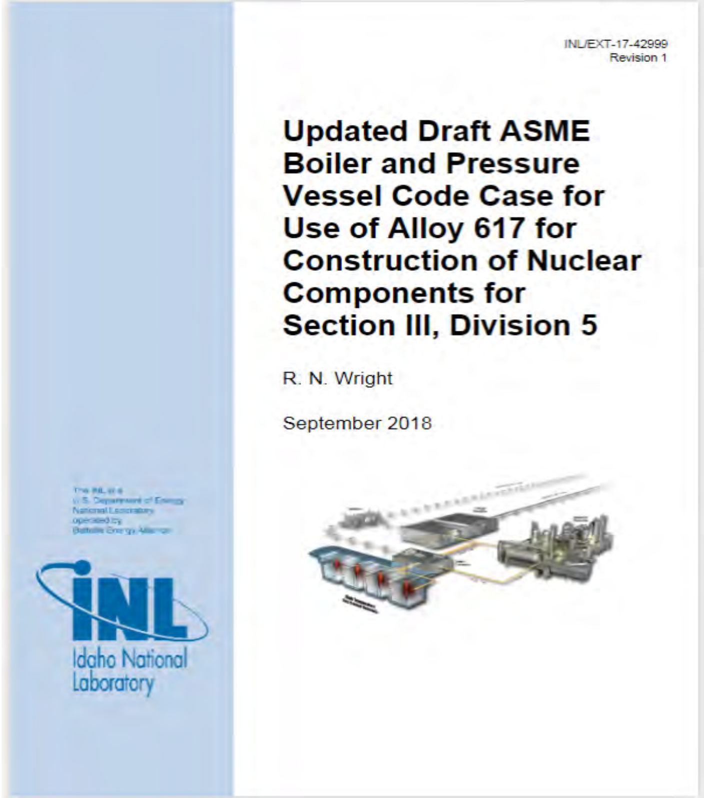
Project Scope and Objectives

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

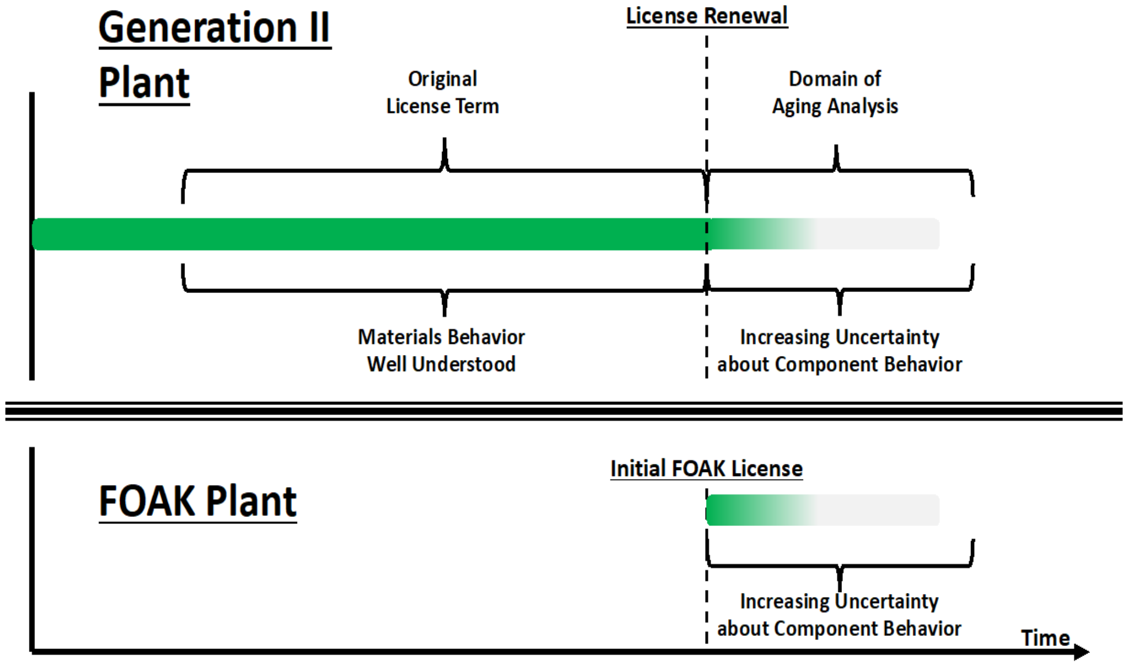
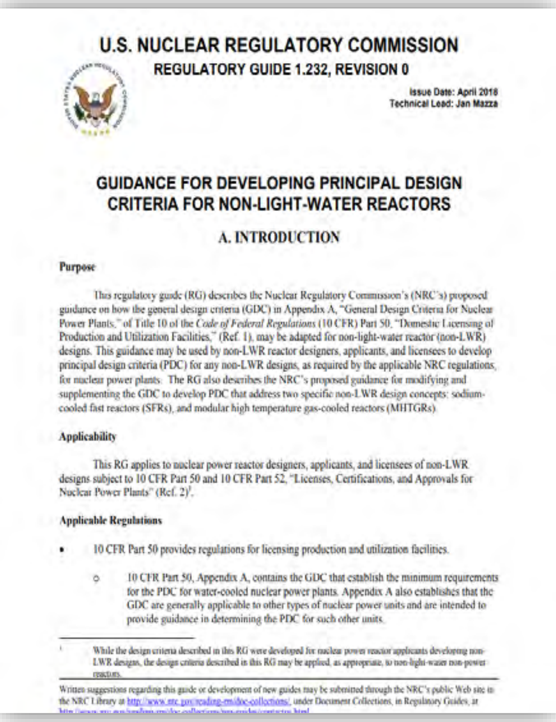


Figure 1. Time-dependent uncertainty in a Generation II Plant compared to a First of a Kind (FOAK) Plant.

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

- 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

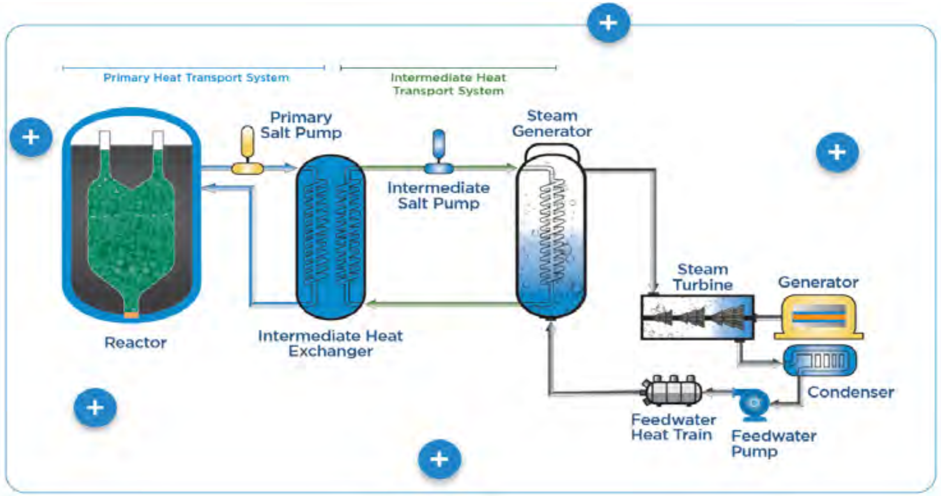
(e) Applications for a design certification, combined license, manufacturing license, operating license or standard design approval that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997. Or use simplified, inherent, passive, or 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.

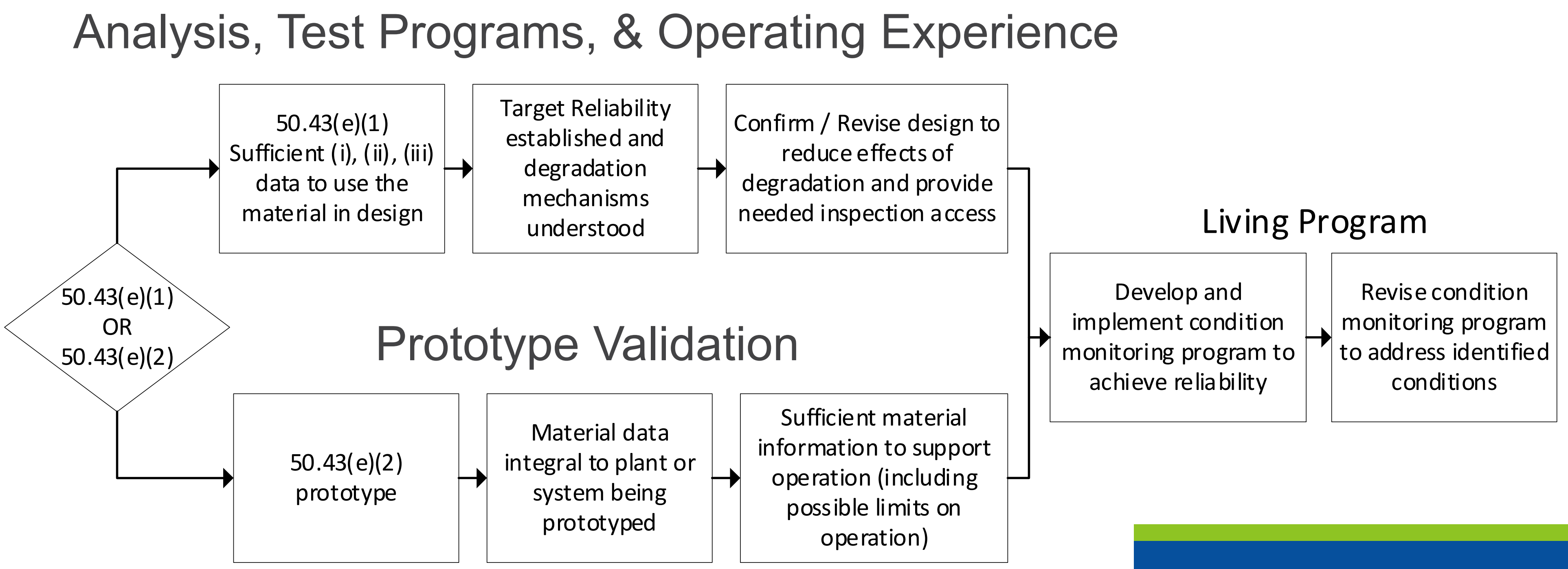
- Large scale "Plant Application" of novel materials technology deployment
- Can establish data and code case information with plant limitations that may be imposed by the regulator
- Larger scale risk vice targeted, and risk informed singular approaches in 50.43(e)(1)



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

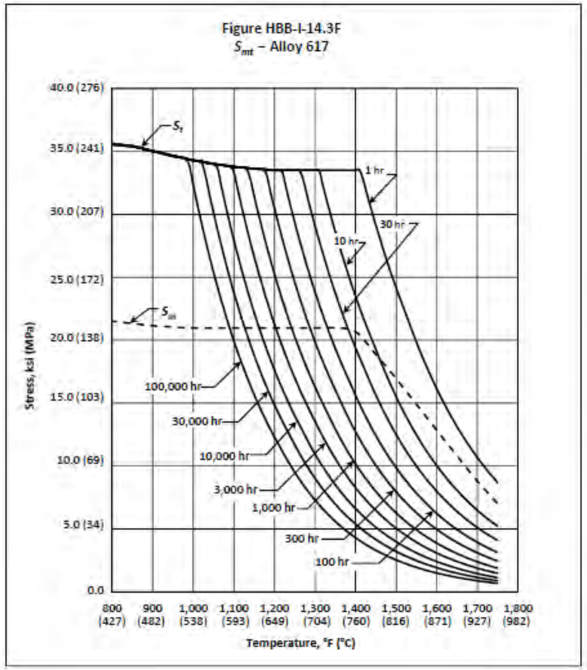
- There is currently no endorsed approach to license a plant incorporating novel materials (or materials being deployed in novel environments): in many cases, there are no directly applicable code cases for decision-makers to rely on
  - 50.43 can provide a means to regulatory consideration of new designs 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

- 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 formulates 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 – 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
- Development of guidance for integration of condition monitoring into design

IDAHO NATIONAL LABORATORY

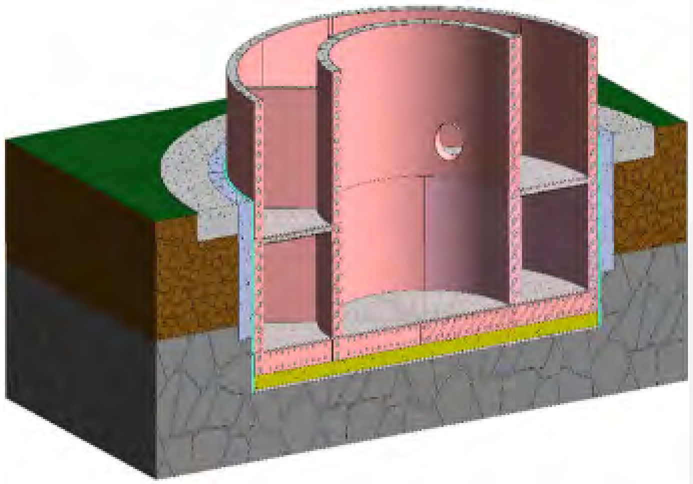
75TH ANNIVERSARY

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.

INL Idaho National Laboratory | www.inl.gov

National Reactor Innovation Center

Advanced Construction Technology Initiative Program



Luke Voss, Program Manager

9/25/2024

ACTI Program Scope

- Demonstrate technologies to significantly reduce the cost and schedule for construction of advanced reactors.
- Demonstrate the technology by 2026/2027 to improve the economics of deploying advanced reactors.
- Selected technologies will not require major R&D efforts. With prototyping and testing, the technologies will be ready for deployment at scale.

Benefits of Demonstration & Testing

- Bridge the gap between development and commercialization
  - Mature technology readiness and reduce risks to participants for first of a kind build
  - Facilitate partnership between technology developers, end users, national labs, universities, regulators, industrial participants
- Learn by doing reduces risks associated with first commercial build
- Build confidence with regulators
- Develop supply chain

NRC Collaboration

- Congress recognized the importance of agency coordination in the Nuclear Energy Innovation Capabilities Act
- DOE/NRC MOU to "coordinate DOE and NRC technical readiness and sharing of technical expertise and knowledge on advanced nuclear reactor technologies and nuclear energy innovation, including reactor concepts demonstrations, through the [NRIC]."
- Monthly Coordination Calls – DOE/NRC/NRIC
- NRIC Rotations

Fred Sock
Office of Nuclear Regulatory Research

Allen Fetter
Office of Nuclear Reactor Regulation

Recap - ACTI Project with GEH

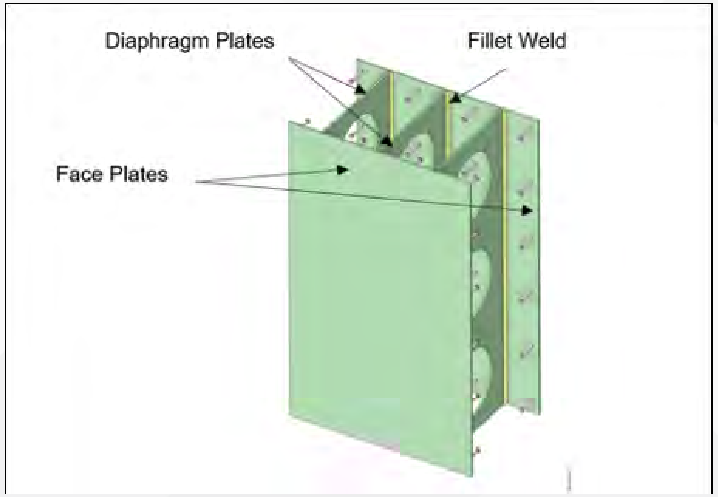
- Team - General Electric Hitachi
  - EPRI, Black & Veatch, Purdue, UNCC, Aecon Wachs, and Tennessee Valley Authority
- Purpose - demonstrate technologies to:
  - Reduce the cost of new nuclear builds
  - Speed the pace of advanced nuclear deployment
- Phase 1:
  - Build & test Steel Bricks™ specimens at Purdue
  - Design a reactor building demonstration
  - Develop advanced monitoring and digital twin technologies

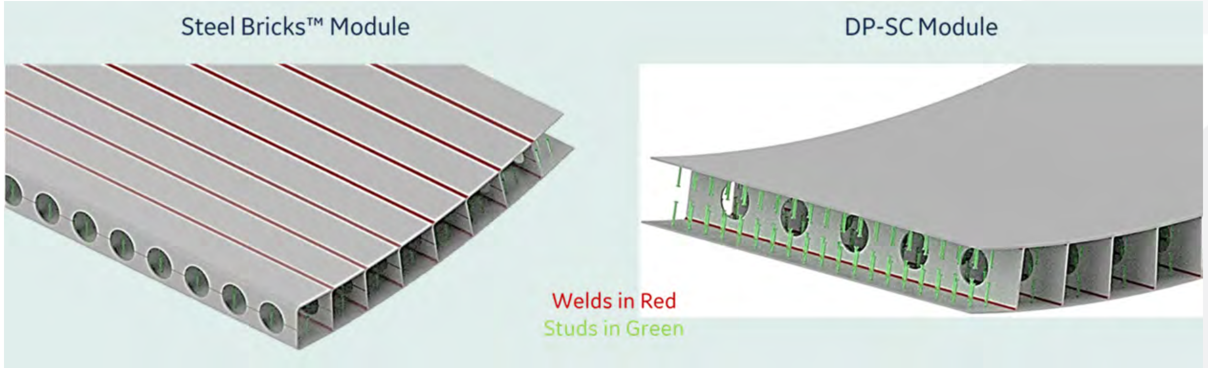
Recap - ACTI Project Accomplishments

- Demonstrated concept of fabricating Steel Bricks™ assemblies in a factory setting
- Successfully tested Steel Bricks™ specimens at Purdue
- Established digital twin and monitoring techniques
- Demonstrated NDE methods to inspect concrete inside Steel Bricks™

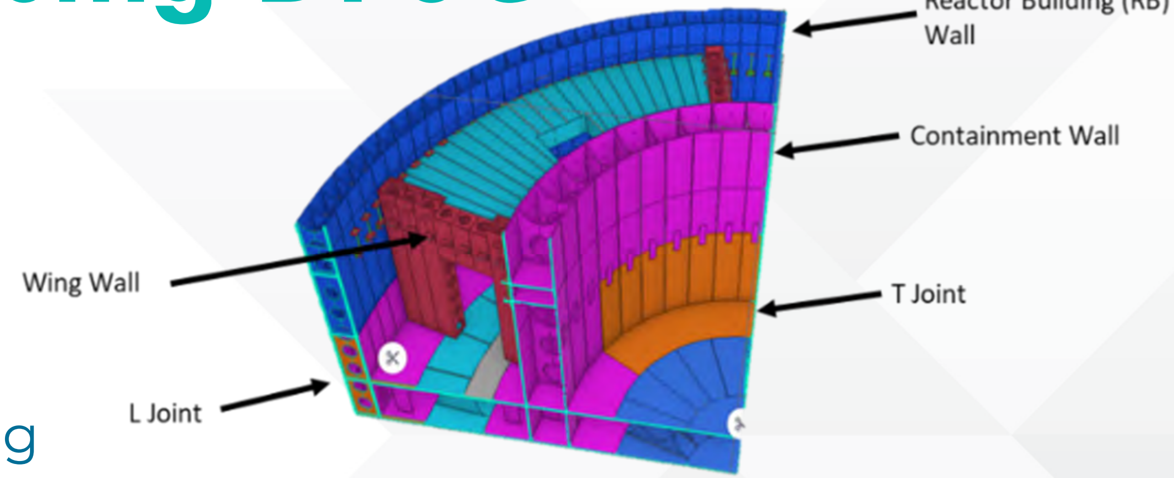
Design Pivot

- Design Pivot to Diaphragm Plate Steel Composite (DPSC):
  - From lessons learned in Phase I, GEH determined that DPSC are a better solution for the ACTI Project
  - Benefits over Steel Bricks™
    - Major reduction in weld volume and inspection
    - Faster to fabricate
    - Does not require post-forming heat treatment
    - Simplified fit-up
    - More cost effective

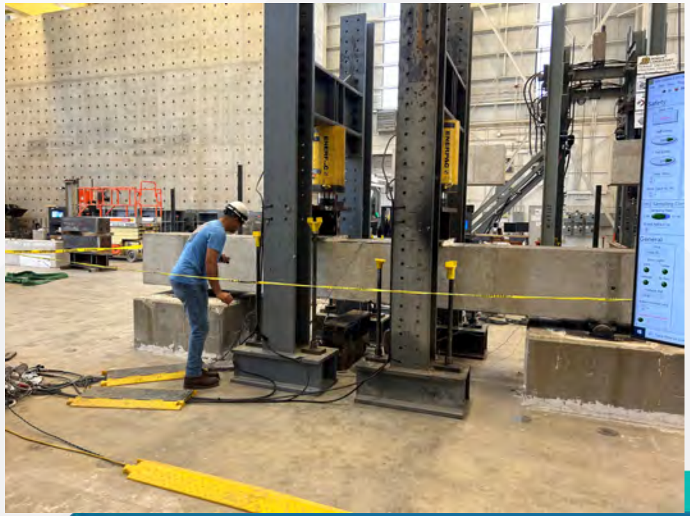




Phase 1 Completion using DPSC



- Consists of three major scopes
  1. DPSC Engineering to support demonstration facility construction
     - Final Design Complete
  2. DPSC Sample Fabrication and Testing
     - All fabrication complete
     - Six of the nine specimens successfully tested
  3. Phase 2 Proposal
     - Initial, technical proposal submitted to NRIC for reviews
     - GEH developing detailed costs and schedule portion of proposal



Current Project Schedule

- Extended Phase 1 to Jan ‘25
  - Allow for Phase 1 Completion using DPSC design
- Potential Phase 2 scope may include:
  - Build and test structure using DPSC
  - Disassemble and decommission
  - If executed, will occur in 2025

Project Objectives & Benefits

Benefits to the nuclear industry through the following:

- Demonstrate DPSC submodules fabrication and field erection of the critical joint and section types
- Develop construction and fabrication workforce capability for DPSC modules
- Educate the workforce in building techniques using advance welding and assembly processes
- Establish and improve supply chain capabilities for mass deployment to nuclear industry
- Demonstrate viability of non-destructive testing methods during construction
- Advance fit up techniques with digital twin technology to better align modules
- Enable more accurate estimation of timelines for new plant construction
- Reduce regulator risks for using SC for containment and basemat structures
- Capture Lessons Learned with constructability of DPSC, NDE techniques, and digital twin technologies to share with industry and future projects

NRIC National Reactor Innovation Center

09/25/2024

www.nric.inl.gov

Advances & Improvements to US Codes for SC Construction

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Kettelhut Professor of Civil & Construction Engineering

Director, Bowen Laboratory of Large-Scale CE Research

Exec. Dir., Purdue Applied Research Institute (PARI)

PURDUE UNIVERSITY | Lyles School of Civil Engineering

September 25, 2024

OUTLINE

- *Small Modular Reactor Applications*
- *US Design Codes and Standards*
- *Code Improvements for SMRs*
- *Future Developments and Current Progress*

Small Modular Reactors

- *Significant interest and focus on SMRs in the US and abroad*

- *Different sizes, shapes, and designs*
  - *Typically less than or 300 MW*
  - *Pressurized and also Boiling Water Designs*

- *Portions buried underground and portions above ground*

Small Modular Reactors

- *Portions above ground … designed for aircraft impact, seismic design and analysis*
- *Portions below ground … soil-structure interaction, seismic design and analysis, corrosion protection become important considerations*
- *Design for accident thermal / pressure conditions. Containment structure or functional containment*

Small Modular Reactors

- *Interest in expediting construction schedule, optimizing time spent in the pit…*
- *Interest in higher quality construction using pre-fabrication, modularization, quality control, better materials, etc.*
- *Several SMRs (if not all) are considering or already designing using steel-plate composite (SC) or modular composite construction approaches.*
- *In some cases portions of the plant, and in other cases the entire plant*

Existing Codes and Standards in the US

AISC N690-18 ... Design Guide 32

- *For steel and composite structures in safety-related nuclear facilities*
  - *AISC N690-18 for steel structures and App. N9 for steel-plate composite (SC) structure*
  - *RG 1.243 – Regulatory Guide published by US NRC endorsing AISC N690 and providing some edits / changes / exceptions*
  - *AISC also published a Design Guide 32 showing how to use AISC N690-18 for design of SC walls and connections, etc.*

ANSI/AISC N690-18
An American National Standard

Specification for Safety-Related Steel Structures for Nuclear Facilities

June 28, 2018

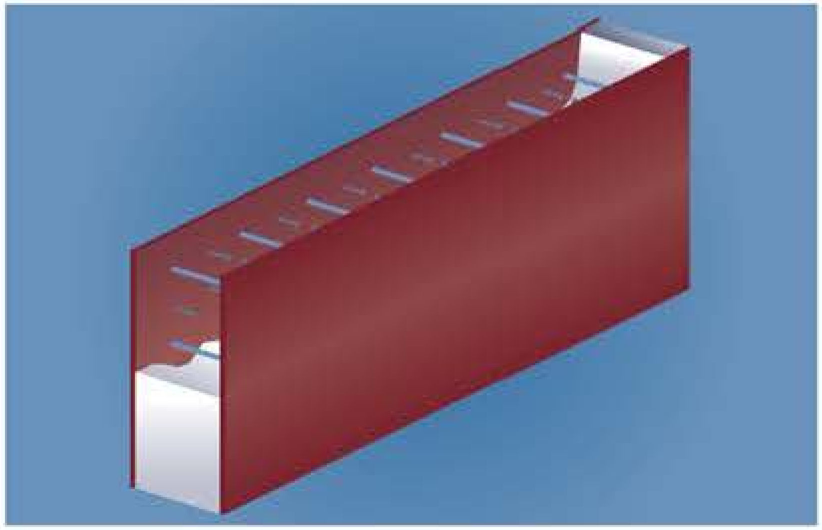
Supersedes the *Specification for Safety-Related Steel Structures for Nuclear Facilities* dated January 31, 2012 including Supplement No. 1 dated August 11, 2015 and all previous versions

Approved by the Committee on Specifications

Smarter.
Stronger.
Steel.

32
Steel Design Guide

Design of Modular Steel-Plate Composite Walls for Safety-Related Nuclear Facilities



U.S. NUCLEAR REGULATORY COMMISSION
REGULATORY GUIDE 1.243, REVISION 0

Issue Date: August 2021
Technical Lead: M. Rolón Acevedo

SAFETY-RELATED STEEL STRUCTURES AND STEEL-PLATE COMPOSITE WALLS FOR OTHER THAN REACTOR VESSELS AND CONTAINMENTS

A. INTRODUCTION

Purpose

This regulatory guide (RG) describes a method acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for compliance with NRC regulations for the design, fabrication, and erection of safety-related steel structures and steel-plate composite (SC) walls for other than reactor vessels and containments. This guide endorses, with exceptions and clarifications, the procedures and standards of the 2018 edition of American National Standards Institute (ANSI)/American Institute of Steel Construction (AISC) N690, "Specification for Safety-Related Steel Structures for Nuclear Facilities" (Ref. 1).

Applicability

This RG applies to applicants and licensees subject to Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities" (Ref. 2), and 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 3).

Applicable Regulations

- Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50 establishes necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components (SSCs) important to safety through general design criteria (GDC). GDC applicable to this RG include the following:
  - GDC 1, "Quality standards and records," requires, in part, that SSCs "important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated for applicability, adequacy, and

Improvements – Codes & Standards

- *AISC N690-18 and Design Guide 32 published in 2017, about 7 years ago… based on work done up to 2014 (almost 10 years ago) on Advanced Light Water Reactors*

- *Lots of new developments, research results, progress etc. over the past 10 years… Emergence of SMRs… ARs…*

- *Over the past 10 years, significant research and development of SpeedCore, adaptation of SC in high-rise building construction*

Continuing Research & Development on SC Systems

SMRs, Safety Related Nuclear Facilities

SMRs involve the use of SC construction in new and creative ways, e.g,:

1. *SC construction underground to optimize time in pit*
2. *Corrosion protection research and testing ongoing*
3. *SC slabs… SC basemat / foundation … SC Containment Vessels*
4. *New and innovative SC designs and details further optimized for fabrication, erection, construction*
5. *Aircraft impact protection, Blast / Impulsive loading protection*
6. *Splices or connections between SC and RC foundations, RC slabs-SC walls, SC-to-RC walls etc.*

Research & Development

SMRs, Safety Related Nuclear Facilities

- *Missile impact testing, analysis, and design*
  - *Large-scale, small-scale, detailed 3D FEM analysis, development of design methods*

- *SC-RC connection testing, analysis, and design*
  - *Full-scale testing, 3D FEM analysis, development of design methods*

- *Research on damping, new tie / diaphragm details starting soon*

AISC N690-2024

Complete and Being Published Shortly…

- *Most of the SC related changes are contained in Appendices N9 and N10 of the standard; however, some other sections are slightly affected*

- *Includes changes can be grouped in the following categories:*
  a) clarifications/simplifications of existing requirements, or relaxations of deemed conservative requirements;
  b) based on the findings from recent research; and
  c) address emergent needs associated with ARs and SMRs (e.g., potential for high temperature exposure)

- *Some additional guidance provided in EPRI Report 3002026498 from 2023*

AISC N690-24

APPENDIX N9 – SCOPE CLARIFICATION

This appendix addresses the design and detailing requirements, including for seismic applications, for steel-plate composite (SC) structural elements and their connections. SC structural elements include SC walls, SC slabs, and SC basemats.

Rationale: Introduces a new term "SC structural elements" to cover SC walls, SC slabs, and SC basemats.
Such usage (i.e., beyond just SC walls) was not stated explicitly in the previous editions

AISC N690-24

Improvements of Minimum Requirements

- *Changes to General Provisions N9.1.1(a), (b), (c) - Sizing of SC cross-section*

The following provisions shall apply to SC structural elements:

(a) For exterior SC structural elements, the minimum section thickness, t_{sc} , shall be 15 in. (380 mm). For interior SC structural elements, the minimum t_{sc} shall be 10 in. (250 mm).

(b) Faceplates shall have a thickness, t_p, not less than 0.25 in. (6 mm) nor more than 1.5 in. (38 mm).

(c) The reinforcement ratio, ρ, shall have a minimum value of 0.015 and a maximum value of 0.10, where ρ is determined as follows:

Rationale: The earlier cross-section dimensioning provisions were conservative and empirical; larger reinforcement ratio is now permitted

AISC N690-24

Improvements to Minimum Requirements

Revision to General Requirements N9.1.1(d) and (e) for min/max steel and concrete strengths

(d) The specified minimum yield stress of faceplates, F_y, shall not be less than 50 ksi (350 MPa) nor more than 80 ksi (550 MPa).The minimum elongation shall be at least 15%, and the minimum tensile-to-yield ratio, F_u/F_y, shall be 1.20.

(e) The specified compressive strength of the concrete, f'_c, shall not be less than the greater of 4 ksi (28 MPa) or [0.04+0.80ρ] times F_y , nor more than 10 ksi (70 MPa).

Lightweight concrete shall not be used.

Rationale: Higher strength faceplates, up to 80-ksi yield, are now permitted as long as they satisfy certain elongation and ultimate-to-yield strength criteria.

AISC N690-24

Improvements in Detailing

General Requirement N9.1.1(l) – Splice at the seams between faceplates

(l) Splices at the seams between adjoining faceplates shall be designed to develop the nominal yield strength of the weaker of two connected faceplates.

Rationale: The previous edition required CJP weld at the seams (or a bolted connection); the new requirement is less specific, which is consistent with the corresponding requirement in AISC 341 for seismic design

AISC N690-24

Improvements in Detailing

1. *Slightly more relaxed faceplate slenderness requirement in interior regions*
2. *Improved shear connection spacing requirements for interfacial shear, allows for designs with only ties and improves spacing requirements*
3. *Slightly relaxed requirements for yielding vs. non-yielding classification of ties*
4. *Completely new tie spacing requirements to help with concrete casting requirements and height of wet concrete in empty steel modules*
5. *Further clarification on definition of "opening"*
6. *Relaxed detailing requirements for "very small" openings*
7. *Cleaned up, clarified and simplified requirements for detailing of "small opening"*
8. *Clarified requirements for "bank of small openings"*

AISC N690-24

Improvements for SMRs

- *Section N9.2.4 – New Temperature Limits for Service and Accident Conditions Based on Recent Research and the needs of Advanced Reactors*

For normal operation or other long-term period exposure:

(a) The steel surface temperatures shall not exceed 180°F (82°C) except for local areas such as around penetrations, which are permitted to have increased temperatures not to exceed 230°F (110°C); and

(b) The maximum strain in faceplates shall not exceed ε_y under normal thermal gradients.

For accident or any other short-term period exposure, the steel surface temperatures shall not exceed 570°F (300°C). Local areas are permitted to reach steel surface temperatures up to 800°F (430°C) from steam or water jets in the event of pipe failure.

AISC N690-24

Improvements for SMRs

1. *Modified / higher strength equation for out-of-plane flexural strength*
2. *Modified / better equation for in-plane shear strength and discussion of ultimate shear strength for beyond design basis / reserve margin calculations*
3. *Slightly higher phi-factors for out-of-plane shear strength, and equations with more clarity for out-of-plane shear strength*
4. *Slightly better interaction equation for yielding shear reinforcement designed for out-of-plane shear + interfacial shear*
5. *Better discussion of alternate interaction equations*
6. *New option to use prescriptive SC connection design method that uses rebar lap splices with steel faceplates*

AISC N690-24

Appendix N10 *New and Separate Appendix for Impulsive and Impactive Load Provisions*

14. Analysis, Design, and Detailing ~~of Structural Steel and Composite Members subjected to~~for Impulsive and Impactive Loads

The analysis, design, and detailing of structural steel, composite members, and SC structural elements subjected to impulsive and impactive loads shall be evaluated in accordance with Appendix N10.

Rationale: This is similar to how it has been done in ACI 349 for a long time.

- *Section NB3.14 defers this topic to Appendix N10.*
- *Involves many special analysis/design concepts that differ from the regular analysis/design requirements that are not used by all Users.*
- *BASED ON RESEARCH RESULTS MENTIONED EARLIER (US NRC funded work)*

AISC N690-24

NEW APPENDIX N10

- *Special Provisions for Impulsive and Impactive Loads*

  The appendix is organized as follows:

  N10.1. General Provisions
  N10.2. Analysis, Design, and Detailing of Structural Steel, Composite Members, and Steel Plate
  N10.3. Analysis, Design, and Detailing of SC Structural Elements

  - *Rationale: The special analysis, design, as well as detailing requirements for impulsive and impactive loads are now consolidated in Appendix N10.*
  - *Section N10.1 covers General Provisions (e.g., additional material requirements and dynamic increase factors).*
  - *Section N10.3 covers the requirements for SC structural elements.*

AISC N690-24

New APPENDIX N10

1. *Charpy V-Notch Requirements for Materials*
2. *Dynamic Increase Factors for Materials*
3. *Compactness Requirements for Steel Elements*
4. *Local missile penetration / perforation design requirements for SC Elements*
5. *Special Analysis, Design, Detailing Requirements for SC Elements*

ASME Code Case

Steel-Plate Composite Containment Vessel (SCCV)

- *Limitations of Existing Containment Designs*
- *Steel Containment → Additional Shield Building*
  - Radiation shielding, impactive / impulsive loading, seismic resistance
- *RC Containment → Steel liner plates*
  - Impactive / impulsive loading, high strength reinforcement
- *Post-Tensioned Containment → Steel liner plates*
  - Impactive / Impulsive loading
  - PT monitoring and management
- *Advantages of SCCV*
  - Steel liner plate already, redundancy in leak barrier and pressure boundary
  - Significant resistance, strength, resistance to impactive / impulsive loading

ASME Code Case

Steel-Plate Composite Containment Vessel (SCCV)

- *Vendors interested, for conventional small modular reactor (SMR)*
- *Development of Design Code / Criteria under ASME BPV Code umbrella*
- *Preliminary design and cost benefit analysis conducted by collaborative team*
- *Construction schedule and economic benefits justify the pursuit of an SCCV and corresponding ASME Code Case*
- *Can help the industry and profession at the same time*
- *Vendor, Utility, Regulator → all eyes on SCCV and the potential for innovation, economy of scale, and the next step in evolution for the Containment Vessel*

ASME Code Case

Steel-Plate Composite Containment Vessel (SCCV)

- *Several considerations for SCCV*
  - *Design, design checks, fabrication, material, examination…*
  - *Not all information available*
  - *Need to rely on what is available*
- *Leverage existing knowledge and information*
  - *AISC N690*
  - *AISC Design Guide 32*
  - *RG 1.243*
  - *ASME Division 2 - Code for Concrete Containment*
  - *ASME Division 1 – Subsection NE Class MC Components*
  - *ASCE 59*

ASME Code Case

Steel-Plate Composite Containment Vessel

Experimental Investigations & Benchmarking of Numerical Models and Analysis (Japan and US)

1. *Compression Loading Tests*
2. *In-plane Shear Loading Tests*
3. *Axisymmetric In-plane Shear Tests*
4. *Axisymmetric Out-of-plane Shear Tests*
5. *Joint Tests*
6. *Biaxial Tension Tests*
7. *Pressure Tests*

ASME Code Case

Steel-Plate Composite Containment Vessel (SCCV)

- ASME – Section III, Div. 2
  - Modernization Workgroup
  - Task Group on SCCV
- Draft ballot developed
  - Balloted twice
  - Current ballot ongoing
- Format and Contents
  - 5 main sections
  - Multiple subsections
  - Numbering and contents modified

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SCC-1000 INTRODUCTION

SCC-1100 SCOPE AND GENERAL REQUIREMENTS

SCC-2000 MATERIAL

SCC-2100 GENERAL REQUIREMENTS FOR MATERIAL

SCC-2200 CONCRETE AND CONCRETE CONSTITUTENTS

SCC-2300 MATERIAL FOR REINFORCING SYTEMS

SCC-2400 MATERIAL FOR PRESTRESSING SYSTEMS

SCC-2500 MATERIAL FOR LINERS

SCC-2600 WELDING MATERIAL

SCC-2700 MATERIAL FOR EMBEDMENT ANCHORS

SCC-3000 DESIGN

SCC-3100 GENERAL DESIGN

SCC-3200 LOAD CRITERIA

SCC-3300 CONTAINMENT DESIGN ANALYSIS PROCEDURES

SCC-3400 SC CONTAINMENT STRUCTURE DESIGN ALLOWABLES

SCC-3500 SC CONTAINMENT DESIGN DETAILS

SCC-3600 DESIGN CRITERIA FOR IMPULSE LOADINGS AND MISSILE IMPACT

SCC-3700 PENETRATIONS AND OPENINGS

SCC-3800 BRACKETS AND ATTACHMENTS

SCC-4000 FABRICATION AND CONSTRUCTION

SCC-4100 GENERAL REQUIREMENTS

SCC-4200 CONCRETE

SCC-4300 FABRICATION OF EMPTY STEEL CONCRETE STEEL-PLATE COMPOSITE (SC) MODULES

SCC-5000 CONSTRUCTION TESTING AND EXAMINATION

SCC-5100 GENERAL REQUIREMENTS FOR EXAMINATION

CC-5200 CONCRETE EXAMINATION

CC-5300 EXAMINATION OF WELDS

OUTLINE

- *Small Modular Reactor Applications*
- *US Design Codes and Standards*
- *Improvements for SMRs*
- *Future Developments and Current Progress*

Thank You

Questions, Comments, → Amit Varma (ahvarma@purdue.edu)

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The State of Additive Manufacturing Standards in Boiler and Pressure Vessel Applications

Teresa Melfi

Technical Fellow, R&D

September 2024

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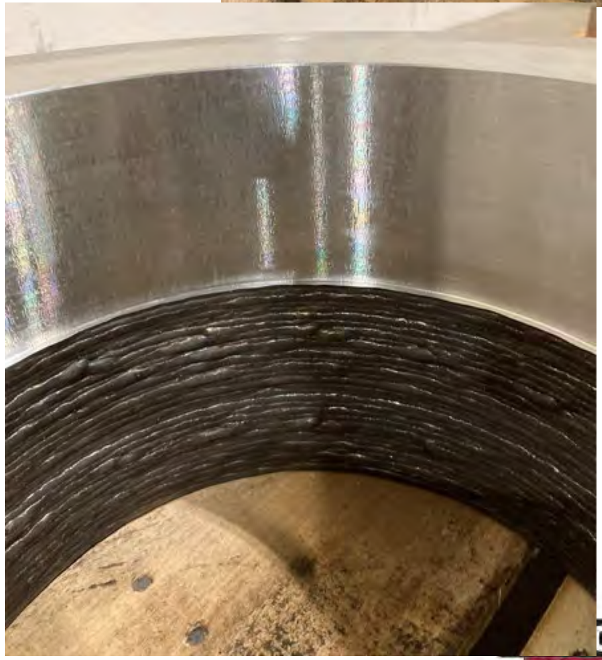
Current Emphasis on Large Parts

- Using weld metal to create materials
- Large, complex parts (1/2 ton to 10 tons)
- Material is very similar to a rough forging
- Generally require some machining (often lots of machining)
- Sometimes requires heat treatment

- *aka DED-Arc, WAAM, GMAAM, etc.*



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Example: Casting Replacements—Pump Casing

Naval Nuclear Lab: Test loop pump casing

- 316L rough machined casting had long lead time ~60 weeks
- Qualified to ASME BPVC IX QW-600 (bracketed qualification approach)
- Printed weight: ~3 tons
- Heat treat @ 1950°F for 3 hours
- Hydrostatic testing
- 100% RT and PT inspection (after machining)

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Example: Replace Casting on CVN-80 Aircraft Carrier

- Nuclear reactor containment door hinges
- Material was months behind schedule
- 3D printing completed in a few weeks
- Extensive NDE and mechanical testing
- First large format 3D metal printed components for permanent use on a US Navy vessel
- Made in the USA

Newport News Shipbuilding

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ASME Code Case Flow Chart

Designer/Certificate Holder chooses
Corresponding Material Specification

↓

Deposition procedure qualified to
Section IX bracketed qualification

↓

Pre-production statistical analysis

↓

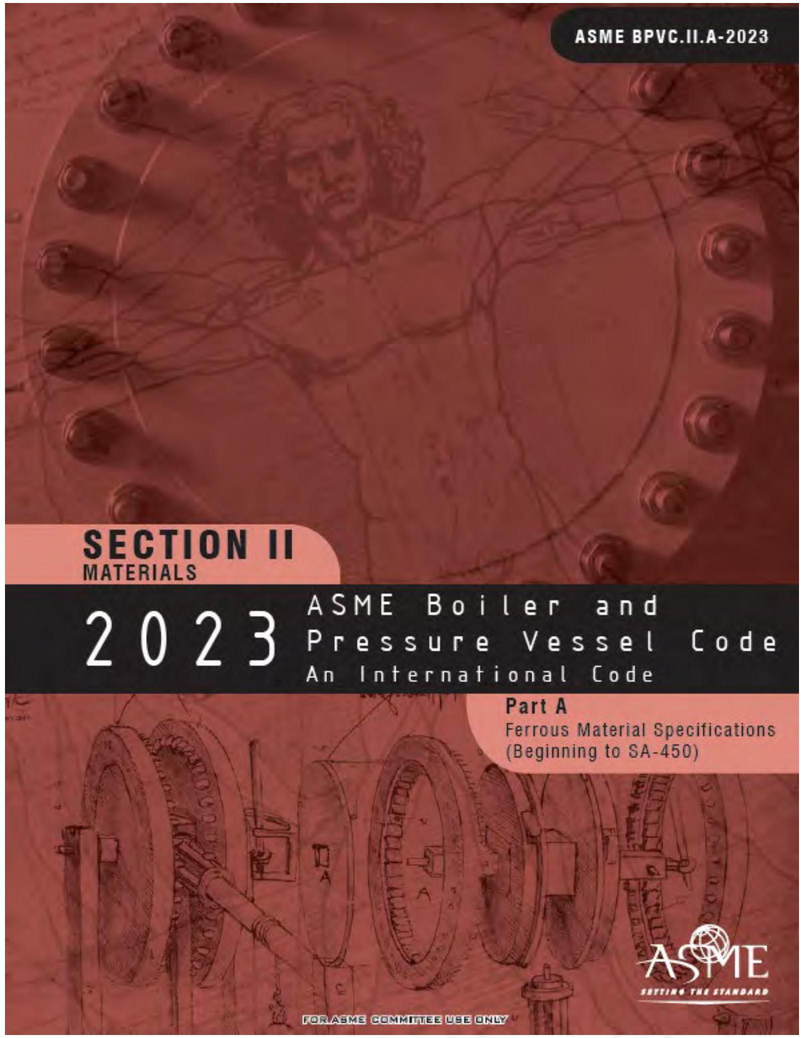
Material build with witness specimen

↓

Material delivery with MTR and data package

Corresponding Material Specification

- Most often a material specification for another form (e.g., casting, forging, plate). Examples are:
  - SA106 gr B
  - SA335 P22
  - SA182 F316
- Specified by the designer, certificate holder, etc.
- For repair, generally the same as the piping or fitting being replaced



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ASME Code Case Flow Chart

Designer/Certificate Holder chooses
Corresponding Material Specification

↓

Deposition procedure qualified to
Section IX bracketed qualification

↓

Pre-production statistical analysis

↓

Material build with witness specimen

↓

Material delivery with MTR and data package

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Bracketed Qualification per ASME IX QW-600

- Must test the highest cooling rate to be used in production
- Must test the lowest cooling rate to be used in production
- Must test the thinnest wall to be printed in production
- Must test the thickest wall to be printed in production

Codes require validation that all production printing stayed within these qualification bounds and also meet all other variables and rules of Section IX.

ASME BPVC Section IX QW-600 Brackets

- Process ***rails***
  - ***Boundaries*** to prevent undesirable results
  - Production ***flexibility***

- To **meet requirements** of *corresponding material specification*
  - Control the results and how they are achieved
  - Contrast this method with existing material specifications

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ASME Code Case Flow Chart

Designer/Certificate Holder chooses
Corresponding Material Specification

↓

Deposition procedure qualified to
Section IX bracketed qualification

↓

Pre-production statistical analysis

↓

Material build with witness specimen

↓

Material delivery with MTR and data package

Pre-production Statistical Analysis

- The shape can be the specific item geometry being built for production or a geometry containing features that capture the bounding heat inputs and interpass temperature for multiple production components.
- Tensile results must support with 95% confidence that 99% of the produced material tensile properties are in accordance with the corresponding material specification.
- Replaces “first article” tests required in some specifications.

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ASME Code Case Flow Chart

Designer/Certificate Holder chooses
Corresponding Material Specification

↓

Deposition procedure qualified to
Section IX bracketed qualification

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Pre-production statistical analysis

↓

Material build with witness specimen

↓

Material delivery with MTR and data package

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Printed Replacement for 800HT Furnace Header

First Article Testing

Orientation	Location	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (%)
Longitudinal	ID	57.6	102.5	44.8
		55.4	99.9	40.1
Longitudinal	OD	65.5	108.7	40.4
		66.4	108.7	40.5
Transverse	Mid-wall	60.9	106.1	45.5
		59.0	102.7	34.9
Transverse	Mid-wall	63.0	107.0	39.9
		61.6	107.9	37.4
Longitudinal	ID	58.0	101.8	43.1
		58.3	102.2	44.9
	OD	64.3	109.4	42.1
		66.7	108.6	42.5
Longitudinal	Mid-wall	60.9	101.8	47.0
		60.4	102.4	48.6
Transverse		61.0	104.2	44.4
		61.5	104.7	43.7
Longitudinal	Mid-wall	60.6	101.1	46.5
		60.5	101.1	46.8
Transverse		61.4	103.5	40.3
		62.5	105.4	40.5

ASME IX Qualification

	Yield Strength *(ksi)*	Ultimate Strength *(ksi)*	Elongation *(%)*
Min	49.9	96.5	33.0
Max	63.5	107.0	56.0
Average	58.0	101.2	47.3

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ASME Code Case Flow Chart

Designer/Certificate Holder chooses
Corresponding Material Specification

↓

Deposition procedure qualified to
Section IX bracketed qualification

↓

Pre-production statistical analysis

↓

Material build with witness specimen

↓

Material delivery with MTR and data package

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Additive Solutions
The Lincoln Electric Company
26250 Bluestone Blvd.
Euclid, Ohio 44132

Material Test Report

LINCOLN ELECTRIC | Additive Solutions

Company Name:	Redacted
Purchase Order No:	Redacted
Part Description:	Redacted
LEAS Print ID(s):	ADD Redacted
Test Coupon ID(s):	ADD17748
Print Completion Date:	February 22, 2023
Reference Material Specification:	MOD 316LSI

This document reviews the Material Specification requirements and summarizes test results for test coupon(s) associated with the additively printed part.

Test Coupon Results *Full Report on Witness Coupon: Redacted_Witness Coupon Fabrication Record_Rev0.pdf*

Element	*Material Spec. Requirment (weight %)*	*Results (weight %)*
C	0.03 max.	0.03
Cr	18.0 - 20.0	18.1
Ni	11.0 - 14.0	11.3
Mo	2.0 - 3.0	2.3
Mn	1.0 - 2.5	1.7
Si	0.65 - 1.0	0.75
P	0.03 max.	0.02
S	0.03 max.	0.01
Cu	0.75 max.	0.24

Mechanical Testing Results	*Material Spec. Requirment*	*Results*	
		Tensile 1	*Tensile 2*
Tensile Strength, ksi	70 min.	76.5	77.0
Yield Strength 0.2%, ksi	30 - 55	37.7	38.1
Elongation, %	40 min.	62	63
Reduction of Area, %	30 min.	68	69

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To:	Redacted
Company:	Redacted
PO No.	Redacted
Date:	March 23, 2024
Subject:	Fabrication Record - Rev.0

Dear Redacted,

We are pleased to provide this fabrication record for work completed under PO number Redacted. The following documentation contains information pertaining to the component(s) identified by LEAS as Print ADD Redacted. The LEAS Print ID corresponds to your purchase order Redacted.

Please feel free to email or call to discuss.

Sincerely,

Brad Barnhart
Engineer, Additive Solutions
The Lincoln Electric Company
+1 (216) 383-8660 (office)
Bradley_Barnhart@LincolnElectric.com

Fabrication Record Content Summary / Index

Print Summary & Certification
Component Dimensional Verification (As-Printed)
WPS Conformance & Essential Variables
- Component
- Witness Coupon

Witness Coupon Testing Summary & Specimen Extraction Plan
Witess Specimen Test Report
PWHT Certification & Chart
Wire Feedstock Heat/Lot Certification
Final Machining
Certification
Inspection Report
Final Images, incl. shipping
Non-Destructive Testing Report(s)
VT - PASS
PT - PASS
RT - PASS
Hydrostatic Test Certification
Buyer Degredation of Specifiaction Requirements (DSR) Documentation

Additive Solutions
The Lincoln Electric Company
26250 Bluestone Blvd.
Euclid, Ohio 44132

Fabrication Record
Dimensional Verification

LINCOLN ELECTRIC | Additive Solutions

Company Name:	Redacted
Purchase Order No:	Redacted
Part Description:	Redacted
LEAS Print ID(s):	ADD Redacted
Print Completion Date:	February 22, 2023

Dimension Verification Information	Value	Notes
3D Scan - Mesh Generation		
Machine Model	MetraSCAN BLACK|Elite	
Mesh Generation Software	VXelements	
Scan Date	February 23, 2023	
3D Scan Aquired By	Brad Barnhart	1mm Mesh Resolution
3D Scan - Alignment		
Scan Comparison Software	SculptPrint™	
Scan Alignment Completed By	Brad Barnhart	

Dimensional Comparison – Informational Only (ISO-View)	As-Printed Image(s)
See Attached *Redacted -3D Scan Verification Summary*	

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ADDF 210
Revised 2024-Jan-16

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ASME - Status of AM Codification

- **BPV I (Power Boilers)**
  - The DED AM Code Case ballot has been circulated for review and comment, and will be balloted to subgroups.
- **BPV III (Nuclear Facility Components)**
  - A ballot for a DED Code Case went to Subgroup Component Design, Subgroup Design Methods, Subgroup General Requirements and Subgroup Manufacturing, Fabrication and Examination has been closed.
  - A ballot is currently open to the Section III Standards Committee. Comments thusfar are in regard to Conformity Assessment of the Material Producer.

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ASME Codification of AM Committee Status

» **PBV VIII (Pressure Vessels)**
  - The TG has added sections to address material acceptance under UG-11, NDE requirements, marking requirements, and a graded approach to partial volumetric examination.
  - Making its way through subgroup approval process

» **B31 (Code for Pressure Piping)**
  - B31 is planning for a mandatory appendix for AM in the 2026 Edition.

» **B16 (Standards for Pipes and Fittings)**
  - First meeting of AM Task Group was held On July 2, 2024.
  - B16 will implement PBF for their first AM Code Case

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Other DED-Arc Standards using Bracketed Quals

- **AWS D20.2**
  - AWS D20.1 being split between powder and wire processes
  - AWS D20.2 (wire) will reference bracketed qualification methodology
  - Expected to be published in 2025

- **API 20S**
  - API 20S 2nd edition will reference bracketed qualification methodology
  - Expected to be published early 2025

- **US Navy TechPub**
  - Uses bracketed qualification with additional variables

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Teresa_Melfi@LincolnElectric.com

ASME | PLANT SYSTEMS DESIGN

SETTING THE STANDARD

PSD-1: A Hub for Alignment of RI-PB Design Standards

NRC Standards Forum

Virtual Presentation – September 25, 2024

Ralph Hill, Chair ASME
Plant Systems Design Standards Committee
Hill Eng Solutions, LLC

Topics

- Risk-Informed and Performance-Based
- Hub for Alignment of RI-PB Design Standards
- Key Processes
- Overview
- Top Level Structure & Contents
- Hub for Standards Alignment
- Not a Burden
- Summary

PSD-1 is Risk-Informed and Performance-Based

- Plant hazard analysis and risk evaluation risk-informs the design (RI)
- Systems engineering provides a (PB) structured approach for performance-based design
- PSD-1 integrates these to provide a **RI-PB** design

ASME SETTING THE STANDARD

PSD-1: Hub for Alignment of RI-PB Design Standards

- PSD-1 integrates risk evaluation standards into qualitative and quantitative hazard analyses processes
-
- PSD-1 integrates other design standards in the systems engineering processes

ASME SETTING THE STANDARD

PSD-1 Objectives

Relative to current design practices, the objectives of this PSD-1 are to:

- optimize integration of health, safety, and environmental risk evaluations with design
- reduce new plant design, construction, commissioning, and life cycle costs
- reduce licensing and construction uncertainty
- further optimize operating plant availability

3-Key PSD-1 Activities

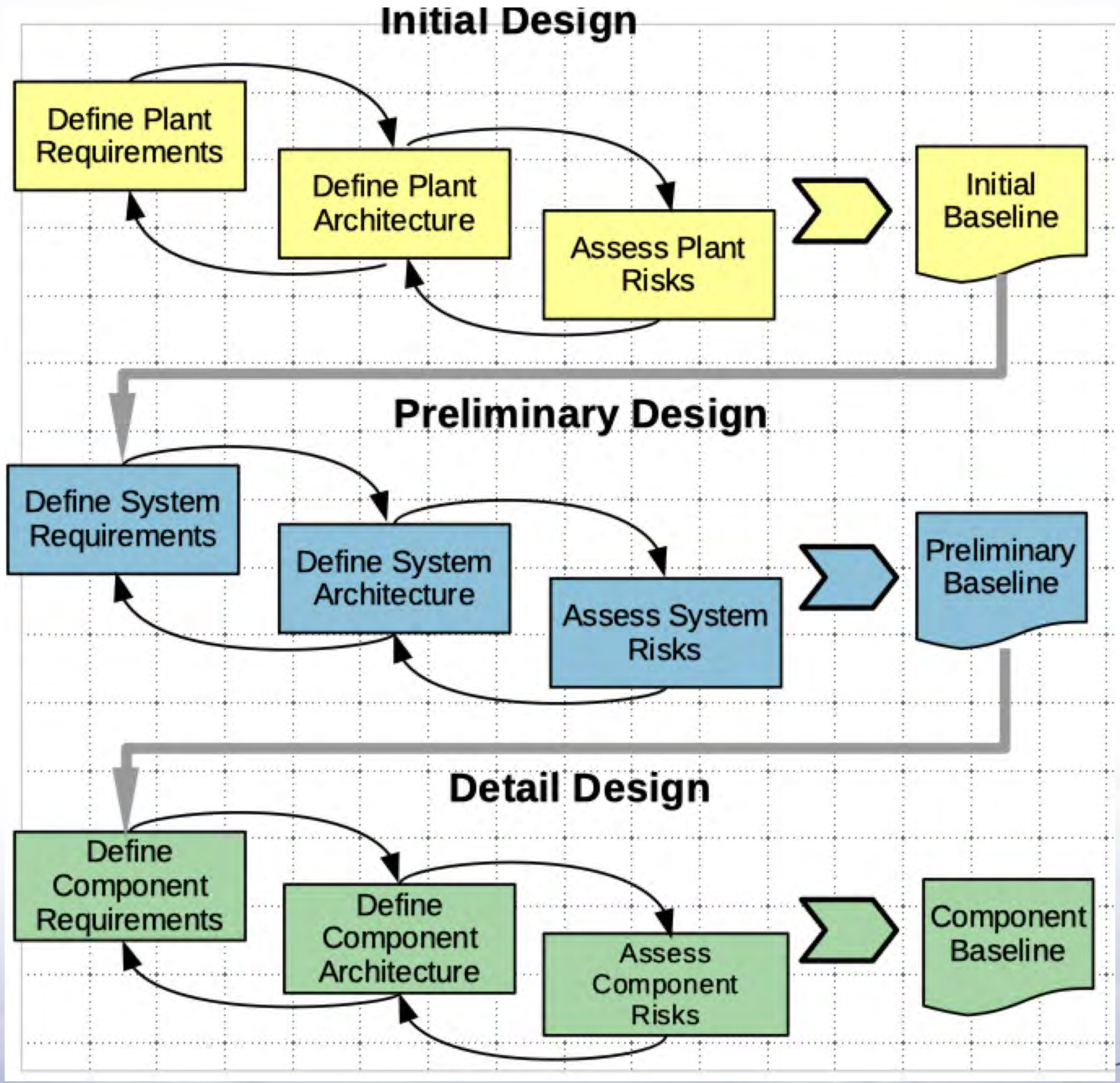
1. Conduct plant process hazard evaluations and analysis in the early phases of design that:
   a. Provide early identification of hazards, including strategies to avoid and mitigate them
   b. Advance as the design matures
   c. Provide structure to the development of a quantitative risk assessment

3-Key PSD-1 Activities **(Continued)**

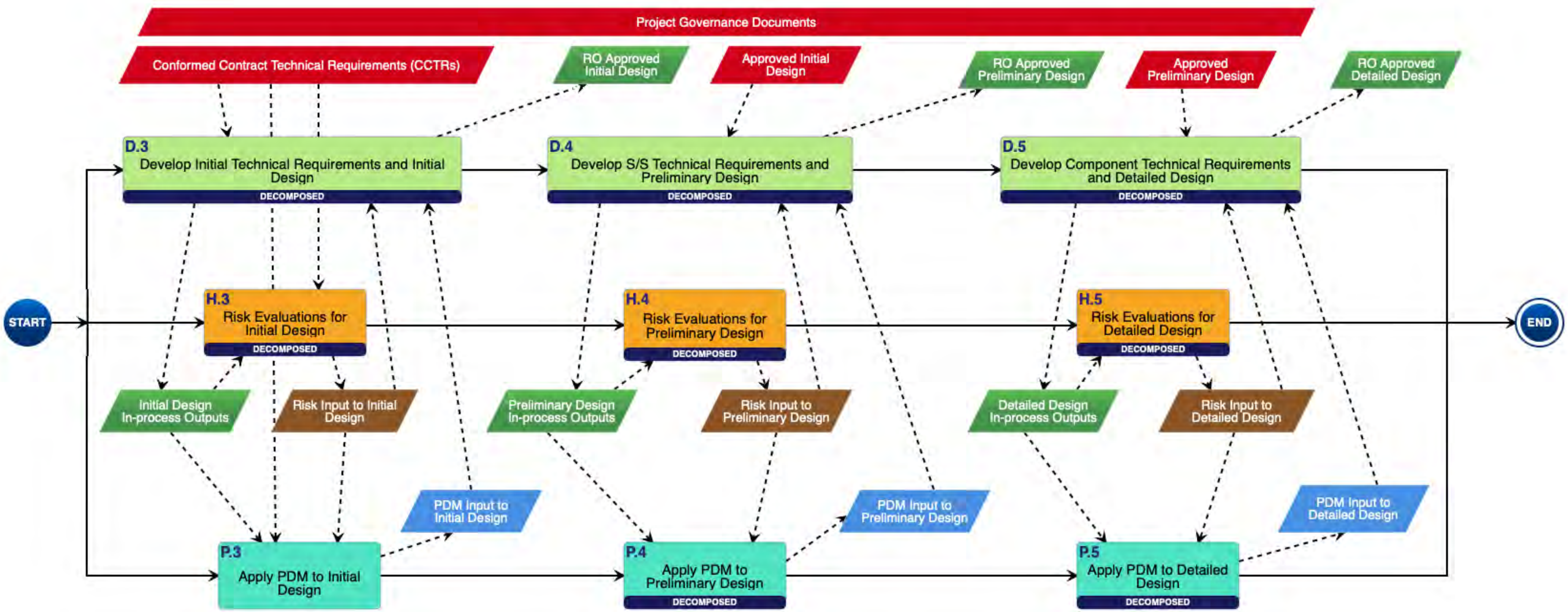
2. Incorporate and integrate systems engineering design processes, practices, and tools with traditional architect engineering design processes, practices, and tools
3. Integrate probabilistic design processes, practices, and tools with traditional deterministic design processes using reliability and availability targets

ASME SETTING THE STANDARD

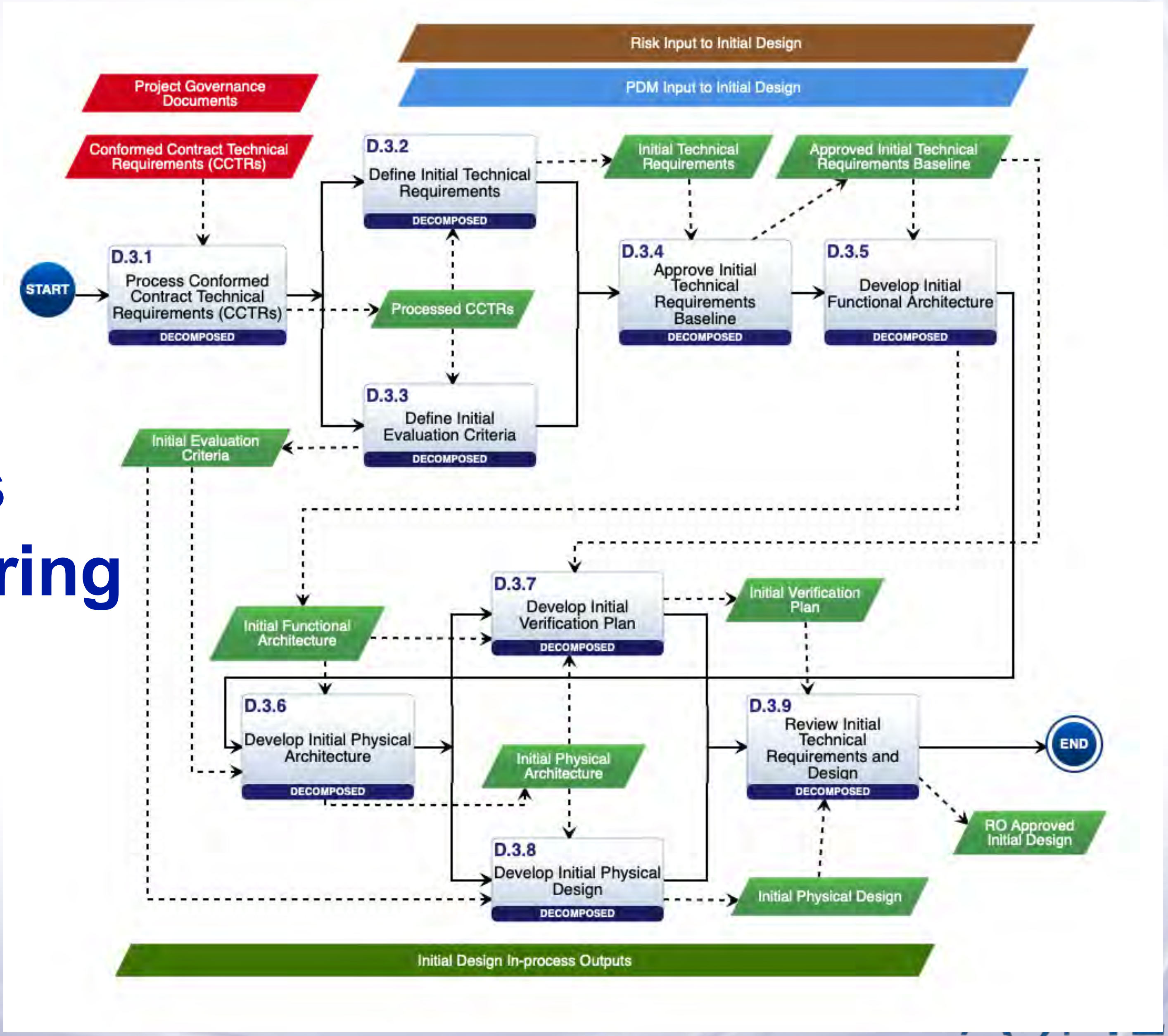
PSD-1 Overview



PSD-1 Top Level Structure

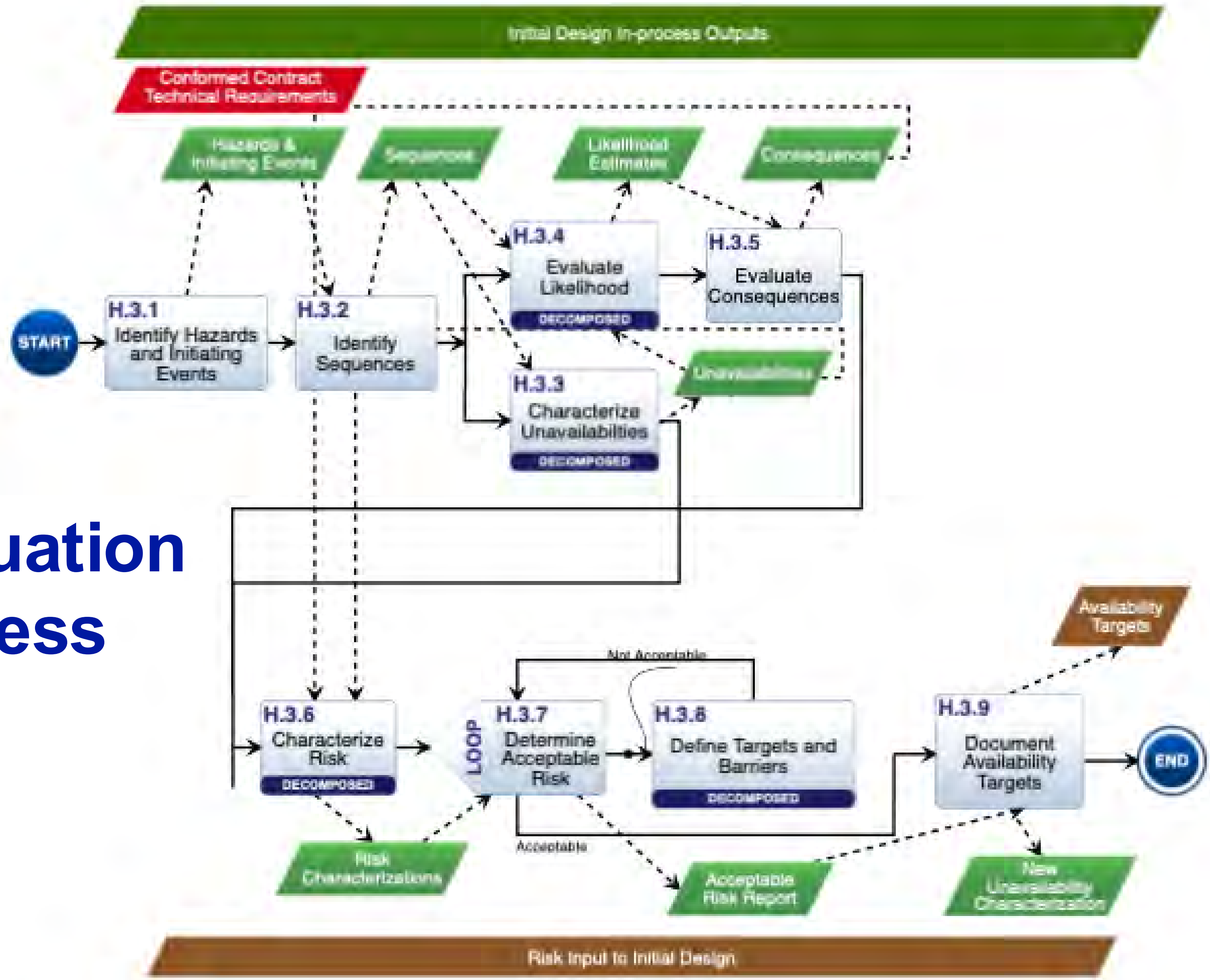


Systems Engineering Process



SETTING THE STANDARD

Risk Evaluation Process

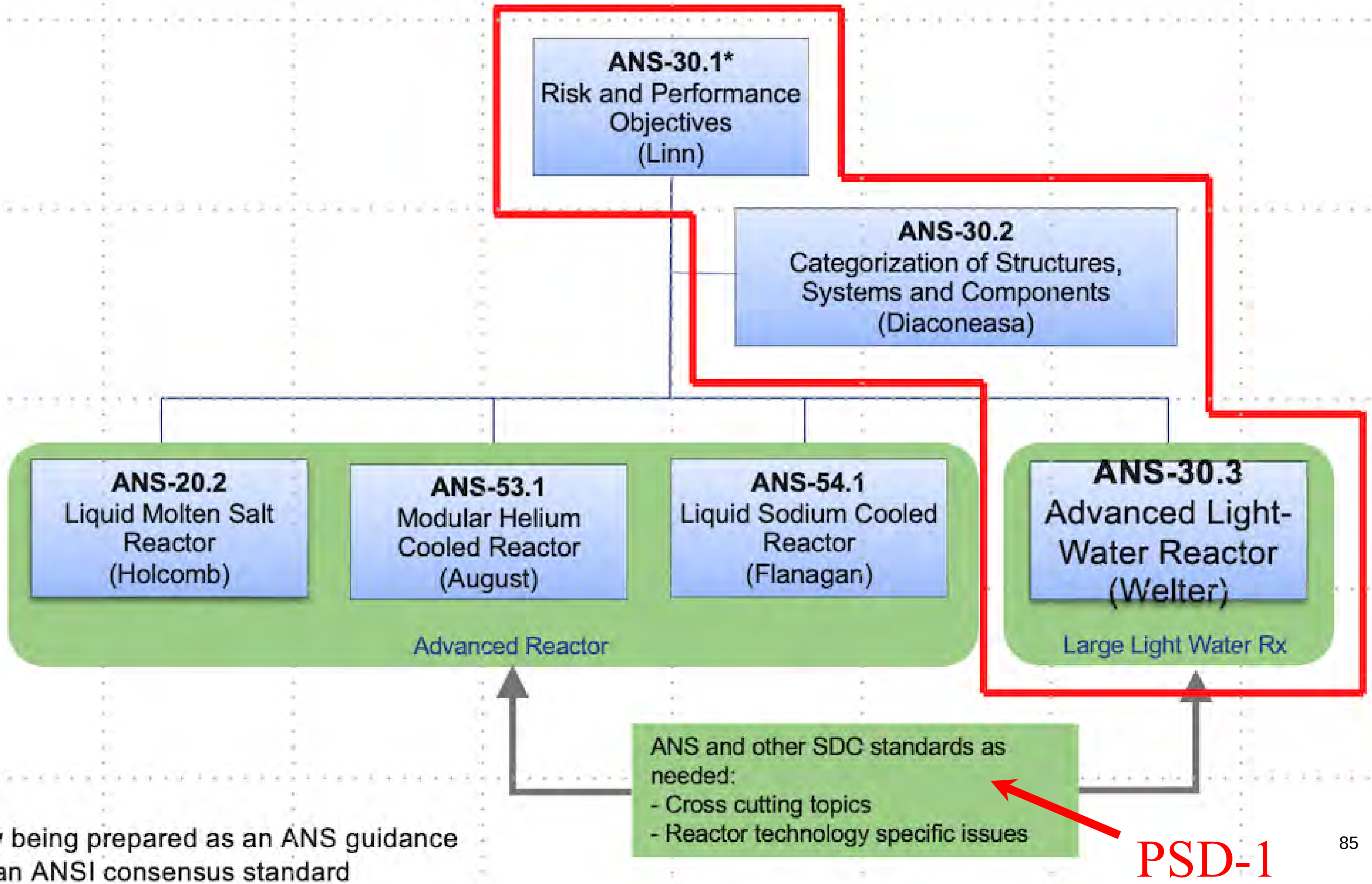


Hub for RI-PB Standards Alignment 1 of 4

PSD-1 provides a general description of how activities are performed but does not provide detailed information on how to perform the activities.

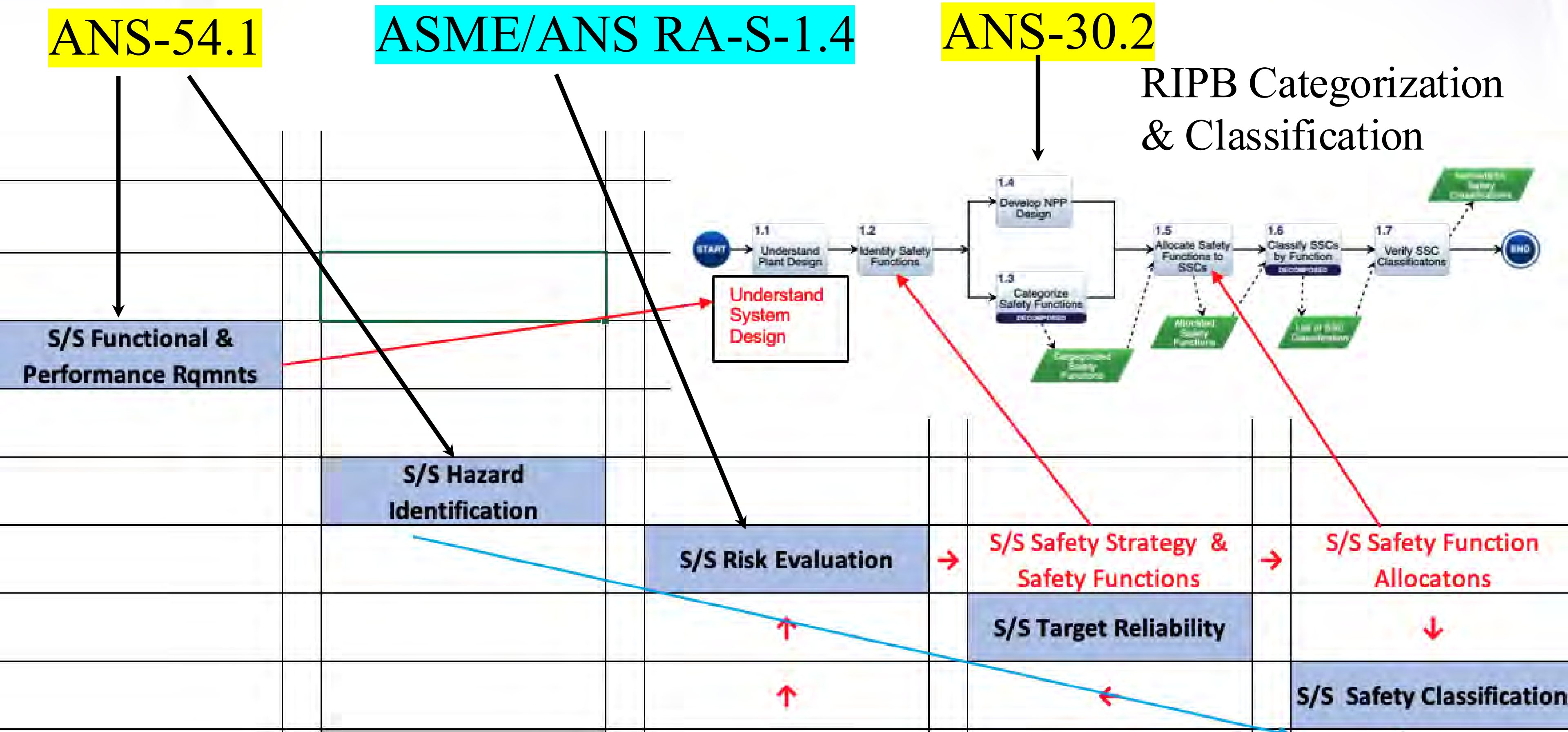
- Detailed "how to" references are provided in toolboxes.
- These references include industry standards.
- There are toolboxes for each of the 3 key technical areas.
- For example, ASME/ANS RA-S-1.4 – 2021, Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants is included in the risk evaluation toolbox to provide detail on how to perform a PRA.
- This is one way that PSD-1 is a hub for standards alignment.

Hub for RI-PB Standards Alignment 2 of 4



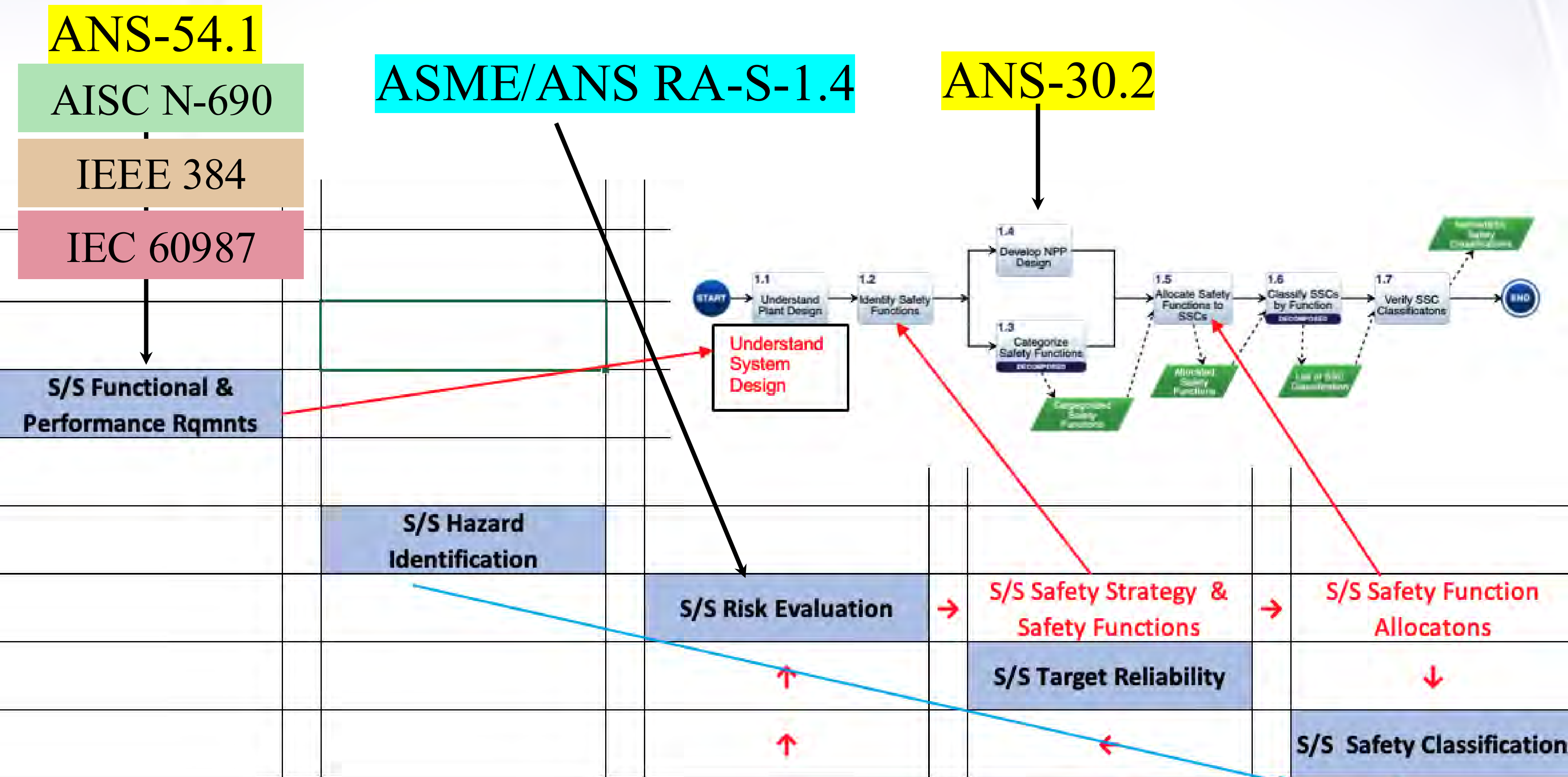
ANS-30.1 is now being prepared as an ANS guidance tandard, not as an ANSI consensus standard

PSD-1: Hub for Standards Alignment 3 of 4



S/S = Systems and Structures

PSD-1: Hub for Standards Alignment 4 of 4



S/S = Systems and Structures

PSD-1 Not an Added Burden

Means to improve current design processes, methods and tools to:

- enhance health, safety, and environmental risk reduction
- reduce the cost of new plant design, construction, commissioning, and life cycle costs
- increase cost and schedule certainty
- increase licensing and construction certainty
- further optimize operating plant performance and availability
- provide capability for cloud-native publishing

ASME
SETTING THE STANDARD

Summary: PSD-1 is …

- Risk-Informed and Performance-Based
  - Hazard analysis and risk evaluation risk-informs the design (**RI**)
  - Systems engineering provides a structured approach for performance-based design (**PB**)
  - Integrates these to provide a **RI-PB** design
- A Hub for Alignment of RI-PB Design Standards
  - Qualitative and quantitative hazard analyses processes integrate risk evaluations standards
  - Systems engineering processes integrate other design standards