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

Molten Salt Reactor PROGRAM

# Consensus Standards for Design and Licensing Liquid-Fueled MSRs

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# Overview of project

- **Work package number and title**
  - WBS Parent No. 1.15.07.04, Advanced Reactors Regulatory Development
  - Work Package No. RD-23OR070402, Assess consensus standards for use in licensing liquid-fueled Molten Salt Reactors (MSRs)

- The objective of this assessment is to provide input and guide the prioritization of identified update of existing standards and guidance documents for licensing, or to identify new guidance that will be needed for licensing liquid-fueled MSRs

- Although not required, the use of voluntary consensus standards and industry standards would be helpful in the design and licensing of advanced reactors to improve the effectiveness and efficiency of the licensing and regulation of liquid-fueled MSRs

- Most of the regulations and associated guidance and standards applicable to nuclear power plants were developed for water-cooled plants, so they may not directly or adequately address the coolants, materials, temperatures, operations, testing, maintenance, etc., for liquid-fueled MSRs. ORNL will identify those standards and guidance documents that are endorsed or approved by regulatory guidance or required by regulations. From this list ORNL will identify the level of effort required for those standards and guidance documents to be revised to make them appropriate for application to liquid-fueled MSRs and will also identify the need for new standards unique to MSRs

- Advanced reactor technology licensing and deployment will likely be delayed significantly if applicable and endorsed standards are not available for use by both technology developers and the NRC. Delays in providing the NRC with the knowledge base and tools for reviewing non-LWR applications will increase the effort needed to review an application and in turn will delay its approval

# The Use of Codes and Standards Will Be An Integral Part of Licensing An Advanced Reactor

- **OMB Circular A-119 Revised**
  - Establishes policies on Federal use and development of voluntary consensus standards and on conformity assessment activities
  - Directs agencies to use voluntary consensus standards in lieu of government-unique standards except where inconsistent with law or otherwise impractical
  - Provides guidance for agencies participating in voluntary consensus standards bodies and describes procedures for satisfying the reporting requirements in the Act

- **NRC expects that the use of codes and standards will improve its readiness to regulate non-LWR technologies**
  - The staff intends to incorporate codes and standards into its regulatory framework
  - The NRC will work with standards development organizations (SDOs), non- LWR designers, and other stakeholders to identify and facilitate new codes needed for non-LWR development
  - NRC MD 6.5, “NRC Participation In The Development And Use Of Consensus Standards” states that NRC’s participation in the development and use of consensus standards consists of three steps:
    - Identifying and prioritizing needed new and revised technical standards
    - Participation in codes and standards development
    - Endorsement of codes and standards
  - The NRC’s mid- and long-term action plans developed as part of the NRC non-LWR implementation action plans (IAPs) include:
    - Continue efforts to facilitate development of industry codes and standards
    - Develop RGs and conduct rulemaking, as needed, to endorse industry codes and standards

# The down-selection process focuses on high priority standards

- **Codes and standards may be endorsed, approved for use, or required by NRC**
  - Consensus codes and standards are endorsed in NRC's Regulatory Guides (RGs) and play a key role in the LWR regulatory infrastructure
  - Consensus codes and standards may be approved for use via the Standard Review Plan (NUREG-0800)
  - Consensus codes and standards may be required for use via the Code of Federal Regulations (CFR)

- **To understand the magnitude and scope of work required to establish codes and standards for MSRs, ORNL, under DOE funding, is performing a scoping study focused on codes and standards that could be beneficial for the licensing of MSRs:**

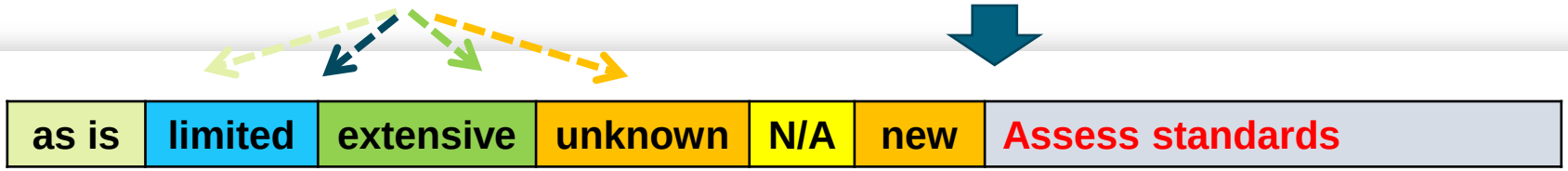
  1. Estimate of the number of standards that need revision;
  2. Estimate of the levels of effort required to revise those standards;
  3. Identify gaps in the current body of standards;
  4. Provide a description of the process for revising or creating a new standard; and
  5. Provide a description of the NRC's process for endorsing a standard.

# Number of Standards to be Assessed

| Standards | SDOs | RGs | Coverage |
|---|---|---|---|
| 865+ | 30 | 486 | Div 1-10 RGs |
| 180 | 14 | 67 | Div 1, 3 and 5 RGs (Power Reactors, Fuels and Materials Facilities, Materials and Plant Protection), active RGs; unique, active, endorsed standards |

| Standards | SDOs | SRP sections | Coverage |
|---|---|---|---|
| 466 | – | All | 3364 citations to standards, reports, articles |
| 77 | 13 | All | Active standards approved for use |
| 10 | 7 | All | Unique active standards approved for use (i.e., not endorsed by RG) |

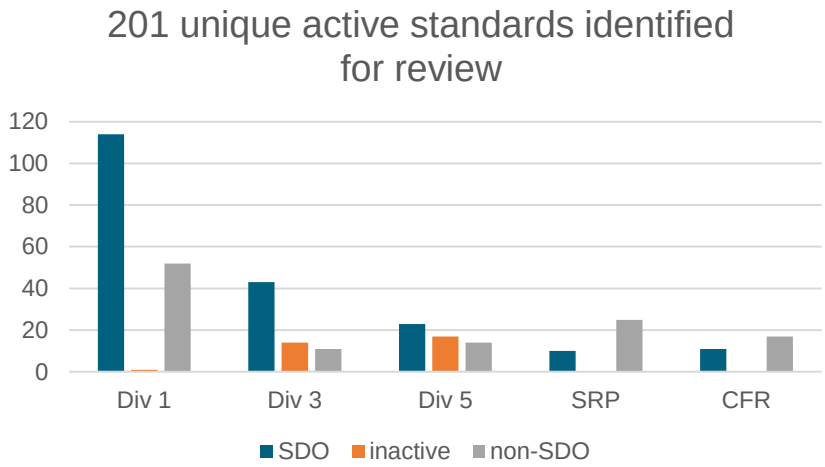
| Standards | SDOs | CFR | Coverage |
|---|---|---|---|
| 11 | 6 | All | Unique active standards required by CFR |

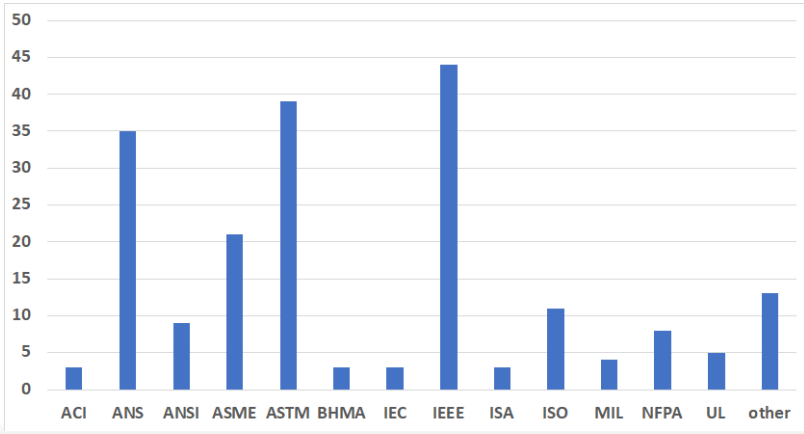


# Identifying the standards to review is complete

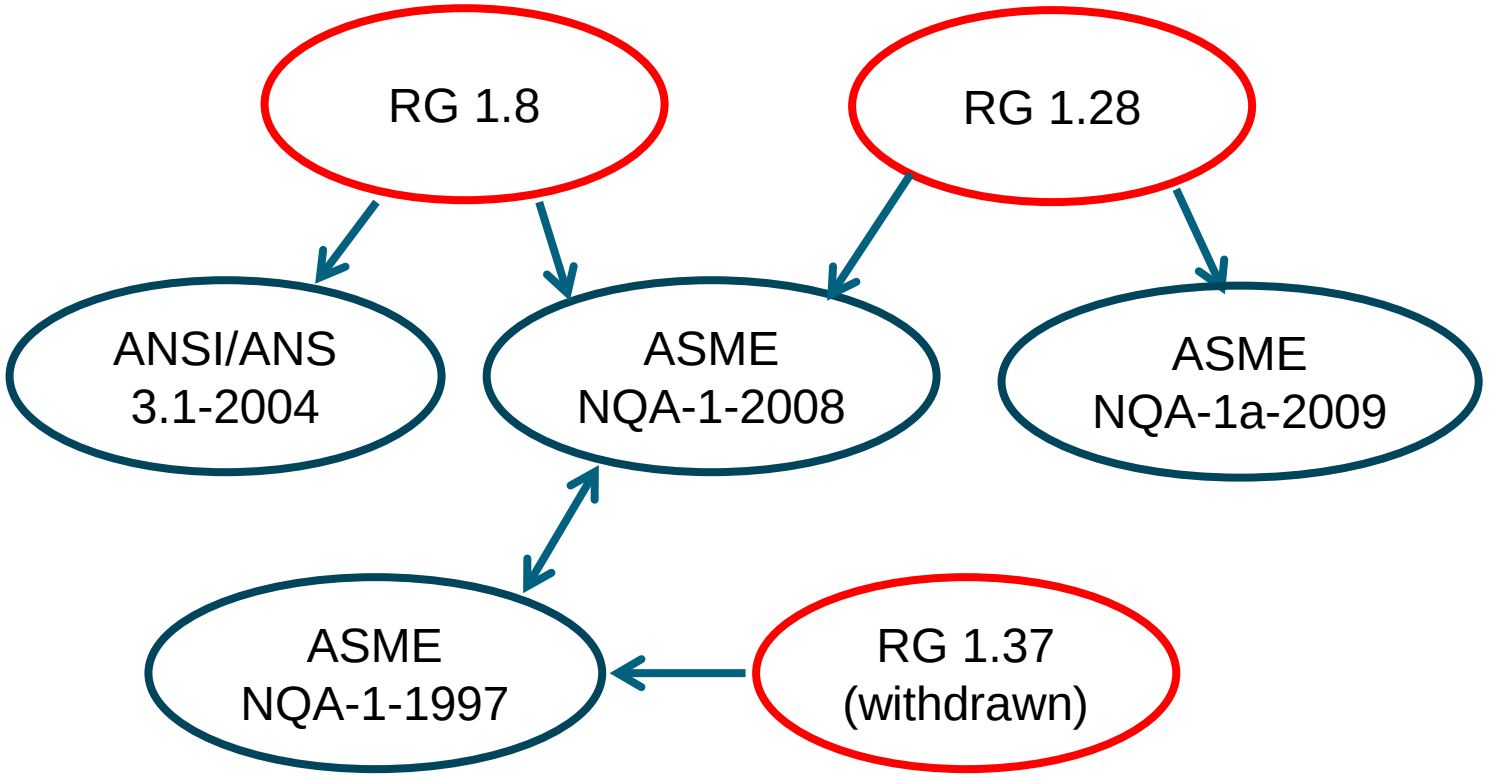
- **201 unique standards from Standards Development Organizations (SDOs) were identified for review for MSRs that are endorsed (RG), approved for use (SRP), required (CFR)**
  - A Regulatory Guide (RG), Standard Review Plan (SRP) subsection, or Code of Federal Regulation (CFR) requirement may identify more than one standard from different SDOs, and those documents may cite the same standard
  - **180** unique active standards endorsed by RGs
    - Div 1 – Power Reactors (114 unique active standards from 14 SDOs endorsed (54 cited in duplicate RGs), 1 inactive standard endorsed, 52 documents from 4 non-SDOs endorsed)
    - Div 3 – Fuels and Materials Facilities (43 unique active standards from 12 SDOs endorsed (4 cited in duplicate RGs, 14 inactive standards from 4 SDOs endorsed, 11 documents from 7 non-SDOs endorsed)
    - Div 5 – Materials and Plant Protection (23 unique active standards from 11 SDOs endorsed, 17 inactive standards from 6 SDOs endorsed, 15 documents from 5 non-SDOs endorsed)
  - **10** additional unique active standards from 7 SDOs approved for use by the SRP not endorsed by RGs
    - 74 standards from 12 SDOs are approved for use, 25 documents from 5 non-SDOs approved for use
  - **11** additional standard from 1 SDO required by the CFR
    - 11 standards from 6 SDOs required, 17 documents from 17 non-SDOs required

- **Guidance documents from non-SDOs, which are not within the scope of this review, include individual journal articles and documents from AECL, ANL, EPRI, GE, NEI, NRC, NUMARC, and Westinghouse**



# A RG may endorse more than 1 standard
# A standard may be endorsed by more than 1 RG




RG 1.8 Qualification and Training of Personnel for Nuclear Power Plants
RG 1.28 Quality Assurance Program Criteria (Design and Construction)
RG 1.37 Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants
ANSI/ANS 3.1-2004 Selection, Qualification, and Training of Personnel for Nuclear Power Plants
ASME NQA-1-2008 Quality Assurance Requirements for Nuclear Facility Applications
ASME NQA-1a-2009 Addenda to ASME NQA-1-2008

# Identification of new standards needed (gaps)

- **RG 1.232**, Rev. 0, “Guidance for Developing Principal Design Criteria for Non-light-water Reactors”
  - Appendix A of RG 1.232 provides Advanced Reactor Design Criteria (ARDC) to develop all or part of the principal design criteria (PDC). Licensees may choose among the ARDC, SFR-DC (Appendix B), or MHTGR-DC (Appendix C) to develop each PDC. Applicants/designers may also develop entirely new PDC as needed to address unique design features in their respective designs
  - The additional design criteria for the SFR and MHTGR added in the adaption of the GDCs in 10 CFR 50, Appendix A to SFR-DCs and MHTGR-DCs address unique features not adequately addressed in the GDCs

- **ORNL/TM-2020/1478**, “Proposed Guidance for Preparing and Reviewing a Molten Salt Non-Power Reactor Application”
  - The Evaluation Findings in an NRC Safety Evaluation Report (SER) presents the type of conclusions needed to accept the particular review area. The staff’s SER includes a conclusion for each section to document the results of the review
  - The Evaluation Findings are being reviewed to ensure that the endorsed, approved for use, or required standards are sufficient to support a safety evaluation (SE)

- **ORNL/TM-2021/2176**, “Molten Salt Reactor Fundamental Safety Function PIRT”
  - The PIRT process provides a structured mechanism to elicit and document expert opinions on the most important phenomena and the corresponding level of knowledge with regard to achieving the fundamental safety functions

- **How these documents work together to identify potential gaps**
  - As an example, to support the Evaluation Findings in ORNL/TM-2020/1478, the information on the reactor fuel should include a description of the required characteristics. RG 1.232 states that “An MSR designer may need to develop new PDC for liquid fuel and systems to support this design.” The PIRT indicates that understanding the phenomena of the mass/volume and energy of the molten salt (fueled salt) pool is of high importance and the knowledge base is insufficient making this a high priority for further research. The NRC reviews the fuel system description and design drawings with emphasis on product specifications rather than process specifications (SRP 4.2). The closest standard approved for use (SRP 4.2) is ASTM C776-89, Part 45, Standard Specification for Sintered Uranium Dioxide Pellets, which specifies the chemical, nuclear, and physical characteristics of UO2 pellets.
  - A standard similar to ASTM C776-89 should be developed for molten salt.

# How the revision to NUREG-1537 can be used to identify new standards

- LWR technology is based on heterogeneous fuel that includes a protective clad for the uranium oxide fuel pellets. Fission products are retained within the fuel rod structure. Therefore, fuel lifecycle is limited by burnup and fission product accumulation within the fuel rods. Chapter 4 focuses on the fuel, the neutronics, and the thermal-hydraulics in the core. The focus of the NUREG-0800 Chapter 4 review is to (1) provide assurance that the reactor design is capable of maintaining core parameters within specified acceptable fuel design limits (SAFDLs) during normal operation and anticipated operational occurrences (AOOs), and (2) provide assurance that the core can be maintained in a coolable core geometry during accident condition. The focus of the NUREG-0800 Chapter 5 review is to (1) provide assurance that the reactor coolant pressure boundary (RCPB) will remain intact to supply continuous core heat removal, and (2) evaluate the interaction of interconnected RCPB systems on the ability to provide assurance that the RCPB will remain intact. The focus of the NUREG-0800 Chapter 6 review is to ensure that plant safety features are provided to mitigate the consequences of design-basis accidents, particularly loss-of-coolant accidents for LWRs, even though the occurrence of these accidents is very unlikely. The NUREG-0800 Chapter 9 review evaluates LWR auxiliary systems including cooling systems, diesel systems, and fuel handling and storage systems. The NUREG-0800 Chapter 11 review evaluates plant waste management.

- MSR technology is based on homogenous liquid fuel in a halide salt mixture. The halide salts used have good heat transfer characteristics. Additionally, actinides have been demonstrated to be highly soluble in halide salts, so the fuel becomes part of the cooling system. Liquid fuel is present in the core and outside the core region. Traditional fuel fabrication is eliminated and excess reactivity, and consequently control rod worth, can be limited because additional fuel can be blended into the fuel salt as needed. Burnup limits are also eliminated as a fuel lifecycle limitation. The fuel salt has a low vapor pressure at operating temperatures, so the fuel salt system boundary is a low pressure system. In addition, AOOs and accidents that add heat to the system tend to shut the fission process down. The equivalent of the LWR fuel clad essentially becomes the fuel salt system boundary. This combination of fuel and coolant blurs the traditional lines of separation between the fuel and the coolant system found in NUREG-0800 Chapters 4 and 5. In addition, many of the engineered safety features discussed in Chapter 6 do not apply to MSRs. Additional auxiliary systems need to be considered for Chapter 9 due to the unique nature of MSR operations. Finally, waste processing must be evaluated in Chapter 11 in light of the highly radioactive environment created by MSR operations.

# Prioritization of standards efforts

**1 = none**
- e.g., grades of fuel oil

**2 = limited changes**
- e.g., although applicable to all types of NPPs, specifically cites LWRs

**3 = substantive changes needed**
- e.g., transients for simulator training for BWRs and PWRs

**4 = insufficient design info**
- e.g., qualification of active mechanical equipment

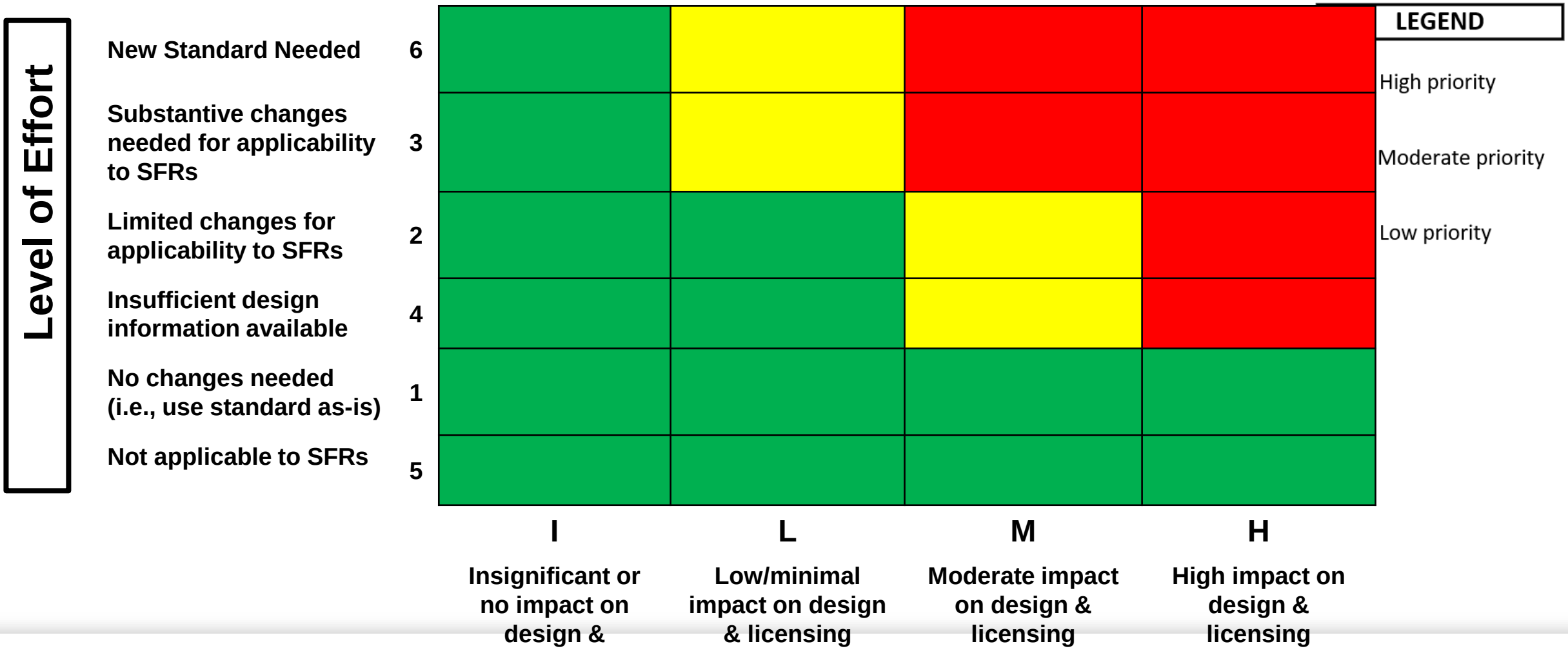
**5 = not applicable (N/A)**

**6 = new design-specific requirement**
- e.g., code cases for materials (e.g., HT9)

**7 = RG withdrawn**

**8 = not reviewed**

# Exploring ways to make the identification of standards more focused and useful



# Preliminary notes from reviews

- Temperatures in MSRs may exceed concrete and steel limits in standards
- BPV Section III, Division 5 now endorsed by RG 1.87, Rev. 2 (January 2023)
- Types of steel, concrete, and source terms may differ greatly for MSRs compared to LWRs
- Those components required to function during a design basis accident (DBA) will be different for MSRs and will require modification to some standards (e.g., seismic, dynamic qualifications)
- Fuel storage and handling differences noted
- A new standard is needed to define: 1. the means to detect leakage into inert or air environments, 2. the extent to which salt-air and salt-concrete reactions are limited and controlled, 3. the degree to which the effects of fires are mitigated, and 4. the means for evaluating the effectiveness of special features or conditions containing molten salt to ensure that the safety functions of SSCs important to safety are maintained

# Thank you

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