ELECTRIC POWER RESEARCH INSTITUTE

Program on Technology Innovation: Owner-Operator Requirements Guide (ORG) for Advanced Reactors, Revision 1

2019 TECHNICAL REPORT

Program on Technology Innovation: Owner-Operator Requirements Guide (ORG) for Advanced Reactors, Revision 1

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Technical Report, June 2019

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All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

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The ORG research work (including both Revision 0 and Revision 1 reports) is the product of collective input obtained at dedicated workshops from an expert team of advisors comprising EPRI member utilities, reactor technology developers and vendors, Architect/Engineering/Procurement/Construction professionals, and other industry representatives.

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ABSTRACT

Public and private sector interest and investment in advanced nuclear reactor technologies is growing as utilities and other energy suppliers seek options for scalable, dispatchable, concentrated, and non-emitting energy generation. Advanced reactors employ a combination of new coolants, fuels, materials, and power conversion technologies that, if commercialized, offer substantial improvements over current generation technology in terms of safety, economics, performance, and long-term energy security.

Successful commercialization requires early engagement of potential technology customers (electric utilities and other owner-operators) with developers and vendors for alignment of requirements. In order to achieve this, prospective advanced reactor owner-operators require clear guidance to aid in technology selection and assessment of design maturation. Conversely, prospective advanced reactor vendors require information on what prospective owner-operators want in order to develop viable, competitive designs.

In keeping with its previous leadership role in the commercialization of advanced light water reactors and experience with development of the *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Revision 13* (URD) report (3002003129), EPRI brought together advisors representing nuclear and non-nuclear utilities, the advanced reactor development community, and architect/engineering/procurement/construction (AEPC) professionals. The goal was to obtain their feedback regarding the scope and development of a new advanced reactor Owner-Operator Requirements Guide (ORG). This report provides the ORG, Revision 1, which is a living document for the advanced reactor community and is the result of extensive collaboration among members of this community.

The ORG is intended to be technology inclusive and will apply to a wide range of advanced reactor technologies and missions. By bringing together the advanced reactor stakeholder community, the ORG encourages innovation and successful designs while leveraging lessons learned from commercial nuclear reactor construction and operation. The ultimate role for the ORG is as an alignment tool for communicating the expectations and desires of potential owner-operators (U.S. and international community) to developers. The ORG thus supports the vetting of new designs, communicates advanced reactor capabilities and limitations to stakeholders, and facilitates access to advanced nuclear designs in new market segments and by potential customers.

Keywords

Advanced nuclear technology
Advanced reactors
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PRIMARY AUDIENCE: Future advanced reactor technology customers (electric power utilities and other potential owner-operators) and advanced reactor technology developers and vendors

SECONDARY AUDIENCE: Other stakeholders with an interest in understanding the attributes of and expectations for advanced reactor technology, including architect/engineers/procurement/construction (AEPC), regulators, policymakers, investors, and the general public

KEY RESEARCH QUESTION

Advanced nuclear generation technologies offer compelling options for meeting future energy needs by taking advantage of new fuels and fuel cycles, lower reactor pressures, higher outlet temperatures, and advanced energy conversion technologies. Most technologies have been demonstrated at some scale and span a wide range of technological maturity landmarks, from proof-of-concept to actual operation at commercial scale. While many options exist—and are being pursued by governments and private ventures—communication and alignment of customer needs with product development is lacking. EPRI seeks to answer the fundamental question, "What do utilities and other potential owner-operators want and need in terms of advanced reactor technologies in order to facilitate the vetting of new designs, communicate advanced reactor capabilities and limitations to relevant stakeholders, and adopt new nuclear technology as part of an energy generation infrastructure?"

RESEARCH OVERVIEW

In keeping with its previous leadership role in the commercialization of advanced light water reactors (ALWRs)—and in collaboration with relevant stakeholders from the advanced nuclear community (utilities, vendors, and developers)—EPRI has developed a common set of requirements reflecting the expectations and needs of prospective owner-operators for advanced nuclear reactor designs that offer significant improvements with respect to currently available nuclear technologies.

While the experience and information associated with EPRI's *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Revision 13 (URD)* report (3002003129) provided a starting point for the Owner-Operator Requirements Guide (ORG) development, this product is also aligned with other relevant EPRI products and international standards.

The highest levels of guidance provided in the ORG are the policy statements and aspirational goals. Policy statements act as philosophies that should be embodied by advanced reactor developers. Conversely, aspirational goals are specific, ambitious capabilities that, if achieved in the future, will provide advanced reactors with distinct, measurable advantages over competing energy sources in the market of choice. Following the policy statements and aspirational goals, the ORG is organized into three tiers. Tier I provides 11 categories into which lower level requirements may be grouped including constructability, cyber security, and licensing and safety analysis; Tier II provides high-level guidance intended to support the design, construction, operation, and economic case of advanced reactors; and Tier III requirements provide technology-level guidance for a select set of reactor technologies intended to guide the reactor design.

KEY FINDINGS

- The ORG incorporates decades of experience in designing, licensing, constructing, and operating LWRs to assist owner-operators in deploying advanced reactors. Based on the feedback received, special attention was given to the requirements, with guidance on 1) operational and deployment flexibility; 2) constructability; 3) planning for obsolescence; and 4) designing for inspection, maintenance, and replacement.
- Each lower tier requirement is mapped to a higher tier requirement, which provides a better flow and logical justification for any of the existing ORG requirements.
- The ORG document addresses all possible missions for the advanced reactors, although it primarily focuses on electricity generation (the traditional role of nuclear reactors).
- Additional missions may be added to future ORG revisions if market factors create a new or previously overlooked opportunity for advanced nuclear reactors or if a new reactor technology makes a previously unviable mission viable.
- Additional technologies may be added to future ORG revisions if the conceptual development of a new reactor technology reaches a point where it may be deemed realistically viable.
- A new and intuitive numbering scheme was developed providing each requirement with a unique identifier reflecting the corresponding tier and the “parent” requirement.

WHY THIS MATTERS

As with the commercialization of ALWRs, early and meaningful engagement of prospective owners, operators, and architect/engineering/procurement/construction (AEPC) firms in the design and development of advanced reactors using the ORG provides many potential, far-reaching benefits including:

- Communication of the expectations and desires of potential owner-operators to developers, thus promoting alignment
- Exchange of AEPC experience to inform the design
- Communication of owner-operator expectations and needs to developers and vendors
- Aid to owners and operators in vetting new designs
- Identification of unaddressed gaps and risks
- Facilitating access of advanced nuclear designs to new markets and customers
- Informing the development of other infrastructural and institutional support

Failure to obtain sufficient industry engagement in the advanced reactor development enterprise may constrain the identification and successful commercialization of suitable advanced reactor technologies on scales and time frames needed to meet future societal energy needs in an environmentally and economically sound manner.

HOW TO APPLY RESULTS

This report provides the first revision of the ORG, which is the result of development workshops with several stakeholders representing a range of perspectives (nuclear utilities from different countries, non-nuclear utilities pursuing nuclear technologies, architect engineering firms). The ORG should aid owner-operators in vetting vendor designs, establish a useful structure for formatting a bid specification, and inform stakeholders of advanced reactor capabilities and limitations. In addition, the ORG should help reactor vendors better understand the needs and expectations of potential customers and possible constructability limitations or opportunities. It is important to note, however, that the ORG is not intended to supplant or negate any country's existing regulations.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI has established an Advanced Reactor Technical Advisory Group (TAG) under the Advanced Nuclear Technology Program to provide a forum for exchanging information and obtaining input on the direction and nature of EPRI's strategic focus on advanced reactor technology.
- Related EPRI work includes the following reports: *Program on Technology Innovation: Scoping Study for an Owner-Operator Requirements Document (ORD) for Advanced Reactors* (3002008041, 2016), *Program on Technology Innovation: Owner-Operator Requirements Guide (ORG) for Advanced Reactors, Revision 0* (3002011802, 2018), and *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Revision 13* (URD) (3002003129, 2014).
- EPRI is seeking international collaboration opportunities with governments, utility members, and advanced reactor developers/vendors to provide resources and expertise needed to drive timely completion of future revisions of the advanced reactor ORG.

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ACRONYMS

The following terms, acronyms, and initialisms appearing in figures and text are defined as follows:

- AC: Alternating Current
- AEPC: Architect, Engineering, Procurement, and Construction
- ALARA: As Low as Reasonably Achievable
- ALWR: Advanced Light Water Reactor
- ANS: American Nuclear Society
- ANT: EPRI Advanced Nuclear Technology Program
- ASME: American Society of Mechanical Engineers
- B&PVC: Boiler and Pressure Vessel Code
- BOP: Balance-of-Plant
- BWR: Boiling Water Reactor
- CCF: Common Cause Failure
- CMIS: Configuration Management Information System
- COTS: Commercial Off-the-Shelf
- DC: Direct Current
- DOE: US Department of Energy
- DSRS: Design-Specific Review Standard
- D-RAP: Design Reliability Assurance Program
- EIA: US Energy Information Administration
- EPC: Engineering, Procurement, and Construction (also see AEPC)
- EPG: Emergency Procedure Guidelines
- EPRI: Electric Power Research Institute
- EPZ: Emergency Planning Zone
- EUR: European Utility Requirements for LWR Nuclear Power Plants
- FHR: Fluoride salt-cooled High Temperature Reactor

- FME: Foreign Material Exclusion
- FOAK: First-of-a-Kind
- GDC: Generic Design Criteria
- GEN IV: Generation IV Reactor
- GFR: Gas-cooled Fast Reactor
- GIF: Generation IV International Forum
- HMI: Human-Machine Interface
- HTGR: High Temperature Gas-cooled Reactor
- IAEA: International Atomic Energy Agency
- I&C: Instrumentation and Controls
- IEA: International Energy Agency
- IEEE: Institute of Electrical and Electronics Engineers
- INL: Idaho National Laboratory
- INPO: Institute of Nuclear Power Operations
- ISI: In-Service Inspection
- LCOE: Levelized Cost of Electricity
- LMFR: Liquid Metal-cooled Fast Reactor
- LWR: Light Water Reactor
- M&TE: Maintenance and Test Equipment
- MSR: Molten Salt Reactor
- NEI: Nuclear Energy Institute
- NUREG: US Nuclear Regulatory Commission Regulation
- OE: Operating Experience
- O&M: Operation and Maintenance
- OEM: Original Equipment Manufacturer
- ORG: Owner-Operator Requirements Guide
- ORNL: Oak Ridge National Laboratory
- PDD: Programmable Digital Device
- PEMS: Plant Environmental Monitoring System
- PHWR: Pressurized Heavy Water Reactor
- PRA: Probabilistic Risk Assessment

- PWR: Pressurized Water Reactor
- QA: Quality Assurance
- RCCS: Reactor Cavity Cooling System
- RPV: Reactor Pressure Vessel
- SCWR: Supercritical Water-cooled Reactor
- SFR: Sodium-Cooled Fast Reactor
- smLWR: Small Modular Light Water Reactor
- SMR: Small Modular Reactor
- SSC: Structures, Systems, and Components
- TEMA: Tubular Exchangers Manufacturers Association
- TMI: Three Mile Island
- TR: Technical Report
- TRISO: Tristructural-Isotropic (nuclear fuel)
- URD: EPRI Utility Requirements Document
- USNRC: US Nuclear Regulatory Commission
- V&V: Verification and Validation
- VHTR: Very High Temperature Gas-cooled Reactor
- WANO: World Association of Nuclear Operators
- WRS: Weld Residual Stress

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1 INTRODUCTION

1.1 Purpose

This technical report contains the supporting material for the Owner-Operator Requirements Guide (ORG) for Advanced Reactors and serves as an introduction to the ORG, providing both history and context.

Advanced nuclear generation technologies offer compelling options for meeting future energy needs by taking advantage of new fuels and fuel cycles, lower reactor pressures, higher outlet temperatures, and advanced energy conversion technologies. Most technologies have been demonstrated at some scale and span a wide range of technological maturity landmarks—from proof-of-concept to actual operation at commercial scale. While many options exist, and are being pursued by governments and private ventures, communication and alignment of customer needs with product development is lacking. With the publication of the ORG, EPRI seeks to answer the fundamental question, "What do utilities and other potential owner-operators want and need from advanced reactor technologies to encourage and enable the adoption of a new nuclear technology?"

In keeping with its previous leadership role in the commercialization of advanced light water reactors (ALWRs) and the development of the Utility Requirements Document (URD), EPRI has worked with relevant stakeholders from the world's advanced nuclear community (utilities, vendors, and developers) and Architect/Engineering/Procurement/Construction (AEPC) professionals to develop a common set of requirements that reflect the expectations and needs of prospective owner-operators for advanced nuclear reactor designs, that offer significant improvements with respect to currently available nuclear technologies.

Given the variety of missions, technologies, and customers, and the lack of advanced reactor operating experience, the ORG is not intended to duplicate the URD in depth and detail but is, instead, intended to provide a common framework for communicating expectations of potential owner-operators and experience of AEPC professionals to advanced reactor developers and vendors and establish a foundation for understanding the benefits and limitations of these technologies in a way that will aid in their development, licensing, and deployment.

In short, the ORG is intended to:

- promote alignment of technology attributes with customer needs;
- convey AEPC experience to inform the design;
- standardize terms, attributes, and requirements (vs. prescribing them);

- facilitate communication with key stakeholders, including regulators; and
- provide a flexible, inclusive framework compatible with multiple advanced reactor missions and technologies.

1.2 Background and Context

Utility Requirements Document

EPRI first published the *Utility Requirements Document for Advanced Light Water Reactors* (ALWRs) in 1990, and has continued to maintain and update the URD over the intervening three-decade period. The URD provides a set of requirements to align ALWR plant designs with utility needs. The current Revision 13 of the URD has been expanded to address small modular light water reactors (smLWRs) and to incorporate post-Fukushima learnings (EPRI, 2014a). The URD comprises three tiers:

- Tier 0: Executive Summary
- Tier 1: Policy and Top Tier Design Requirements
- Tier 2: Requirements for ALWR plants

These tiers extend in granularity down to bid specification detail for a number of ALWR design concepts. EPRI initially pursued development of the URD in support of a U.S. electric utility sector to address nuclear plant performance, flat electricity demand, and the 1979 accident at Three Mile Island Unit 2. Nuclear utility executives expressed to EPRI that in order to consider new nuclear plant construction, they would need proven light water reactor technology implemented in designs that were:

- simpler with higher design margins and enhanced safety features;
- economically competitive with other generation sources; and
- prelicensed by the U.S. Nuclear Regulatory Commission.

In response, EPRI began development of the URD to provide, among other things,:

- a stabilized regulatory basis and more predictable licensing path for new technologies;
- a standardized framework for elaborating attributes, expectations, and requirements for use in design and potential design certification; and
- a standardized template for defining requirements for future owner bid packages.

While initially U.S.-centric in scope, the URD has expanded to include more than 30 U.S. and international utilities.

Advanced Reactors

Proven commercial reactor technologies are commonly categorized into three generations, with the latest commercially-available large light water reactor designs falling under Generation III. Designs that extend beyond these commercial offerings are often collectively referred to as Generation IV (GEN IV) technologies. Generation IV reactors are generally understood to be fission reactor designs that offer significant improvements with respect to current nuclear technologies in terms of potential for enhanced resource utilization, inherent safety, economics, and proliferation resistance and security. Meanwhile, smLWRs, which offer elements of both Generation III and IV fall somewhere between the two. For the purposes of ORG, the term "advanced reactor" is used preferentially when discussing the more general set of non-LWR reactor technology options.[1]

While a much anticipated nuclear renaissance has failed to materialize in the United States and Europe, construction of new light-water reactors has continued in China, Russia, and India. Development of smLWR designs continues as well, although the ultimate commercial penetration of smLWRs remains uncertain. Meanwhile, government interest in advanced, non-LWR reactors continues globally and has coincided with unprecedented influx of private investment in a growing field of entrepreneurial developers in North America. One driver for this renewed interest in advanced nuclear technology is recognition of a looming need for scalable, dispatchable, energy-dense, and non-emitting energy generation options that could be commercially available in the 2030 – 2050 timeframe to replace retiring generation assets and meet future energy demands in the face of uncertain policy, regulatory, and market environments.

A compelling driver for advanced reactors is the potential for greater access to new markets and economic opportunities, including alternative applications spanning national (public) and commercial missions. For instance, reactors designed to perform electricity generation or process heat missions will primarily serve competitive commercial markets where the end product has economic value. However, some reactors may address public needs where the service or product, e.g., actinide burning for non-proliferation and waste management, provides a public or societal good supported or driven by national policy.

Electricity generation currently represents the dominant market for nuclear power and will remain a primary mission for nuclear technologies of the future. Therefore, ORG Rev. 1 focuses on electricity generation while also providing nominal structures to support future extension to other missions in subsequent revisions as they emerge or are warranted by interest.

Landscape of Nuclear Power

Around the world, economic growth has traditionally been tied to growth in the use of electricity. However, in the United States and some other countries, that link has weakened as more efficient use of electricity has allowed for economic growth with electricity usage that was flat or increasing at a much slower rate. In recent years, balancing this growth while continuously pushing for a cleaner energy portfolio has become more important. Other important societal needs (e.g., transportation) are met by fuel sources and technologies which are becoming more unfavorable due to their environmental impact and the questionable long-term availability of resources. While governments will be key in funding research and development efforts for the improvement or replacement of existing technologies in these markets, there is increasing recognition that privately funded development is required to achieve deployment in many markets.

[1] The terms "GEN IV" and "advanced" are often used interchangeably when referring to reactor technologies beyond current Generation III designs, with most employing coolants other than water. However, the term GEN IV also carries the stricter, more limited definition established under the Generation IV International Forum (GIF) in 2002 for six reference designs and four goals.

The United States Energy Information Administration (EIA) 2017 Annual Energy Outlook reviewed electric generating assets according to their installed capacity (EIA, 2017). Generally, the changes over the last half-century can be described as a switch from coal to nuclear first (with the development and deployment of commercial light water reactor designs), then natural gas as the major producer, with a greater penetration of renewables. However, depending on fossil fuel prices, constraints on carbon emissions, electrification of transportation, and other government policy intervention, competitiveness of advanced nuclear technologies could increase substantially in future energy markets.

Large-Scale Electricity Generation

The International Energy Agency (IEA) reports the potential for a clean energy market of 5 trillion US dollars if global carbon dioxide reduction goals are to be realized (IEA, 2012). Meeting even a small portion of this anticipated need with clean technologies would introduce an opportunity for advanced nuclear technologies worth on the order of several tens to hundreds of billions of U.S. dollars. Even in developed markets with flat electricity demand, there are likely to be continuing opportunities and demand for nuclear generation. In the United States, for example, the competitiveness of nuclear power is strongly influenced by regional factors, local, state and federal policies, and opportunities for revenue beyond electricity sales (EPRI, 2018a).

Other Applications

There are aspects of certain advanced reactor designs that make them feasible for applications beyond electricity generation that have never been well-suited for traditional light water reactors (LWRs). Many designs, such as the high temperature gas reactor (HTGR), operate at significantly higher temperatures than LWRs, which offer access to markets for high quality process heat applications. Designs such as the sodium-cooled fast reactor (SFR) can be highly scalable and deployable in transportable sizes, making them ideal for deployment to isolated locales, such as remote villages in Alaska, USA, for reliable municipal electricity generation. These MW-scale reactors would also be useful for enhanced oil recovery applications in remote areas beyond the reach of existing electrical grids. These and other applications increase the marketability of advanced nuclear power by expanding the customer base beyond the large-scale electric utility.

1.3 ORG Development Approach

The ORG development was initiated with the completion of a scoping study (EPRI, 2016a). The scoping study addressed the following questions:

1. Is the ORG a needed resource?
2. How would the ORG be structured and who would use it?
3. What references would form the basis of the ORG's content?
4. How would the ORG be developed and by whom? How would it be updated in the future?

The scoping study reviewed historical operation of various reactor designs, lessons learned in commercial operation of light water reactors (LWRs) and other reactors, and the changing needs of owner-operators. The resulting report identified the importance of maintaining a technology inclusive ORG given the diversity of both advanced reactor designs (Figure 1-1) and their potential application beyond electricity generation.

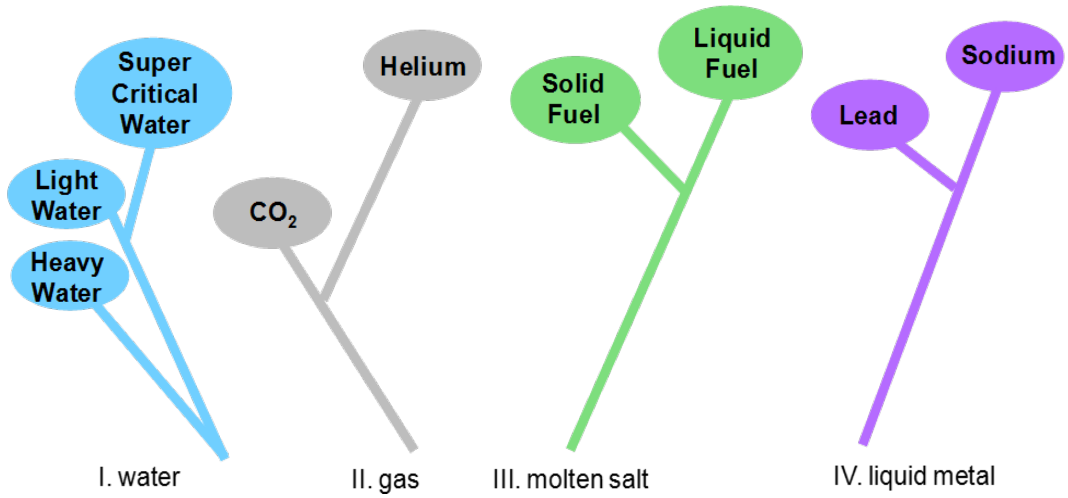

Figure 1-1
Diversity of Reactor Technologies, Organized by Primary Heat Transfer Fluid

Maintaining technology inclusivity requires careful consideration of terminology and some adjustment in development of the ORG framework and high-level requirements provided therein. For example, the term "heat transfer fluid" is used in Figure 1-1 instead of "coolant" to decouple the primary function of heat transfer from more design- and technology-specific safety-related function associated with cooling.[2] Elsewhere in the ORG, requirements that would normally reference specific equipment instead reference the functionality of the equipment to maintain technology and design inclusiveness. For instance, requirements that may appear to apply to traditional control rods may reference "variable reactivity control devices" instead.

The ORG Revision 0 (EPRI, 2018b) was developed with an approach similar to that used in the scoping study (EPRI, 2016a). EPRI conducted workshops during which utility and reactor vendor representatives reviewed suggested formats and advanced reactor guidance and requirements. These workshops provided the clearest view of the advanced reactor community's needs at this time. Following the creation of a relatively complete framework, two advanced reactor developers (TerraPower, LLC and X-Energy, LLC) participated in a pilot program to apply the ORG to their designs. Lessons from this pilot program were reflected in ORG Revision 0.

The ORG Revision 1 development occurred in a similar manner. EPRI conducted several meetings with a variety of stakeholders, most new to the project, to obtain new feedback to include in modifying and expanding the ORG for Revision 1. Stakeholders included existing nuclear utilities (from the United States, France, and Canada), non-nuclear utilities with an interest in pursuing advanced nuclear power for future capacity, and Architect, Engineering, Procurement, and Construction (AEPC) contractors with previous experience in nuclear plant construction.

[2] For example, in many HTGR designs, the loss of the primary heat transfer fluid (helium) does not have a significant safety impact from a cooling perspective.

1.4 ORG Revision 1 Objectives

The objective of Revision 1 of the ORG is to expand the content to more thoroughly cover areas of particular interest and fill identified gaps in guidance in Revision 0. The “natural” gaps existing in ORG Revision 0 (e.g., not enough depth) were identified and addressed in ORG Revision 1 work. These areas resulted in new requirements addressing:

- Balance-of-plant
- Non-electric missions (e.g., industrial heat, hydrogen production, medical isotopes)
- Automation and digital I&C
- Cyber security
- Investment/Business case
- Integration of advanced reactors with renewables

ORG Revision 1 introduced the addition of a checklist tool, intended to enhance the utility/value of this guideline document. The main purpose of this is to help with the navigation, understanding and use of the ORG Revision 1 text and requirements.

The ORG Revision 1 checklist can also serve as a screening tool by helping the reader to evaluate the completeness of this product.

2
FEATURES OF THE OWNER-OPERATOR REQUIREMENTS GUIDE

2.1 Learning from Experience

While the ORG attempts to anticipate future owner-operator needs, continuing incorporation of lessons learned from previous experience remains an important element of ORG development and maintenance philosophy. More importantly, the ORG draws upon decades of experience in designing, licensing, constructing, and operating LWRs to support owner-operators in the evaluation of advanced reactor designs.

If advanced reactor developers can leverage the materials research and development, the operating experience, the supply infrastructure, the licensing infrastructure, and other knowledge by-products of LWR construction and operation to expedite the process and make it more cost-effective, then advanced reactors have a much better chance of reaching commercialization and providing long-term economic benefits. The following topics were considered in the development of the ORG, as they apply regardless of technology or mission:

- Operational and deployment flexibility
- The emerging smLWR market – and its customers
- Construction methods and construction planning
- Cooling water demands
- Passive safety system design
- Design and operating margin
- Seismic isolation
- Planning for obsolescence
- Designing for reduced radiation exposure
- Designing for inspection, maintenance, repair, and replacement
- Designing for decommissioning

2.2 Other Sources of Requirements

The ORG does not aim to aggregate all applicable requirements associated with design, construction, licensing, operation, and decommissioning. Accordingly, existing standards, regulatory guidance, and industry practices will still need to be incorporated into owner-operators plans, with attendant modification for the advanced reactor design. Site design (e.g., designing site drainage for maximum predicted precipitation, potential flood waters, and runoff from higher topography) is a good example.

The primary resources to guide the reactor developer and the owner-operator are the latest version of the URD document (EPRI, 2014a), the European Utility Requirements for Light Water Reactors Nuclear Power Plants (EUR, 2012), USNRC Guidance for Developing Principal Design Criteria for Non-Light Water Reactors (USNRC, 2018), and USNRC Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NUREG-0800) (USNRC, 2017).

Also, the ORG is aligned with relevant international standards and applicable EPRI products like the Siting Guide (EPRI, 2015a), Managing Digital I&C Obsolescence (EPRI, 2014b), New Plant Turnover Guide (EPRI, 2016c) or Emergency Planning Zone Evaluations for Small Modular Reactors (EPRI, 2016d). For guidance regarding uses of nuclear power beyond large-scale electricity generation, the ORG makes use of various studies, including those done by EPRI (EPRI, 2004), Idaho National Labs (INL, 2011a; INL, 2011b; INL, 2011c; INL, 2012; INL, 2013), and the Joint Institute for Strategic Energy Analysis (JISEA, 2016).

Because the combined volume of information contained in these documents above, is far beyond what could be accommodated in the ORG guidelines, the more detailed guidance is left out of ORG. The ORG is intended to provide high-level guidance, documents general lessons learned, and incorporates requirements more appropriate for advanced reactor technologies.

2.3 Organization

Where possible, the tier structure of the ORG is adapted from that used for the URD. Figure 2-1 illustrates the ORG structure described in this section. The ORG is organized as follows:

- ‘Policy Statements’ and ‘Aspirational Goals’ are presented before the three Tiers and provide guidance generally applicable to advanced reactors as a whole. These represent high-level goals for advanced reactor technologies, and answer the question “What is an advanced reactor?” and “Why build one?”
- Tier I provides broad Categories for grouping the lower level Tier II and Tier III requirements. The Categories are introduced to briefly summarize the types of requirements contained in the category.
- Tier II provides high-level guidance intended to support the design, construction, operation, and economic case of advanced reactors in general, and in service to particular missions. The principles used are adaptable to new missions and new technologies that are not yet developed. This tier answers the question “What could an advanced reactor accomplish?” Each Tier II requirement stems from one Tier I Category.
- Tier III provides technology-level guidance for a selected set of reactor technologies intended to guide, but not hinder, reactor design. These are detailed requirements which take advantage of experience applicable to specific reactor types; they answer the question “How will an advanced reactor accomplish its goals?” Each Tier III requirement stems from one Tier II requirement.

More detailed requirements are beyond the intended scope of the ORG and are left to the developer/vendor and owner-operator to define and maintain. Under this paradigm, the combination of the higher-level ORG (Tiers I – III) requirements and the site- and design-specific requirements collectively comprise a complete requirements document for the owner-operator.

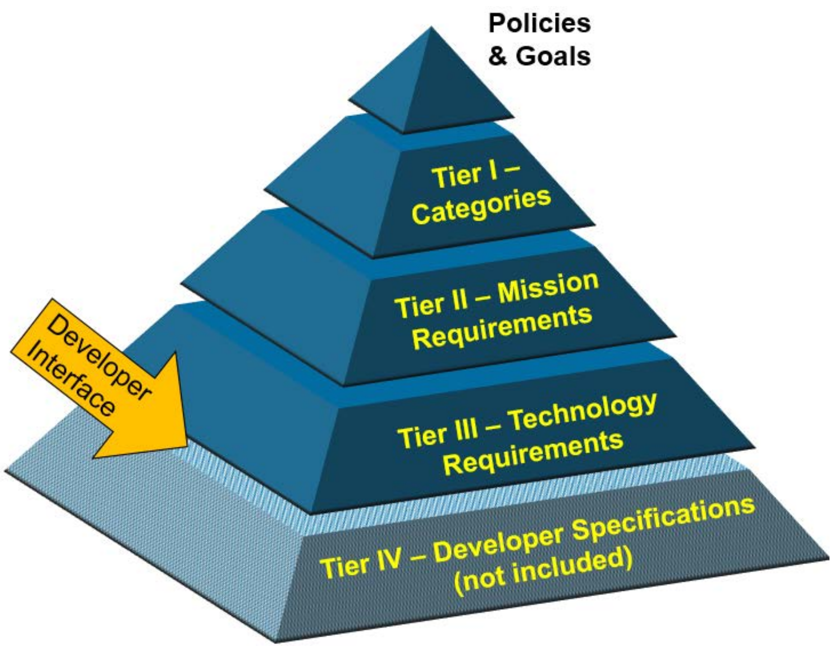

Figure 2-1
ORG Structure

2.4 Acceptable ORG Requirements

To maintain the purpose of the ORG and to ensure requirements do not expand the scope of the document or unnecessarily constrain technological innovations, several "rules" have been applied to the generation of requirements in the ORG. These rules should be maintained and applied for future revisions, with appropriate modifications as the document evolves.

1. It is acceptable (though not required) to repeat (or come close to repeating) an existing regulation, especially where the regulation or regulatory guidance is internationally relevant.
2. The level of detail should be limited in higher tiers to facilitate high level understanding and to promote the technology inclusivity of the ORG. Requirements should appear at the lowest appropriate level.
3. A requirement should represent a single coherent thought. Requirements should be split into two (or more) individual requirements as needed to maintain clarity and coherence.
4. Requirements should avoid constraining innovation and design solutions to the extent possible. They should be based on function or objective for the owner-operator, or they should prompt a solution to a known technical issue. The requirements should communicate the basic need of the owner-operator but leave it up to developer to create the technical solution.

5. To the extent possible, prescriptive, technology specific requirements should be left to the owner-operator and/or developer/vendor to develop and maintain.
6. Requirements for specific missions/technologies should be reviewed to determine if:
   - The requirement should be generalized for all missions or all technologies; or
   - An analogous requirement (i.e., similar but not generalized) for other missions or technologies is needed; or
   - An analogous requirement may exist but cannot be articulated for a given mission or technology. In these cases, a requirement should be established in as general terms as needed to produce a coherent thought. The alignment column can then indicate the source of the ambiguity and what may be required to resolve it. This requirement effectively serves as a placeholder for further development in a subsequent version of the ORG.
7. Tier II level of detail: Numerical values for requirements should be used carefully and avoided where possible. In lieu of specifying metrics numerically, requirements should identify that the owner-operator must define their expectation in sufficient depth to avoid misunderstanding their needs. Target values could be included but should be identified as such.
8. Tier III level of detail: Similar to Tier II, Tier III requirements should, in general, represent good solutions and best practices from previous designs, but without prescriptive language that restricts innovation. The driver for the previous solution should form the “basis” of the requirement and the best practice should reflect the “alignment” category, as reflected in the corresponding Tier II requirements within the ORG text. The requirement should indicate which design issues need to be addressed, not how to address them.

2.5 Differences from Previous Guidance Documents

The ORG shares many common purposes with the URD, EUR, and other existing guidance in providing clear and agreed upon expectations for new reactors. The URD’s structure and, to a limited extent, content, were utilized to the maximum extent practical in the initial development of the ORG. However, the broader applicability in terms of technologies, missions and audience warrants departure from these examples.

The URD defines evolutionary requirements for a well-developed technology with decades of operating experience (OE) serving one well understood mission. The ORG provides guidance for multiple missions and multiple reactor technologies with very little directly applicable OE. Also, the ORG anticipates a desire for flexibility in operations and even in variable missions.

For these reasons, it is neither possible nor desirable for the ORG to go to a great level of detail in terms of defining specific requirements. To this end, a key difference between the ORG and many previous advanced reactor guidance documents is the intent of the requirements. Whereas other reactor design and development requirements generally invoke “shall” statements and are intended to present true requirements by which all applicable reactors are to abide, absent strong justification, the ORG requirements comprise “should” statements, and therefore do not represent true “requirements” in the traditional sense. Instead, the ORG guidance is intended to inform decisions and ensure that new or different solutions and approaches are visible, documented and justified.

2.6 Emphasis on Key Issues and Challenges

The ORG contains requirements intended to address major barriers, challenges, and gaps associated with the commercialization of advanced reactors. These are highlighted below.

2.6.1 Flexibility

The uncertainty of future energy demands, and the potential scale of the opportunity justify solutions that reliably fulfill several missions or can adapt to changing circumstances. Reactors that deliver flexibility in deployment, operation, and production will distinguish themselves in adapting to uncertain markets of the future.

2.6.2 Cyber Security

The concern for malicious acts targeting information systems has become a critical issue for nearly all commercial endeavors and in all public infrastructure. Nuclear power plants represent large capital investments and are sometimes key nodes in infrastructure networks. Maintaining cyber security is essential to the continued security of any large asset and most existing installations have been forced to apply retroactive solutions to facilities that either pre-date most digital technologies or were built when cyber security threats were much less prolific. Cyber security should be inherent in the design to ensure that advanced reactor facilities are hardened against the cyber threats of today and tomorrow.

2.6.3 Constructability

Construction timelines, labor costs, construction productivity, rework and material costs can combine to shift a new reactor project from economic promise to financial burden. Modular construction techniques have been employed to reduce on-site construction efforts and increase the confidence in construction timelines, but these efforts by themselves are insufficient to provide confident cost and schedule estimates. If done improperly, modular construction techniques can increase the risk to a new reactor’s construction. Advanced reactors will need to be manufactured and constructed with techniques and management practices that promote success well in advance of first concrete.

3
ORG APPLICATION AND USE

The following sections provide insight into the use of the ORG including information on how to initiate revisions to the ORG, possible interactive methods of presenting the ORG content in future revisions, and a pilot program that was used to assess the compatibility of ORG requirements with vendor requirements.

3.1 ORG Revisions

EPRI has published the ORG with the intent to revise it as necessary based on feedback from the advanced reactor community. The ORG is a living document, and stakeholder input is encouraged for the continual adaptation of the document to industry needs.

3.2 ORG Requirements Format

The ORG front matter is provided as a standard electronic document. The ORG Policy Statements, Tier I Categories, and Tier II and Tier III requirements are also provided in an electronic format, which can be imported as part of an interactive electronic database (in lieu of using a traditional printed format).

3.3 Pilot Program

The last stage of development for ORG Revision 0 included a "pilot program" wherein two volunteer advanced reactor vendors (TerraPower, LLC and X-Energy, LLC) utilized a draft ORG to interface with their existing functional requirements. The goal of the pilot program was to take requirements from the ORG and tie them to vendor functional requirements in order to:

1. Validate that ORG requirements are reasonable and achievable;
2. Validate that ORG requirements do not unnecessarily constrain design;
3. Validate that low-level ORG requirements are traceable to high-level requirements;
4. Validate that the ORG format is easily applied to common requirement management software packages used by reactor developers and vendors; and
5. Show that advanced reactors have novel, robust approaches for meeting the fundamental owner-operator needs.

OWNER-OPERATOR REQUIREMENTS GUIDE (ORG) FOR ADVANCED REACTORS, REVISION 1

The following is the ORG Revision 1 in its entirety.

ORG Executive Summary

The Advanced Reactor Owner-Operator Requirements Guide (ORG) is a product of EPRI's Advanced Nuclear Technology (ANT) Program. The ORG is intended to illustrate the expected benefits of advanced nuclear technologies to potential owner-operators, and the public at large, facilitating the development and growth of the industry. The ORG is also intended to provide guidance to owner-operators for how to be successful in designing, building, and operating an advanced nuclear reactor while capitalizing on the expected benefits of these technologies. Lastly, the ORG is intended to communicate the expectations and desires of the owner-operator for reactor design, facilitating dialog between the potential owner-operator and the reactor vendor at an early stage in the design process. This will help ensure reactor vendors design a reactor that: (1) meets the needs of the owner-operator in an early iteration of the design, (2) avoids an expensive and time consuming iterative process, and (3) meets fundamental licensing expectations.

The highest level of guidance provided in the ORG are the 'Policy Statements' and 'Aspirational Goals'. Policy statements act as philosophies that should be embodied by advanced reactors and indicate broad areas in which advanced reactors should provide advantages over traditional reactor designs. Aspirational Goals are specific, ambitious characteristics that, if achieved in the future, will provide advanced reactors with distinct, measurable advantages over competing energy sources in the reactor's market of choice.

After the Policy Statements and Aspirational Goals, the ORG is organized into three Tiers. Tier I provides "Categories" into which lower-level requirements may be grouped. Tier II provides high-level guidance intended to support the design, construction, operation, and economic case of advanced reactors, and in service to specific missions. A mission is the desired end product of the reactor, such as electricity generation or radioisotope production. Tier II requirements are intended to be technology-inclusive, meaning the requirements do not assume a particular type of reactor design. Additionally, Tier II requirements are not concerned with specific components or equipment, but focus on processes, design philosophies, and other high-level objectives.

Tier III provides technology-level guidance for a selected set of reactor technologies intended to inform/guide, but not hinder, reactor design. Tier III uses lessons learned from the construction and operation of traditional light water reactors (LWRs) and experimental advanced reactors to provide this guidance. Tier III requirements are separated by the technologies to which they apply.

ORG Revision 1 Checklist

Revision 1 introduced the addition of a checklist tool, as a way of enhancing the utility/value of the ORG. The main purpose of this checklist is to offer utilities and other potential owner-operators an easy-to-use option for the ORG, as it identifies key guidelines for the advanced reactors discussed in this ORG Revision 1 document. It is also intended to serve as a screening tool and to help evaluate the completeness of the guideline. The content of this checklist is found below.

The proposed advanced nuclear reactor design and deployment strategy should be **innovative**.

- Where properly demonstrated and justified by cost and/or schedule savings, the designer should use advanced construction techniques such as additive manufacturing and robotic welding to build a plant that can be deployable in a variety of environments.
  - Difficulties with advanced techniques should be anticipated.
  - Code and standard acceptability of advanced techniques should be justified.
- First of a kind design features should be justified and demonstrated by prototype or laboratory testing.
- The use of standardized and market available components (commercial off-the-shelf [COTS]) is preferred wherever advanced technology is not key to the design.
- Proven computerized design tools should be included in the design process.
  - Verification and qualification of new analysis tools should be accomplished early.
- The design should employ modular construction considering constructability and providing flexibility to accommodate schedule deviations.
- The dependence on active safety systems should be minimized in favor of passive systems.
- Use of digitalization and simple human-machine interface (HMI) is preferred.
  - Calibration and maintenance should not interfere with plant operation.
- The use of robots in maintenance activities should be considered.
- Modern technologies (fiber optic networks, wireless, distributed antenna systems) for data transmission should be used.
  - The capability for adding remote sensors should be provided.
- The design process should incorporate cybersecurity considerations: any cybersecurity vulnerabilities should be identified, and defense-in-depth approaches should be planned.
- The I&C systems for safety and control should be physically isolated from outside input.
- A cyber-security program should be developed to address changes from development throughout the life of the plant, including construction.
- Digital systems for instrumentation and control should be developed, verified, and tested according to international standards.
- The reactor designer and owner-operator should plan for obsolescence risks during the design phase and mitigate it during the reactor life, by identifying a replacement strategy.
- Diversification of the plant output (heat, actinide burning, and hydrogen production) should be considered.

- The plant's design should allow following a load profile that is appropriate for the specific applications and should be remotely dispatchable for load following.
  - Load following may be accomplished by changing the reactor thermal power or by redistributing the plant power to alternative uses (e.g., hydrogen production when electrical demand is low).

The proposed advanced nuclear reactor should be **economically viable, and the investment should be adequately protected.**

- The owner/operator should actively engage with the public to gain trust and credibility to foster positive public relations.
- The reactor designer should provide a detailed cost estimate for the entire project and update periodically as the project evolves.
- The owner-operator should implement a risk mitigation strategy during planning, construction, and operation to protect the investment.
- Design, construction, procurement, inspection, testing activities, and deployment time should be included in an integrated schedule.
  - Each activity should be planned and scheduled with the level of accuracy defined before starting the project and as appropriate for the current phase of the project.
- Schedules should be consistent with the plant construction experience.
- The capital cost and the lifetime levelized cost should be estimated with a level of accuracy identified as appropriate for the current phase of the project.
  - These costs should be competitive with the lowest priced, equivalent scale generating method in the local market where the advanced reactor will be deployed.
- An ongoing discussion between the owner-operator and construction contractor should begin early in the conceptual design phase.
- Conservatism in the design should be identified and monitored to avoid buildup of excess conservatism and should be evaluated and eliminated where not necessary for safety or investment protection.
- The safety and non-safety areas of the plant should be separated to achieve lower costs in non-safety related areas. The safety related portions of the plant should be minimized.
- Plant operation should be resilient against postulated events.
- Single point vulnerability and reliability analysis should be performed in order to minimize economic losses.
- Critical equipment should be protected from credible natural or man-made hazards. The potential for outlier events should be considered.

- The reactor designer should distinguish between components intended to be replaceable and those that are intended to be qualified for the entire life of the plant.
  - For the former, a means for ready replacement should be included in the design.
  - For the latter, a strategy that considers the impact of an unexpected replacement should be developed.
  - Use of replaceable components may be desirable to reduce initial capital cost and reduce obsolescence risk.
- The design should consider possible disruption in the supply chain and allow for flexibility in deployment, operation, and product.

The proposed advanced nuclear reactor **design and licensing strategy** should facilitate a streamlined process.

- The design analyses should use proven methods and conservative assumptions, taking into account postulated and severe events, and should establish safe shutdown and cooling with safety-related equipment only.
- The design should consider the economic and environmental requirements for decommissioning.
- The reactor designer should anticipate first of a kind (FOAK) licensing challenges and develop mitigation strategies.
- The licensing basis should avoid unnecessary detail that would unduly constrain operational or construction flexibility without affecting safety.
- The design should be as simple as possible, minimize the vulnerability as well as susceptibility to initiating events.
- Probabilistic risk assessment (PRA) tools should be used to evaluate severe accident risk, including internal and external events. The PRA assumptions should be periodically validated during the plant's life.
- The design should include means to control the release of radioactive materials during operation and severe accidents.
- The reactor designer should account for human-made hazards as well as natural occurring events, and develop the technical basis for postulated and severe accident management, such as procedure guidelines, emergency procedure guidelines, and severe accident management program.
- The reactor designer should communicate with the owner-operator to assure that the design features, selected site, and implementation plan are appropriate and consistent.
- The reactor designer should assist with the implementation of a licensing plan and support the license application and review.
- Deviations from current regulatory requirements should be justified technically if financially advantageous.

- A set of principal design criteria and any deviations from current requirements and guidance should be established and documented.
- The plant design should allow enough time for the operator to evaluate the plant conditions.

The **construction process** should be efficient and adequately planned in advance.

- The owner/operator and reactor designer should obtain input from a construction contractor early in the design process.
- The constructability review program should inform design decisions to optimize construction cost, schedule, risk, and future operability and maintainability.
- The design approach should allow realistically achievable construction tolerances.
- The reactor designer should classify the structures, systems, and equipment with respect to the nuclear safety function, and with respect to their ability to withstand the effect of postulated events.
- The reactor designer should consider the construction experience in previous nuclear and non-nuclear projects.
- The designer should allow the flexibility to use updated industry codes and standards.
- Design decisions regarding the balance between site and off-site construction should consider logistics (e.g., transportation, availability of skilled workforce, weather).
- The site material control program should be in place prior to accepting applicable deliveries.
  - The quantity and location of components and bulk commodities should be tracked.
  - Preventive maintenance of components in storage should be tracked.
- The site construction plan should provide sufficient lay-down areas to accommodate planned and delayed construction schedules.
- If multiple units in a staggered build (i.e., all units are not built at the same time) are planned:
  - The effect of construction on adjacent operating units is evaluated.
  - Shared services (e.g., dry fuel storage, service water, fire water) should be designed to be shareable from the start, rather than retrofitted with each new unit.
- The constructor chosen by the owner-operator should have a significant amount of previous experience serving as the EPC firm for large industrial construction projects.

Regarding **maintenance and operability and quality assurance (QA),** the proposed advanced nuclear reactor should observe the following guidelines.

- For each plant design, a standard set of operating and maintenance procedures, as well as training materials and simulators should be available.
- The reactor designer should take into account decommissioning, try to minimize the amount of waste produced, and should not assume the availability of centralized facilities for waste storage.

- The security of the plant should be simplified and improved (e.g., minimizing the number of control points that access the plant), simplifying the actions required to secure the perimeter and minimizing the size of the guard force.
- The QA program should be established early.
  - The reactor designer, constructor, and owner-operator should each define the QA program requirements and ensure that the program is consistent with the appropriate regulator-endorsed requirements.
  - Clear expectations for maintaining documentation should be established.
  - Commercial grade dedication should be used where technically and financially justified.
  - The owner-operator should review and audit the reactor designer and original equipment manufacturer (OEM) QA programs.
  - The QA manuals and procedures should be based on those already successfully used in comparable nuclear facilities.
- The designer should develop and implement Design Reliability Assurance Program (D-RAP) based on Operating Experience and PRA. D-RAP should provide information to the future owner-operator for plant reliability assurance activities.
- The reactor designer should classify the structures, systems, and equipment with respect to the nuclear safety function, and with respect to their ability to withstand the effect of postulated events.
- Where possible, seismic testing and environmental qualification should be performed at the system rather than the component level.
- The design should identify all applicable codes and standards.
- The designer should pursue commonality in material where possible. The materials chosen should have demonstrated high corrosion/erosion.
- Industry codes should not be considered sufficient to demonstrate adequate performance if the service conditions cannot be supported by previously accepted practice.
- The fuel system should demonstrate a benign behavior over a range of conditions that could be experienced during operation and postulated event conditions
- The reactor designer and owner-operator should make the information turnover process a part of original EPC contract.

ORG Chapter 1 – Description of Policy Statements and Aspirational Goals

1.1 Introduction

The highest level of the ORG consists of Policy Statements and Aspirational Goals.

Policy statements are high-level principles for advanced reactors. They apply to all missions and technologies and are useful communication tools for all stakeholders. Each ORG requirement stems from one or more policy statements, and the most desirable features of advanced reactor technologies are those that most effectively realize these statements.

The aspirational goals consist of high-level performance and design features which prospective advanced reactor customers have identified as providing significant value. Aspirational goals are distinct from policy statements in that the policy statements are considered essential for the successful deployment of any advanced reactor design, whereas the aspirational goals are capabilities hoped for in the future.

1.2 Policy Statements

A. Constructability – Focus on manufacturability, transportability, work efficiency, and construction duration. Similar to maintenance, practical issues relating to the construction should be considered in the early stages of design. Applicable experience and lessons learned from both recent nuclear and non-nuclear construction projects (major infrastructure and process plants) should be applied. A design that is difficult to construct increases risks of cost escalation and schedule delays. The plant owner-operator is concerned with meeting targets of cost, quality, schedule, and risk mitigation. Predictability in construction enhances the owner-operator's confidence in meeting these targets and is nearly as important as lowering costs.

B. Decommissioning – Envision end-of-life activities including plant decontamination and decommissioning. Similar to design and maintenance, practical issues relating to decommissioning of the plant should be considered in the early stages of design. A design that is difficult to decommission could create regulatory liabilities and require that more money be retained in the decommissioning fund for costs incurred after useful economic life has ended. The use of automation and robotics to support decommissioning could be greatly beneficial and should be accommodated into the design of the facility.

C. Design Margin – Provide enhanced margins to failure of fission product barriers compared to current reactors and current licensing requirements. Design margin is also desired for operational and performance considerations. These enhancements should provide greater operational flexibility for addressing emergent problems encountered following completion of design and during construction and operation.

   Nuclear power plants, particularly in the U.S., have experienced degradation of material condition resulting in an unacceptable reduction in margin to regulatory limits. Greater performance and safety margins in advanced reactor designs should allow changes in regulatory margins with minimal physical modifications and upgrades to address them. Greater margins should also enhance economic performance by allowing for operational modification throughout the life of the reactor and will increase flexibility for dealing with failures and other unforeseeable issues.

D. Economics – Effectively compete with other (nuclear and non-nuclear) technologies to fulfill the specified mission(s) based on evaluation of costs using clearly justified assumptions, consistent with best cost estimating practices for capital, operating, maintenance, and fuel.

- Lifetime costs should be considered but may not be relied upon alone to justify the plant's competitiveness (i.e., a 50-year cost recovery is unlikely to be acceptable even for a hypothetical reactor with a 100-year life). At the same time, a long plant life may offset high initial capital costs, especially if replacement costs/decommissioning of the competing technology are considered.
- Tradeoffs affecting competitiveness should be identified.
- Assumptions should be clearly identified and justified.
- Availability, reliability, and capacity factor have major effects on economic performance.
- Ongoing major societal/political changes should be addressed in economic models.
- Economics should be based on a whole-plant model.

Regardless of any other areas in which the reactor may excel (safety, performance, environmental protection), if the reactor is not competitive in its chosen market, no owner will pursue it. It is possible for future regulations, resource availability, and market demand to significantly impact the economic performance of the reactor. Thus, a forward-thinking approach should be used to determine the economic strategy of the reactor.

E. Flexibility – Support a wide range of needs and desires with regards to operations, deployment, and product without sacrificing quality or competitive advantage. Designs should be adaptably deployed and operated under challenging, changing, or uncertain external conditions and constraints, and they should reliably fulfill one or more missions. EPRI report 3002010479 specifically addresses the concept of flexibility for advanced reactors (EPRI, 2017c).

- Operational flexibility refers to the ability of a reactor to be operated under a range of conditions. Most commonly, it is equated to the ability of a power plant to adjust to grid conditions and support power quality via load following and grid frequency control. However, there is increasing recognition of other desirable attributes of operational flexibility. As a result of this, other components of operational flexibility include the ability of a reactor to use various types of nuclear fuel, being able to integrate with technologies such as topping cycles and energy storage, or the ability to operate in "island mode."
- A plant that is flexible in where or how it can be deployed will increase the number of potential sites.
- A reactor that is flexible may be repurposed if a more profitable market emerges.
- A plant that is flexible can justify or adapt deployment and operation under challenging or uncertain external conditions and constraints, operating when it may otherwise need to shutdown, increasing revenues and reducing financial risks.

F. Good Neighbor – Provide an overall benefit to the surrounding community through protection of the environment and other benefits, while providing a dependable source of economic well-being. The design and siting of the reactor should consider the needs and objectives (economic, social, etc.) specific to the community in which the reactor is deployed.

- The jobs provided will stimulate a local economy and create growth.
- A nuclear reactor will improve the quality of the air and water by displacing other energy sources.

The support of the surrounding community will be key to every proposed advanced reactor project. Many otherwise promising infrastructure projects have failed due to a lack of public support. Local and general considerations should be taken into account in design, siting, construction, operation, and decommissioning. Steps should be taken to:

- Emphasize the societal benefits of nuclear power sources with respect to greenhouse gas emissions and absence of air pollution in electricity and process heat generation. Climate change is generally recognized as a significant societal risk, and nuclear power's advantages should be recognized.
- Educate the public on the safety case for nuclear power in easily understandable terms beyond the traditional probabilistic metrics used by regulators.
- Demonstrate a plan for used fuel disposal and reactor decommissioning for advanced reactor designs, which may include the dispositioning of the legacy inventories of used fuel resulted from the operation of existing commercial nuclear reactors.
- Define the community benefits (or minimize the liabilities) of placing advanced reactors near population centers or near industrial facilities.
- Minimize the "footprint" of the facility by considering societal impacts (e.g., traffic, visual aesthetics, and noise).

G. Human Factors and Automation – Human-machine interfaces (HMI) should be simple and intuitive, be consistent across all system displays, and consider remote or multi-unit operation where permitted by regulations. Any interaction between human and machine creates opportunities for human error. These errors can be minimized by the following.

- Making the HMI as simple and easy to use as possible.
- Making the HMIs consistent throughout the plant.
- Building HMIs with possible future capabilities in mind to support Aspirational Goals.
- HMIs should be customizable to allow conformance to societal norms in different countries (e.g., reading direction, significance of colors).
- The use of automation should be optimized to balance the reduction in human errors with reliability, staffing considerations, costs, etc.

H. Innovation and Proven Technology – Innovative features will be used where justified to meet the mission but should be demonstrated where necessary prior to commercial deployment to reduce licensing and investment risk. In other words, FOAK or immature technologies should be used only where they provide a clear competitive advantage and manageable risk. Appropriate measures should be taken commensurate with the accumulated operating experience of each new technology by planning for extensive testing or prototype demonstration of FOAK features. The long-time horizon for fuel and materials qualification is of particular concern.

Innovation could appear to be at odds with the use of Proven Technology; however, both have a prominent place in the ORG design philosophy. The use of proven technology supports the use of innovative features. Some basic technical solutions have been proven in LWR experience and are directly transferrable to advanced reactor designs. Other industries (e.g., aviation, petrochemical, automotive) also have vast experience related to robotics and digital instrumentation and controls. In many cases, the technologies used in other industries are more advanced than those used in the nuclear industry. The lessons learned from decades of LWR operation regarding materials and components used in certain applications should not be discarded when designing advanced reactors; rather, such lessons learned should be thoughtfully considered and applied throughout the design process – even applied directly to innovative technologies implemented in the design. This will allow the lower levels of the design to have a pedigree of operating history that proves the adequacy of the component in the desired application, capitalizing on previous experience and investments, and increasing the reliability and safety of the reactor.

I. Investment Protection – Ensure that the plant is protected from extensive, costly, and potentially irrecoverable damage.

- Large, critical components that are expensive to repair and replace should be protected from damage in realistic scenarios. In particular, balance-of-plant components should be evaluated since they often are relegated to lower priority in a nuclear plant. If the reactor designer is not familiar and has insufficient resources to evaluate balance-of-plant issues, the owner-operator should ensure other entities are brought in to fill the gap.
- The design should include features that ensure forced shutdowns not due to major equipment problems (e.g., shutdowns due to neutron poison injection) are recoverable without a prolonged shutdown period.

J. Licensing Preparation – Address current applicable regulatory expectations and provide, at a minimum, equivalent safety provisions appropriate to the technology. Design features unaddressed by or inconsistent with current regulatory expectations may be made practical with advanced reactors (e.g., remote operation). These should be noted as increasing regulatory risk and should have a carefully developed rationale and justification to present to the regulator.

- It is important for potential owner-operators of advanced reactors to consider regulatory issues early in development so that time and money are not wasted developing a design that cannot be reasonably expected to be licensed to operate.
- Analytical methods should be developed in a manner that will give regulators an assurance of safety, accounting for the current lack of experience with advanced reactor technology.
- Pre-application discussion with regulators is essential to identify expectations.
- The key safety basis elements should be effectively justified, but defense in depth must still be addressed.

K. Maintainability – Accommodate access for personnel and/or robotic devices to efficiently accomplish maintenance. Plant arrangements should provide transfer routes for replacement of major components without removal of major structures, systems, or components (SSCs). Additionally, procedures should be put in place to ensure the difficulty of maintenance activities is minimized.

- The design of SSCs should consider inspectability, testability, and expected and unexpected replacement.
- All health and safety hazards to personnel, including radiological exposure, should be considered (e.g., components and systems requiring frequent maintenance should be located in low-dose areas of the plant, industrial safety should be given equal consideration to radiation protection).
- Replacement may be more economical than repair.
- Maintenance facilities should be considered early in the design. Planning for the adaption of construction facilities into long-term maintenance facilities can provide significant cost savings, and the inadequate planning for maintenance facilities can lead to higher costs for the life of the plant.
- Design controls should be in place so that design information is maintained.
- Special emphasis should be placed on the use of automated maintenance equipment and robotics in order to reduce manpower requirements and exposure. However, any use of such equipment should include considerations for repair and retrieval.

When designing any product, system, or facility, it can be easy to focus on increasing efficiency and performance while ignoring the practical problems of how the design would be serviced. Such issues should be considered in the early stages of design, so that maintenance may be completed quickly and efficiently (minimizing cost), and its effect on plant operation can be minimized.

L. Operational Sustainability – Account for long term management of key factors in operation and maintenance. The case for any nuclear technology will rely on establishing confidence in the viability of the technology for a certain time period, specific to each owner-operator. If no thought is given to the future availability of specialty materials, the continued technical capabilities to support the design, or the provision of required spares, the reactor could be forced to shut down prematurely due to unanticipated costs. Early decommissioning is likely to detract from the economic case of any reactor, having an adverse economic impact on stakeholders and resulting in the loss of benefits provided by the reactor. Key factors to consider include:

- Ensuring supply chains or appropriate mitigation methods are in place to reduce supply chain risk.
- Implementing programs to ensure continuity of technical cognizance for reactor design and specialized components.
- Managing critical spares.

M. Quality Assurance (QA) – Design, development, construction, and maintenance should be performed in accordance with nuclear quality program requirements, including configuration management, training, etc.

- Due to the unique nature of and hazards posed by nuclear energy systems, effective implementation of QA programs is of paramount importance. Organizations involved in design, construction, or operation should have well established, successful QA programs.
- Programs developed for LWRs should be evaluated for applicability to advanced reactors, and program modifications should be made where necessary.
- QA programs should be applied consistently with regulatory requirements, and in a manner that provides confidence that the safety functions will be fulfilled, without unduly hampering the design process. A graded approach should be applied, commensurate with the function of the SSC. Modern design processes depend on validated software solutions, making software QA particularly important. A graded approach should also be applied to ensure that the appropriate quality measures are in place early in the design process.
- Organizations involved should implement a "quality culture" among workers.

N. Simplification – Minimize the number of SSCs (including interconnections, such as conduit, cable, piping, etc.) to reduce complexity of operation and to reduce capital, operating, and maintenance costs. Emphasis should be placed on limiting the complexity and number of safety-related components. One method of simplification could be to employ passive means for reactor stabilization and cooling during operational and abnormal conditions. Simpler designs will result in:

- Increased safety (the plant's ability to mitigate potential threats the reactor may present to the health and safety of plant personnel, the local community, the environment, and society as a whole) and improved performance of the reactor due to fewer failure modes and higher reliability.

- Reduced costs due to reduced scope and commensurate simplification of construction as well as reduced maintenance requirements.
- Reduced burden on operators and reduced opportunity for human error with the use of passive safety systems.
- Reduced costs due to minimizing the number of safety-related SSCs by maximizing the ability to use commercial grade materials and takes advantage of state-of-the-art innovations for support and balance-of-plant systems.

O. Standardization – In order to leverage design effort, facilitate licensing, distribute support costs, benefit from operating experience, and expedite construction, successive plants should be standardized to the extent feasible. However, standardization should be balanced against the benefits of innovation. Standardized designs should not rely on specific components from specific suppliers; rather, they should be flexible enough to support variety in sourcing materials and components, where possible. Standardization allows for:

- The ability of supporting vendors to collectively service the industry by manufacturing equipment in bulk with dimensions, material properties, and other characteristics common across all plants.
- The ability of owner-operators to learn from the operating experience of many other plants, strengthening the knowledge and quality of the industry as a whole.
- Increased predictability of regulation for reactors with standardized components, as the collective operating experience provides assurance of safety for new reactors.

While standardization provides many benefits, the philosophy should be tempered by the idea that advanced reactors are fundamentally innovative. While standardization in equipment and components is preferred, there should still be room for flexibility in design. One possibility is to maintain a design stable for some period (as in a ship class) before implementing accumulated changes.

P. Threat Protection – Protect against internal and external physical and cyber threats that could credibly challenge the integrity of fission product barriers, provide unauthorized access to the fuel, or affect the availability of the plant to fulfill its mission. Such protection should:

- Not detract from nuclear safety.
- Minimize cost over plant life.
- Take advantage of passive means or inherent features of the design where possible to reduce the need for large security forces and active security barriers.
- Reduce reliance on guards because a guard force is one of the largest contributors to staffing costs.

It is the responsibility of those who operate nuclear technology to protect the public and the environment from the possibility of fission product release or disruption of critical infrastructure. However, advanced reactors should consider alternate means of ensuring such protection that are more economically favorable, and at least as effective as the security measures in place at existing nuclear plants.

Q. Waste and Used Fuel Management – Production and management of wastes should be considered during design and be consistent with anticipated regulatory requirements. Owner-operators should:

- Not assume the availability of off-site facilities for used fuel storage.
- Not assume any outside entity taking possession of used fuel during the life of the plant to allow for continued operation of the reactor.
- Manage waste and used fuel such that the effect on normal operations is minimized.
- Minimize inventory of difficult to manage waste streams.
- Provide radioactive waste forms compatible with and suitable for offsite transportation and disposal without extensive onsite processing.
- Account for prevailing public concerns with respect to waste and used fuel management.

The criterion for on-site storage of used fuel reflects the importance of decoupling reactor operations, including waste management, from external factors such as availability of offsite interim storage and permanent disposal facilities.

1.3 Aspirational Goals

The policy statements are general characteristics or philosophies which advanced reactors should satisfy, whereas the aspirational goals are specific characteristics or features that could be an important consideration for some potential owner-operators. Aspirations should be those goals that, through existing experience, owner-operators have identified as being highly desirable, though not necessarily required. In an evolutionary sense, current aspirations may become future customer "must haves" as technologies and business cases mature.

Aspirational goals are provided to illustrate the possibilities of advanced reactors. These are characteristics that owner-operators have expressed interest in for advanced designs. The aspirations are presented as "could" statements, whereas Tier II and Tier III requirements are mostly presented as "should" statements. The aspirations are not meant to set a standard by which all reactors must abide, but are appealing possibilities intended to capture the compelling attributes and opportunities that advanced reactor technologies offer.

The bold aspirations provided within the ORG are intended to raise the bar for advanced reactor design without adversely constraining commercialization efforts. Including such a wish list provides developers, vendors, regulators, and other stakeholders a view into desired features that may not be otherwise documented or communicated. Below is a list of aspirational goals, expressed by some in the advanced reactor community prior to, and during, the development of the ORG. Some of these have been demonstrated to various degrees in other industries but have yet to overcome hurdles in the commercial nuclear industry.

- Closed Fuel Cycle – Reactors could be designed to operate on a closed fuel cycle, or specialized reactors could be built to utilize used fuel from open-cycle reactors as fuel, effectively closing the fuel cycle. This initially became an attractive goal because uranium was thought to be in short supply. While uranium availability is no longer a large concern, a closed fuel cycle is still a more efficient use of natural resources (potentially useful energy is wasted in an open fuel cycle). Additionally, a closed fuel cycle is beneficial from a political/public relations standpoint. However, this may make the design more vulnerable to political or economic decisions outside the control of owner-operators.

- Dry (reduced water) Cooling – Although generally too expensive in the past, rejecting heat to the atmosphere has become more attractive for use in water scarce locales, and where water may be abundant but cooling use is restrained. Plants which efficiently reduce the water flow required to reject waste heat would have inherent benefits to many potential customers. Dry cooling would also reduce the plant's impact on the surrounding environment. If dry cooling is used, plant efficiency will be lower than for a water-cooled plant, so the benefits of dry cooling must be balanced with a reduction in efficiency. A hybrid cooling method could also be used for added flexibility (e.g., changing cooling method depending on the time of the year).
- "Hands-Free" Safety – Using passive safety features, reactors could be designed so that the period of time in which the reactor can remain safe after an event without operator action or off-site electric power is unlimited. No operator action or off-site power is required for the reactor to safely shut down and remain safe post-event. Because "unlimited" cannot be objectively demonstrated, a long-time requirement should be specified (e.g., 30 days). If hands-free safety is not feasible, designing to slow transients to lengthen available operator response time is an option.
- Guard-Free Security – The threat to a reactor differs widely around the world. It would be desirable for a reactor to be self-protecting such that the design alone is sufficient to meet safeguards criteria without an on-site security staff. In this case, armed response would be from local law enforcement. For very small remote reactors, hiring a security force would not be economically feasible, so guard-free security would be a necessity. In general, a design that reduces the security staff would also be beneficial. Considerations in implementing this goal are 1) protection against sabotage intended to take the facility out of service or spread radioactivity and 2) theft of special nuclear material.
- On-line Maintenance – Even older LWRs have been highly successfully in transferring many maintenance activities out of shut down periods. Some plants may reduce downtime by operating with restrictions (e.g., reduced power) with some equipment out of service for maintenance. In reactors with longer refueling cycles (or on-line refueling) the ability to perform on-line maintenance tasks on major components could greatly enhance the availability of the plant.
- On-line Refueling – Automated refueling processes which occur on-line can be achieved for some technologies. These methods have the potential to reduce the severity of fuel handling events and enhance the plant's availability.
- No Refueling – Certain applications for advanced nuclear plants (e.g., remote locales) become much more attractive if the plants do not need to be refueled for the entire lifetime of the plant. This would primarily be pursued for very small reactors.

- Remote or Autonomous Operation – Plants could be designed to be operated by personnel off-site or be self-controlling within certain constraints. This would greatly increase the siting options for the plant (e.g., remote locales with extreme weather conditions) and significantly alter the economics. Maintenance needs will require consideration. As plants move toward increased automation, it is expected that humans will begin to have a more supervisory role in maintenance and operations.
- Off-grid Operation – Current nuclear power plants are designed to operate while tied to a functioning, integrated electrical grid. There is increasing interest in using small advanced reactors which do not require offsite power supplied by functioning, stable grids, as dedicated power sources for critical infrastructure (e.g., defense facilities) in the event of a significant, sustained disruption of the grid.
- "Black Start" Capabilities – Current nuclear plants must have offsite power (i.e., a functioning electrical grid) to start up. A plant that can start up using its own resources, without the need to be supplied offsite power by the grid, would be helpful in restoring the electrical grid following a significant, sustained disruption. For remote plants, this is a necessity as there will not be another source of electricity from which to start the plant.
- Decentralized Power Generation – Electricity generating plants would have benefits to being sited at the distribution level. This would save resources on building transmission and would contribute to the decentralization of power. This would likely only be feasible for small reactors, and the challenges associated with siting a nuclear plant near or in population centers would need to be overcome.
- Fleet Licensing – In a fleet licensing approach, a design would be accepted for use at any site meeting certain criteria and would not require a separate technical design review for each site. This may become more feasible from a regulatory standpoint as safety cases for designs become simpler. This is particularly important for Small Modular Reactors (SMRs).
- Siting in Close Proximity to Population Centers – The success of advanced nuclear plants depends greatly on the ability to locate these reactors reactors in close proximity to population centers and co-locate with industrial facilities. Many of the old, small coal plants that were located in critical locations to support grid security and meet load requirements, have shut down due to economic or environmental considerations. Oftentimes, these plants were located near population centers and urban areas. The public and the regulator have to be convinced that the replacement of the older coal plants with advanced nuclear plants is beneficial to the health and safety of the public and the economy of the region. Process heat supply by advanced nuclear plants is only viable if the user is located in close proximity or co-located (otherwise the process heat losses become unacceptable).

ORG Chapter 2 – Description of Tier I Categories

Tier I of the ORG consists of 11 Categories in which all Tier II and Tier III requirements are sorted. The purpose of the categories is to increase the readability of the requirements by grouping requirements that pertain to similar topics. Each category has an underlying philosophy that governs why requirements of the type were included by the ORG authors (i.e., the overall benefits of meeting the requirements in the category).

The relationships between the Policy Statements, Categories, Requirements, and Attributes are explained below:

- **Policy Statements –** Policy Statements are overarching themes of the ORG that apply generally to all Requirements. Individual Requirements do not fall underneath a specific Policy Statement. It should be noted that there is inevitable overlap between the Categories and the Policy Statements as they convey many of the same ideas, but their functions within the ORG are different.
- **Categories –** Tier I, Tier II, and Tier III of the ORG are connected such that each Requirement in Tier III has a parent Requirement in Tier II, and each Requirement in Tier II has a parent Category in Tier I. The Categories exist to provide a convenient grouping of Tier II and Tier III Requirements, and do not provide specific guidance themselves.
- **Requirements –** Tier II and Tier III are comprised of Requirements. Each Requirement provides specific guidance related to some aspect of owning, operating, designing, or constructing an advanced nuclear reactor.
  - Each Requirement is assigned only one Category.
  - Although it is clear that many Requirements could fall into multiple Categories, the Category of each Requirement is chosen to maximize the similarity between Requirements within a Category and balance the number of Requirements in the Categories.
  - For example, if a Requirement could realistically fit in both a broad Category like "Licensing and Safety Analysis" and a more specific Category like "Materials," the Requirement is sorted into the more specific Category so that all Requirements pertaining to the more specific Category may be read together.
  - The broad Categories, like "Licensing and Safety Analysis", are then used to present Requirements that are more general in nature or do not apply to any of the more specific Categories.
- **Attributes –** Each Tier II and Tier III Requirement is tagged with one or multiple Attributes. The Attributes are very general aspects that must be satisfied (e.g., the reactor must be safe, the reactor must generate profit). The Attributes show the end results of implementing each Requirement (e.g., the reactor becomes safer, the reactor becomes more profitable).

The categories used, and the philosophies governing them, are discussed below.

A. Constructability – Constructability strongly affects capital cost, as it has major impacts on scheduling and technical risks. Decreasing the capital cost of nuclear technology is a major goal of advanced reactors. The purpose of the requirements in this category is to adopt lessons learned from recent large-scale construction experience to help ensure future construction projects are well executed and are ultimately successful. Major concerns are:

    - Learning curves for new workforce
    - Modularity
    - Qualification of suppliers
    - Construction site arrangement
    - Prevention of construction rework

B. Cyber security – Requirements in this category pertain to the protection of plant data systems and communications. In recent years, cyber security has become a large concern, particularly in relation to maintaining national critical infrastructures. These requirements are intended to help make plants more resistant to cyber interference.

C. Instrumentation and Controls – This category contains specific requirements for the instrumentation and controls systems. These systems are particularly important and represent many requirements, and therefore merit their own category. The ORG assumes that digital technologies will be fully implemented in advanced reactors due to their distinct benefits. However, the ORG does not preclude the use of analog or digital non-programmable control systems, especially for safety or post-accident monitoring systems. Major considerations are:

    - Sensors: Their ability to adequately characterize plant parameters and to provide accurate readings under the full range of plant conditions.
    - Digital displays, or Human-Machine Interface (HMI): Meeting the current state of the art for human factors engineering and support automation.
    - Reliability: The likelihood of any single component to fail.
    - Redundancy: The concept of having multiple components available to perform the same function to improve overall I&C system reliability.
    - Diversity: The concept of having redundant components with different operating principles, to improve the overall I&C system reliability by minimizing common mode failures. It should be noted that applying diversity means having the second best design of a key feature in the plant.
    - Independence: The concept of limiting interactions between redundant components so that the failure of one component is less likely to cause the failure of another or the system of which they are a part.

D. Investment – Deployment of a nuclear plant constitutes a major investment. Requirements in this category help decrease the risk associated with such an investment. Important concerns are:

- The initial investment must be justifiable by the competitiveness of the technology in the market in which it intends to operate.
- The investment must be viable based on long term supplies of commodities, etc.
- The design should include features which provide confidence in the protection of the asset (e.g., advanced monitoring techniques, protective features/isolations).

E. Licensing and Safety Analysis – "Licensing" and "safety" are grouped together because safety requirements form the bulk of licensing requirements. Regulators are concerned with protection of the public during events due to natural and man-made hazards (including fires, floods, extreme weather, etc.), so safety metrics must support the licensing requirements. Reactors are already extraordinarily safe against foreseeable events, but they benefit from features that maintain the fuel intact for any circumstances. Generally, this is proven with analyses or tests that support the safety criteria. Requirements in this category relate to both design and analysis.

F. Maintenance and Operability – These requirements are to make the plant easier to operate and maintain, which could result in reduced staffing requirements, reduced maintenance hours, and reduced opportunity for human errors. Major concerns are:

- Worker protection
- Ergonomics/human factors
- Access to components
- Component exchangeability and replaceability
- Standardization or equipment and procedures
- Remote maintenance and inspection (reduce dose, heat exposure, etc.)
- Remote operation of important components (reduce dose, heat exposure, etc.)

G. Materials – Selection of the materials used throughout the plant should consider:

- Materials qualification
- Materials selection based on availability and code acceptability
- Nuclear fuel
- Inert gases (heat transfer fluids, process gases, cover gases, fission product gases) and special materials (e.g., graphite blocks, graphite pebbles, control rod materials, coolants, coatings, etc.) that may not be traditional materials of construction or may have unique requirements for how they are employed in advanced reactor designs.

H. Physical Protection and Proliferation Resistance – Requirements in this category pertain to:

- The physical protection of SSCs against sabotage.
- Administrative and process controls that, if compromised, could simplify sabotage of reactor operation, or lead to damage of plant SSCs – from both a safety and an investment protection standpoint.
- The physical protection of nuclear materials against theft.
- The measures taken to ensure nuclear materials are controlled and accounted for to impede their diversion or misuse.

I. Quality Assurance – The ORG assumes compliance with applicable safety regulations and is not intended to ensure such compliance. Rather, the ORG QA requirements emphasize how a QA program may be implemented in a way that leads to a successful project lifecycle, from design to decommissioning. For example, maintaining accurate and current plant drawings is crucial to the success of any QA program.

J. Reliability and Availability – Different markets and missions have their own metrics for reliability and availability. Requirements in this category provide such metrics where possible and provide general guidance for increasing availability and reliability. Items of interest are given below:

- Anticipated equipment failures should be accommodated by the plant with no or minimal interruption in operation.
- Reactor design should achieve required availability metrics without undue assumptions for off-site support services (e.g., short term storage of fuel).

K. Seismic and Structural – Requirements in this category pertain to the design and analysis of plant structures. These requirements overlap with “Licensing and Safety Analysis”, but because there are many requirements that specifically apply to structures and seismic qualification, they merit a separate category. The following are examples of concerns that are addressed by requirements in this category:

- Many of these requirements pertain to the design and analysis required for seismic qualification. However, earthquakes are not the only hazard to structures that should be considered. Hurricanes, tornados, tsunamis, and human-made hazards such as airplanes should also be accounted for in the analysis.
- A classification system for SSCs should be created to ensure the analysis performed for each SSC is adequate relative to the application and importance of the SSC.
- The design of SSCs should be robust enough to allow flexibility in plant siting. However, the designer should not make an effort to make the base design of the plant suitable to the most extreme geographies (e.g., high seismicity region), as this would unnecessarily raise capital costs.

ORG Chapter 3 – Description of Tier II Requirements

3.1 Introduction

Tier II is the first tier of the ORG that begins to define specific requirements rather than high-level philosophies or policies. However, Tier II requirements are still high-level, meaning the requirements are broadly applicable to the entire plant or to major systems rather than specific components. Tier II requirements are also technology-inclusive, meaning requirements apply to a nuclear reactor of any technology type. The same Tier II requirement would be applicable to an SFR, an HTGR, or even an LWR. As a test of technology-inclusivity, Tier II requirements should be applicable to LWRs as well as advanced reactors even though LWRs are not explicitly covered by the scope of the ORG.

The first section of Tier II requirements presents requirements that are universally applicable to all missions. These requirements are both technology-inclusive and mission-independent, so that virtually any reactor built for any purpose should be capable of fulfilling these requirements.

Tier II requirements are segregated by the "mission" the reactor is intended to fulfill. A reactor's mission is related to the ultimate goal (output) of the reactor. The same reactor may serve multiple missions, either at the same time, or at different times throughout the reactor's operation. This differentiation by mission allows presenting a complete set of Tier II requirements that can form a basic idea of what the reactor is expected to accomplish without prescribing how it will be accomplished. The "how" is partially dependent on the reactor technology, so in organizing Tier II by mission, the objective of the ORG is to provide a useful starting place for achieving a predetermined goal without enforcing unnecessary limitations.

Each requirement in Tier II and Tier III is "tagged" with one or more attributes. An attribute is a broad reactor characteristic embodied by many specifications. Each attribute must be adequately fulfilled for a reactor to be viable. These tags should aid in mapping requirements for vendors who have organized their design requirements around high level functional requirements.

3.2 Attributes

As discussed in Section 3.1, requirements in the ORG are assigned attributes – broad, high level types of requirements that must be fulfilled for an advanced reactor to be viable commercially. The following five attributes should be satisfied for each mission discussed in Tier II for the reactor to meet advanced reactor objectives:

A. Safety (SAFE) – the plant's ability to mitigate any credible hazard the reactor may present to the health and safety of plant personnel, the local community, the environment, and society.

B. Performance (PERF) – the plant's ability to reliably carry out its mission. Requirements that satisfy this attribute mitigate risk relating to individuals, communities, or enterprises that rely on the reactor to perform its mission. For example, an electricity generating reactor should reduce the risk of blackouts or brownouts in the areas it services by implementing requirements that support performance.

C. Economics (ECON) – the plant's ability to offer a predictable return on investment for the investors and/or predictable consumer rates by providing reliable operation within controllable budgets. Investors and state utility commissions have common but also competing views. Requirements that satisfy this attribute mitigate the economic risks for all stakeholders, including the investors who receive profits, consumers paying for the energy, and the plant personnel who receive salaries. Advanced reactors offer an opportunity to reduce potential future backfits (i.e., post-TMI and post-Fukushima upgrades) by having fundamental features such as accident tolerant fuel and passive safety that are less likely to be affected by previously unidentified events.

D. Implementation (IMPL) – the processes, procedures, and practices relied upon during the entire life-cycle of the facility. Requirements that satisfy this attribute mitigate the economic and scheduling risks associated with the planning, design, construction, licensing, operation, maintenance, and decommissioning of the reactor.

E. Security & Non-Proliferation[3] (SEC/NP) – the plant's ability to prevent the loss of control of fissile and/or radiological material from plant, either through intentional or unintentional means. It also includes prevention of other adverse effects resulting from active physical and cyber threats initiated from within the plant or external to it. Requirements that satisfy this attribute mitigate the risk of releasing radiological material in a radiological sabotage event, and/or the risk of adversaries obtaining radiological material from the plant. Such requirements should be implemented through a "Safeguards by Design" mentality so that the design is simplified, robust, and secured with optimized security barriers and staffing.

3.3 Missions

The primary focus of this document at this time is on the electricity generation mission, but the ORG structure is intended to accommodate multiple missions in future revisions, including the four described below. This list is not exclusive and additional missions may be added in the future. The requirements provided for the missions listed may not be comprehensive. The ORG is a living document and requirements are continually in development. The missions listed are those considered by the ORG, regardless of the number of requirements presented for each mission.

Additional missions may be added to this list if market factors create a new or previously overlooked opportunity for advanced nuclear reactors, or if a new reactor technology makes a previously unviable mission viable. When adding a new mission, existing requirements for other missions will be reviewed to determine if any are applicable to the new mission (and to confirm that all mission-independent requirements are also applicable to the new mission). Original requirements will then be developed for the new mission using an approach that is consistent with the policies of the ORG.

Note that missions may be complementary (i.e., more than one mission may be supported). Also, some highly specific missions (e.g., desalination, hydrogen production) may be fulfilled by one or more of those listed below.

[3] It is worth noting that this attribute combines the two related but distinct concepts of physical protection and support for non-proliferation objectives. The two attributes were merged with the recognition that decoupling of the two concepts will likely be needed for some requirements.

The following missions are considered in the ORG:

- Electricity Generation (Grid) (GR) – The use of reactor heat to generate electricity for a large electrical infrastructure (i.e., a grid). This is the most developed and well-understood mission for nuclear reactors.
- Electricity Generation (Off-Grid) (OG) – The use of reactor heat to generate electricity in a location or for an application that lacks a large electrical infrastructure. Advanced reactors can be built to operate at much lower power levels than traditional LWRs, making off-grid applications for advanced reactors viable.
- Process Heat (PH) – The use of reactor heat to accommodate processes of various types, such as chemical reactions (including production of energy vectors, such as hydrogen), manufacturing, and steam production. Enhanced oil recovery is one market for steam production that may be of particular interest.
- Actinide Transmutation (AT) – A reactor serving this mission would transmute (or “burn”) the used fuel from other reactors. This mission refers to the reduction of nuclear waste; however, it would likely be paired with another mission as well (likely electricity generation) as the transmutation process will generate heat.
- Radioisotope Production (RP) – This mission refers to the use of the neutron flux produced in the reactor, as opposed to the heat generation (as utilized by the other missions) to generate radioisotopes for medical and industrial use.

ORG Chapter 4 – Description of Tier III Technology Requirements

4.1 Introduction

Tier III begins to provide requirements that apply to individual systems and components in the plant. Tier III is not intended to be a comprehensive set of requirements, meaning plants that meet the ORG Tier III requirements have other requirements (e.g., regulations, standards) that must still be met, and the bid specification for the plant will go into more detail than Tier III of the ORG.

Tier III consists of technology-independent requirements, which are universally applicable to all technologies, and technology-dependent requirements. Technology-independent requirements are distinguished from Tier II requirements because they apply to specific components and systems rather than high-level reactor attributes. Technology-dependent requirements are organized by advanced reactor design family (e.g., SFRs, HTGRs). Technology families are categorized defined by the fluid used to remove thermal energy from the reactor. The heat transfer fluid is a key characteristic that determines many other design aspects and features including design margins, licensing basis events, and material selection among many others.

Each requirement in Tier III is tagged with the attributes discussed in Tier II and missions for which it is applicable. While most Tier III requirements will apply to a technology serving any mission, some requirements may only apply to a specific technology-mission combination.

Each Tier III requirement branches from a Tier II requirement and satisfies some specific aspect of the higher-level objective encompassed by the Tier II requirement. This means each Tier III requirement maps to Tier I (Categories), forming a connected structure.

4.2 Technologies

The ORG considers the technologies listed below. The list is not intended to exclude any viable technologies available now or in the future. Technologies considered to be viable technically and economically within the foreseeable future are included. The requirements provided for the technologies listed are not comprehensive. The ORG is a living document and requirements are continually in development.

Additional technologies may be added to this list if conceptual development on the reactor technology reaches a point where it may be deemed realistically viable. When adding a new reactor technology, existing requirements for other technologies will be reviewed to determine if any are applicable to the new technology (and to confirm that all technology-independent requirements are also applicable to the new technology). Original requirements will then be developed for the new technology.

The following reactor technologies are considered in the ORG, organized by heat transfer fluid:

- *Gas*
  - **High Temperature Gas-cooled Reactor (HTGR) –** HTGRs use flowing gas (generally helium) as a heat transfer fluid. They can use pebble-type fuel or prismatic fuel and can be used in electricity generation and other missions. HTGRs operate at temperatures of approximately 700°C. Commercial gas-cooled reactors have operated successfully around the world.
  - **Gas-cooled Fast Reactor (GFR) –** GFRs are fast spectrum reactors with gas heat transfer media. They can be designed to operate at high temperatures up to the same ranges as HTGRs but are distinguished by their fast neutron spectrum. No GFRs have been built and operated.
  - **Very High Temperature Gas-cooled Reactor (VHTR) –** VHTRs are thermal spectrum gas-cooled reactors. They are not conceptually different from HTGRs except that they operate at elevated temperatures (greater than 800°C) which require the development of new, advanced materials. Many gas cooled reactors have been built and operated, and some have achieved the high temperatures envisioned for future VHTRs but have not done so on a consistent, long-term basis.
- *Liquid Metal*
  - **Sodium-cooled Fast Reactor (SFR) –** SFRs use liquid sodium metal as coolant and operate on a fast spectrum. They are capable of being built as breeder reactors, and they typically operate at high temperatures and very low reactor coolant pressures. SFRs can be large or small and pool-type or loop-type in design. Many SFRs have been built and operated both experimentally and commercially.
  - **Lead-cooled Fast Reactor (LFR) –** LFRs are much the same as SFRs, but they use lead or lead-bismuth solutions as a coolant. The principal differences are in the temperatures of interest for lead properties and the radiological impacts of using bismuth in the primary system. LFRs employing lead-bismuth eutectic as the primary coolant were deployed and operated as part of the Soviet submarine propulsion program.

- *Molten Salt*
  - **Molten Salt Reactor (MSR) –** For the purposes of the ORG, the term MSR refers to the liquid-fueled reactor, but many MSR requirements could be easily adapted to solid-fueled designs (such as the FHR). MSRs are reactors that use a molten salt mixture as coolant with fuel dissolved in it. The fuel and coolant are therefore one and the same. When referring to the liquid fuel in a MSR, the reader should recognize that these discussions refer to aspects of reactor design and operation that would apply to both fuel and heat transfer fluid in other designs. MSRs can operate on a fast or thermal spectrum. To date, two MSR test reactors have operated.
  - **Fluoride salt-cooled High Temperature Reactor (FHR) –** A fluoride salt-cooled, solid-fueled reactor. These reactors are distinguished from typical MSR concepts in that the fuel in the FHR does not circulate. For the purposes of the ORG, the term MSR exclusively refers to liquid-fueled designs, but many MSR requirements will also apply to FHR designs.
- *Water*
  - **Supercritical Water-cooled Reactor (SCWR) –** SCWRs employ light water as a supercritical fluid primary coolant. High pressures and temperatures are used to generate supercritical water. At present, commercial efforts to deploy SCWRs have not been identified, and SCWR-specific requirements are not included in the ORG.

ORG Chapter 5 – Complete ORG Requirements

5.1 Policy Statements

The following pages present the ORG Policy Statements. The reader may skip to Chapter 5.2 if they read the Policy Statements in Chapter 1.2.

Table 5-1
ORG Policy Statements

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Constructability	Focus on manufacturability, transportability, work efficiency, and construction duration. Similar to maintenance, practical issues relating to the construction should be considered in the early stages of design. Applicable experience and lessons learned from both recent nuclear and non-nuclear construction projects (major infrastructure and process plants) should be applied. A design that is difficult to construct increases risks of cost escalation and schedule delays. The plant owner-operator is concerned with meeting targets of cost, quality, schedule, and risk mitigation. Predictability in construction enhances the owner-operator's confidence in meeting these targets and is nearly as important as lowering costs.
Decommissioning	Envision end-of-life activities including plant decontamination and decommissioning. Similar to design and maintenance, practical issues relating to decommissioning of the plant should be considered in the early stages of design. A design that is difficult to decommission could create regulatory liabilities and require that more money be retained in the decommissioning fund for costs incurred after useful economic life has ended. The use of automation and robotics to support decommissioning could be greatly beneficial and should be accommodated into the design of the facility.
Design Margin	Provide enhanced margins to failure of fission product barriers compared to current reactors and current licensing requirements. Design margin is also desired for operational and performance considerations. These enhancements should provide greater operational flexibility for addressing emergent problems encountered following completion of design and during construction and operation. Nuclear power plants, particularly in the U.S., have experienced degradation of material condition resulting in an unacceptable reduction in margin to regulatory limits. Greater performance and safety margins in advanced reactor designs should allow changes in regulatory margins with minimal physical modifications and upgrades to address them. Greater margins should also enhance economic performance by allowing for operational modification throughout the life of the reactor and will increase flexibility for dealing with failures and other unforeseeable issues.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Economics	Effectively compete with other (nuclear and non-nuclear) technologies to fulfill the specified mission(s) based on evaluation of costs using clearly justified assumptions, consistent with best cost estimating practices for capital, operating, maintenance, and fuel. • Lifetime costs should be considered but may not be relied upon alone to justify the plant's competitiveness (i.e., a 50-year cost recovery is unlikely to be acceptable even for a hypothetical reactor with a 100-year life). At the same time, a long plant life may offset high initial capital costs, especially if replacement costs/decommissioning of the competing technology are considered. • Tradeoffs affecting competitiveness should be identified. • Assumptions should be clearly identified and justified. • Availability, reliability, and capacity factor have major effects on economic performance. • Ongoing major societal/political changes should be addressed in economic models. • Economics should be based on a whole-plant model. Regardless of any other areas in which the reactor may excel (safety, performance, environmental protection), if the reactor is not competitive in its chosen market, no owner will pursue it. It is possible for future regulations, resource availability, and market demand to significantly impact the economic performance of the reactor. Thus, a forward-thinking approach should be used to determine the economic strategy of the reactor.
Flexibility	Support a wide range of needs and desires with regards to operations, deployment, and product without sacrificing quality or competitive advantage. Designs should be adaptably deployed and operated under challenging, changing, or uncertain external conditions and constraints, and they should reliably fulfill one or more missions. EPRI report 3002010479 specifically addresses the concept of flexibility for advanced reactors (EPRI, 2017c). • Operational flexibility refers to the ability of a reactor to be operated under a range of conditions. Most commonly, it is equated to the ability of a power plant to adjust to grid conditions and support power quality via load following and grid frequency control. However, there is increasing recognition of other desirable attributes of operational flexibility. As a result of this, other components of operational flexibility include the ability of a reactor to use various types of nuclear fuel, being able to integrate with technologies such as topping cycles and energy storage, or the ability to operate in "island mode." • A plant that is flexible in where or how it can be deployed will increase the number of potential sites. • A reactor that is flexible may be repurposed if a more profitable market emerges. • A plant that is flexible can justify or adapt deployment and operation under challenging or uncertain external conditions and constraints, operating when it may otherwise need to shutdown, increasing revenues and reducing financial risks.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Good Neighbor	Provide an overall benefit to the surrounding community through protection of the environment and other benefits, while providing a dependable source of economic well-being. The design and siting of the reactor should consider the needs and objectives (economic, social, etc.) specific to the community in which the reactor is deployed. • The jobs provided will stimulate a local economy and create growth. • A nuclear reactor will improve the quality of the air and water by displacing other energy sources. The support of the surrounding community will be key to every proposed advanced reactor project. Many otherwise promising infrastructure projects have failed due to a lack of public support. Local and general considerations should be taken into account in design, siting, construction, operation, and decommissioning. Steps should be taken to: • Emphasize the societal benefits of nuclear power sources with respect to greenhouse gas emissions and absence of air pollution in electricity and process heat generation. Climate change is generally recognized as a significant societal risk, and nuclear power's advantages should be recognized. • Educate the public on the safety case for nuclear power in easily understandable terms beyond the traditional probabilistic metrics used by regulators. • Demonstrate a plan for used fuel disposal and reactor decommissioning for advanced reactor designs, which may include the dispositioning of the legacy inventories of used fuel resulted from the operation of existing commercial nuclear reactors. • Define the community benefits (or minimize the liabilities) of placing advanced reactors near population centers or near industrial facilities. • Minimize the "footprint" of the facility by considering societal impacts (e.g., traffic, visual aesthetics, noise).
Human Factors and Automation	Human-machine interfaces (HMI) should be simple and intuitive, be consistent across all system displays, and consider remote or multi-unit operation where permitted by regulations. Any interaction between human and machine creates opportunities for human error. These errors can be minimized by: • Making the HMI as simple and easy to use as possible. • Making the HMIs consistent throughout the plant. • Building HMIs with possible future capabilities in mind to support Aspirational Goals. • HMIs should be customizable to allow conformance to societal norms in different countries (e.g., reading direction, significance of colors). • The use of automation should be optimized to balance the reduction in human errors with reliability, staffing considerations, costs, etc.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Innovation and Proven Technology	Innovative features will be used where justified to meet the mission but should be demonstrated where necessary prior to commercial deployment to reduce licensing and investment risk. In other words, first of a kind (FOAK) or immature technologies should be used only where they provide a clear competitive advantage and manageable risk. Appropriate measures should be taken commensurate with the accumulated operating experience of each new technology by planning for extensive testing or prototype demonstration of FOAK features. The long-time horizon for fuel and materials qualification is of particular concern. Innovation could appear to be at odds with the use of Proven Technology; however, both have a prominent place in the ORG design philosophy. The use of proven technology supports the use of innovative features. Some basic technical solutions have been proven in LWR experience and are directly transferrable to advanced reactor designs. Other industries (e.g., aviation, petrochemical, automotive) also have vast experience related to robotics and digital instrumentation and controls. In many cases, the technologies used in other industries are more advanced than those used in the nuclear industry. The lessons learned from decades of LWR operation regarding materials and components used in certain applications should not be discarded when designing advanced reactors; rather, such lessons learned should be thoughtfully considered and applied throughout the design process – even applied directly to innovative technologies implemented in the design. This will allow the lower levels of the design to have a pedigree of operating history that proves the adequacy of the component in the desired application, capitalizing on previous experience and investments, and increasing the reliability and safety of the reactor.
Investment Protection	Ensure that the plant is protected from extensive, costly, and potentially irrecoverable damage. • Large, critical components that are expensive to repair and replace should be protected from damage in realistic scenarios. In particular, balance-of-plant components should be evaluated since they often are relegated to lower priority in a nuclear plant. If the reactor designer is not familiar and has insufficient resources to evaluate balance-of-plant issues, the owner-operator should ensure other entities are brought in to fill the gap. • The design should include features that ensure forced shutdowns not due to major equipment problems (e.g., shutdowns due to neutron poison injection) are recoverable without a prolonged shutdown period.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Licensing Preparation	Address current applicable regulatory expectations and provide, at a minimum, equivalent safety provisions appropriate to the technology. Design features unaddressed by or inconsistent with current regulatory expectations may be made practical with advanced reactors (e.g., remote operation). These should be noted as increasing regulatory risk and should have a carefully developed rationale and justification to present to the regulator. • It is important for potential owner-operators of advanced reactors to consider regulatory issues early in development so that time and money are not wasted developing a design that cannot be reasonably expected to be licensed to operate. • Analytical methods should be developed in a manner that will give regulators an assurance of safety, accounting for the current lack of experience with advanced reactor technology. • Pre-application discussion with regulators is essential to identify expectations. • The key safety basis elements should be effectively justified, but defense in depth must still be addressed.
Maintainability	Accommodate access for personnel and/or robotic devices to efficiently accomplish maintenance. Plant arrangements should provide transfer routes for replacement of major components without removal of major structures, systems, or components (SSCs). Additionally, procedures should be put in place to ensure the difficulty of maintenance activities is minimized. • The design of SSCs should consider inspectability, testability, and expected and unexpected replacement. • All health and safety hazards to personnel, including radiological exposure, should be considered (e.g., components and systems requiring frequent maintenance should be located in low-dose areas of the plant, industrial safety should be given equal consideration to radiation protection). • Replacement may be more economical than repair. • Maintenance facilities should be considered early in the design. Planning for the adaption of construction facilities into long-term maintenance facilities can provide significant cost savings, and the inadequate planning for maintenance facilities can lead to higher costs for the life of the plant. • Design controls should be in place so that design information is maintained. • Special emphasis should be placed on the use of automated maintenance equipment and robotics in order to reduce manpower requirements and exposure. However, any use of such equipment should include considerations for repair and retrieval. When designing any product, system, or facility, it can be easy to focus on increasing efficiency and performance while ignoring the practical problems of how the design would be serviced. Such issues should be considered in the early stages of design, so that maintenance may be completed quickly and efficiently (minimizing cost), and its effect on plant operation can be minimized.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Operational Sustainability	Account for long term management of key factors in operation and maintenance. The case for any nuclear technology will rely on establishing confidence in the viability of the technology for a certain time period, specific to each owner-operator. If no thought is given to the future availability of specialty materials, the continued technical capabilities to support the design, or the provision of required spares, the reactor could be forced to shut down prematurely due to unanticipated costs. Early decommissioning is likely to detract from the economic case of any reactor, having an adverse economic impact on stakeholders and resulting in the loss of benefits provided by the reactor. Key factors to consider include: • Ensuring supply chains or appropriate mitigation methods are in place to reduce supply chain risk. • Implementing programs to ensure continuity of technical cognizance for reactor design and specialized components. • Managing critical spares.
Quality Assurance	Design, development, construction, and maintenance should be performed in accordance with nuclear quality program requirements, including configuration management, training, etc. • Due to the unique nature of and hazards posed by nuclear energy systems, effective implementation of QA programs is of paramount importance. Organizations involved in design, construction, or operation should have well established, successful QA programs. • Programs developed for LWRs should be evaluated for applicability to advanced reactors, and program modifications should be made where necessary. • QA programs should be applied consistently with regulatory requirements, and in a manner that provides confidence that the safety functions will be fulfilled, without unduly hampering the design process. A graded approach should be applied, commensurate with the function of the SSC. Modern design processes depend on validated software solutions, making software QA particularly important. A graded approach should also be applied to ensure that the appropriate quality measures are in place early in the design process. • Organizations involved should implement a “quality culture” among workers.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Simplification	Minimize the number of SSCs (including interconnections, such as conduit, cable, piping, etc.) to reduce complexity of operation and to reduce capital, operating, and maintenance costs. Emphasis should be placed on limiting the complexity and number of safety-related components. One method of simplification could be to employ passive means for reactor stabilization and cooling during operational and abnormal conditions. Simpler designs will result in: • Increased safety (the plant's ability to mitigate potential threats the reactor may present to the health and safety of plant personnel, the local community, the environment, and society as a whole) and improved performance of the reactor due to fewer failure modes and higher reliability. • Reduced costs due to reduced scope and commensurate simplification of construction as well as reduced maintenance requirements. • Reduced burden on operators and reduced opportunity for human error with the use of passive safety systems. • Reduced costs due to minimizing the number of safety-related SSCs by maximizing the ability to use commercial grade materials and takes advantage of state-of-the-art innovations for support and balance-of-plant systems.
Standardization	In order to leverage design effort, facilitate licensing, distribute support costs, benefit from operating experience, and expedite construction, successive plants should be standardized to the extent feasible. However, standardization should be balanced against the benefits of innovation. Standardized designs should not rely on specific components from specific suppliers; rather, they should be flexible enough to support variety in sourcing materials and components, where possible. Standardization allows for: • The ability of supporting vendors to collectively service the industry by manufacturing equipment in bulk with dimensions, material properties, and other characteristics common across all plants. • The ability of owner-operators to learn from the operating experience of many other plants, strengthening the knowledge and quality of the industry as a whole. • Increased predictability of regulation for reactors with standardized components, as the collective operating experience provides assurance of safety for new reactors. While standardization provides many benefits, the philosophy should be tempered by the idea that advanced reactors are fundamentally innovative. While standardization in equipment and components is preferred, there should still be room for flexibility in design. One possibility is to maintain a design stable for some period (as in a ship class) before implementing accumulated changes.

Owner-Operator Requirements Guide Policy Statements	
Title	**Description**
Threat Protection	Protect against internal and external physical and cyber threats that could credibly challenge the integrity of fission product barriers, provide unauthorized access to the fuel, or affect the availability of the plant to fulfill its mission. Such protection should: • Not detract from nuclear safety. • Minimize cost over plant life. • Take advantage of passive means or inherent features of the design where possible to reduce the need for large security forces and active security barriers. • Reduce reliance on guards because a guard force is one of the largest contributors to staffing costs. It is the responsibility of those who operate nuclear technology to protect the public and the environment from the possibility of fission product release or disruption of critical infrastructure. However, advanced reactors should consider alternate means of ensuring such protection that are more economically favorable, and at least as effective as the security measures in place at existing nuclear plants.
Waste and Used Fuel Management	Production and management of wastes should be considered during design and be consistent with anticipated regulatory requirements. Owner-operators should: • Not assume the availability of off-site facilities for used fuel storage. • Not assume any outside entity taking possession of used fuel during the life of the plant to allow for continued operation of the reactor. • Manage waste and used fuel such that the effect on normal operations is minimized. • Minimize inventory of difficult to manage waste streams. • Provide radioactive waste forms compatible with and suitable for offsite transportation and disposal without extensive onsite processing. • Account for prevailing public concerns with respect to waste and used fuel management. The criterion for on-site storage of used fuel reflects the importance of decoupling reactor operations, including waste management, from external factors such as availability of offsite interim storage and permanent disposal facilities.

5.2 Aspirational Goals

The following pages present the ORG Aspirational Goals.

Table 5-2
ORG Aspirational Goals

Owner-Operator Requirements Guide Aspirational Goals	
Title	**Description**
Closed Fuel Cycle	Reactors could be designed to operate on a closed fuel cycle, or specialized reactors could be built to utilize used fuel from open-cycle reactors as fuel, effectively closing the fuel cycle. This initially became an attractive goal because uranium was thought to be in short supply. While uranium availability is no longer a large concern, a closed fuel cycle is still a more efficient use of natural resources (potentially useful energy is wasted in an open fuel cycle). Additionally, a closed fuel cycle is beneficial from a political/public relations standpoint. However, this may make the design more vulnerable to political or economic decisions outside the control of owner-operators.
Dry (reduced water) Cooling	Although generally too expensive in the past, rejecting heat to the atmosphere has become more attractive for use in water scarce locales, and where water may be abundant but cooling use is restrained. Plants which efficiently reduce the water flow required to reject waste heat would have inherent benefits to many potential customers. Dry cooling would also reduce the plant's impact on the surrounding environment. If dry cooling is used, plant efficiency will be lower than for a water-cooled plant, so the benefits of dry cooling must be balanced with a reduction in efficiency. A hybrid cooling method could also be used for added flexibility (e.g., changing cooling method depending on the time of the year).
"Hands-Free" Safety	Using passive safety features, reactors could be designed so that the period of time in which the reactor can remain safe after an event without operator action or off-site electric power is unlimited. No operator action or off-site power is required for the reactor to safely shut down and remain safe post-event. Because "unlimited" cannot be objectively demonstrated, a long-time requirement should be specified (e.g., 30 days). If hands-free safety is not feasible, designing to slow transients to lengthen available operator response time is an option.
Guard-Free Security	The threat to a reactor differs widely around the world. It would be desirable for a reactor to be self-protecting such that the design alone is sufficient to meet safeguards criteria without an on-site security staff. In this case, armed response would be from local law enforcement. For very small remote reactors, hiring a security force would not be economically feasible, so guard-free security would be a necessity. In general, a design that reduces the security staff would also be beneficial. Considerations in implementing this goal are 1) protection against sabotage intended to take the facility out of service or spread radioactivity and 2) theft of special nuclear material.
On-line Maintenance	Even older LWRs have been highly successfully in transferring many maintenance activities out of shut down periods. Some plants may reduce downtime by operating with restrictions (e.g., reduced power) with some equipment out of service for maintenance. In reactors with longer refueling cycles (or on-line refueling) the ability to perform on-line maintenance tasks on major components could greatly enhance the availability of the plant.

On-line Refueling	Automated refueling processes which occur on-line can be achieved for some technologies. These methods have the potential to reduce the severity of fuel handling events and enhance the plant's availability.
No Refueling	Certain applications for advanced nuclear plants (e.g., remote locales) become much more attractive if the plants do not need to be refueled for the entire lifetime of the plant. This would primarily be pursued for very small reactors.
Remote or Autonomous Operation	Plants could be designed to be operated by personnel off-site or be self-controlling within certain constraints. This would greatly increase the siting options for the plant (e.g., remote locales with extreme weather conditions) and significantly alter the economics. Maintenance needs will require consideration. As plants move toward increased automation, it is expected that humans will begin to have a more supervisory role in maintenance and operations.
Off-grid Operation	Current nuclear power plants are designed to operate while tied to a functioning, integrated electrical grid. There is increasing interest in using small advanced reactors which do not require offsite power supplied by functioning, stable grids, as dedicated power sources for critical infrastructure (e.g., defense facilities) in the event of a significant, sustained disruption of the grid.
"Black Start" Capabilities	Current nuclear plants must have offsite power (i.e., a functioning electrical grid) to start up. A plant that can start up using its own resources, without the need to be supplied offsite power by the grid, would be helpful in restoring the electrical grid following a significant, sustained disruption. For remote plants, this is a necessity as there will not be another source of electricity from which to start the plant.
Decentralized Power Generation	Electricity generating plants would have benefits to being sited at the distribution level. This would save resources on building transmission and would contribute to the decentralization of power. This would likely only be feasible for small reactors, and the challenges associated with siting a nuclear plant near or in population centers would need to be overcome.
Fleet Licensing	In a fleet licensing approach, a design would be accepted for use at any site meeting certain criteria and would not require a separate technical design review for each site. This may become more feasible from a regulatory standpoint as safety cases for designs become simpler. This is particularly important for Small Modular Reactors (SMRs).
Siting in Close Proximity to Population Centers	The success of advanced nuclear plants depends greatly on the ability to locate these reactors in close proximity to population centers and co-locate with industrial facilities. Many of the old, small coal plants that were located in critical locations to support grid security and meet load requirements, have shut down due to economic or environmental considerations. Oftentimes, these plants were located near population centers and urban areas. The public and the regulator have to be convinced that the replacement of the older coal plants with advanced nuclear plants is beneficial to the health and safety of the public and the economy of the region. Process heat supply by advanced nuclear plants is only viable if the user is located in close proximity or co-located (otherwise the process heat losses become unacceptable).

5.3 Tier I Categories

The following is a re-creation of the Tier-I content found in Section 2 above. The ORG Tier II requirements begin in Section 5.4.

Table 5-3
ORG Tier I Categories

Owner-Operator Requirements Guide Tier I Categories		
Req. #	**Title**	**Description**
1.01	Constructability	Constructability strongly affects capital cost, as it has major impacts on scheduling and technical risks. Decreasing the capital cost of nuclear technology is a major goal of advanced reactors. The purpose of the requirements in this category is to adopt lessons learned from recent large-scale construction experience to help ensure future construction projects are well executed and are ultimately successful. Major concerns are: • Learning curves for new workforce • Modularity • Qualification of suppliers • Construction site arrangement • Prevention of construction rework
1.02	Cyber Security	Requirements in this category pertain to the protection of plant data systems and communications. In recent years, cyber security has become a large concern, particularly in relation to maintaining national critical infrastructures. These requirements are intended to help make plants more resistant to cyber interference.

<table>
<tr><td>1.03</td><td>Instrumentation and Controls</td><td>This category contains specific requirements for the instrumentation and controls systems. These systems are particularly important and represent many requirements, and therefore merit their own category. The ORG assumes that digital technologies will be fully implemented in advanced reactors due to their distinct benefits. However, the ORG does not preclude the use of analog or digital non-programmable control systems, especially for safety or post-accident monitoring systems. Major considerations are:
Sensors: Their ability to adequately characterize plant parameters and to provide accurate readings under the full range of plant conditions.
Digital displays, or Human-Machine Interface (HMI): Meeting the current state of the art for human factors engineering and support automation.
Reliability: The likelihood of any single component to fail.
Redundancy: The concept of having multiple components available to perform the same function to improve overall I&C system reliability.
Diversity: The concept of having redundant components with different operating principles, to improve the overall I&C system reliability by minimizing common mode failures. It should be noted that applying diversity means having the second best design of a key feature in the plant.
Independence: The concept of limiting interactions between redundant components so that the failure of one component is less likely to cause the failure of another or the system of which they are a part.</td></tr>
<tr><td>1.04</td><td>Investment</td><td>Deployment of a nuclear plant constitutes a major investment. Requirements in this category help decrease the risk associated with such an investment. Important concerns are:
The initial investment must be justifiable by the competitiveness of the technology in the market in which it intends to operate.
The investment must be viable based on long term supplies of commodities, etc.
The design should include features which provide confidence in the protection of the asset (e.g., advanced monitoring techniques, protective features/isolations).</td></tr>
<tr><td>1.05</td><td>Licensing and Safety Analysis</td><td>“Licensing” and “safety” are grouped together because safety requirements form the bulk of licensing requirements. Regulators are concerned with protection of the public during events due to natural and man-made hazards (including fires, floods, extreme weather, etc.), so safety metrics must support the licensing requirements. Reactors are already extraordinarily safe against foreseeable events, but they benefit from features that maintain the fuel intact for any circumstances. Generally, this is proven with analyses or tests that support the safety criteria. Requirements in this category relate to both design and analysis.</td></tr>
</table>

1.06	Maintenance and Operability	These requirements are to make the plant easier to operate and maintain, which could result in reduced staffing requirements, reduced maintenance hours, and reduced opportunity for human errors. Major concerns are: • Worker protection • Ergonomics/human factors • Access to components • Component exchangeability and replaceability • Standardization or equipment and procedures • Remote maintenance and inspection (reduce dose, heat exposure, etc.) • Remote operation of important components (reduce dose, heat exposure, etc.)
1.07	Materials	Selection of the materials used throughout the plant should consider: • Materials qualification • Materials selection based on availability and code acceptability • Nuclear fuel • Inert gases (heat transfer fluids, process gases, cover gases, fission product gases) and special materials (e.g., graphite blocks, graphite pebbles, control rod materials, coolants, coatings, etc.) that may not be traditional materials of construction or may have unique requirements for how they are employed in advanced reactor designs.
1.08	Physical Protection and Proliferation Resistance	Requirements in this category pertain to: • The physical protection of SSCs against sabotage. • Administrative and process controls that, if compromised, could simplify sabotage of reactor operation, or lead to damage of plant SSCs – from both a safety and an investment protection standpoint. • The physical protection of nuclear materials against theft. • The measures taken to ensure nuclear materials are controlled and accounted for to impede their diversion or misuse.
1.09	Quality Assurance	The ORG assumes compliance with applicable safety regulations and is not intended to ensure such compliance. Rather, the ORG QA requirements emphasize how a QA program may be implemented in a way that leads to a successful project lifecycle, from design to decommissioning. For example, maintaining accurate and current plant drawings is crucial to the success of any QA program.

1.10	Reliability and Availability	Different markets and missions have their own metrics for reliability and availability. Requirements in this category provide such metrics where possible and provide general guidance for increasing availability and reliability. Items of interest are given below: • Anticipated equipment failures should be accommodated by the plant with no or minimal interruption in operation. • Reactor design should achieve required availability metrics without undue assumptions for off-site support services (e.g., short term storage of fuel).
1.11	Seismic and Structural	Requirements in this category pertain to the design and analysis of plant structures. These requirements overlap with “Licensing and Safety Analysis”, but because there are many requirements that specifically apply to structures and seismic qualification, they merit a separate category. The following are examples of concerns that are addressed by requirements in this category: • Many of these requirements pertain to the design and analysis required for seismic qualification. However, earthquakes are not the only hazard to structures that should be considered. Hurricanes, tornados, tsunamis, and human-made hazards such as airplanes should also be accounted for in the analysis. • A classification system for SSCs should be created to ensure the analysis performed for each SSC is adequate relative to the application and importance of the SSC. • The design of SSCs should be robust enough to allow flexibility in plant siting. However, the designer should not make an effort to make the base design of the plant suitable to the most extreme geographies (e.g., high seismicity region), as this would unnecessarily raise capital costs.

5.4 Tier II Requirements

The following pages present the ORG Tier II Requirements.

Table 5-4
ORG Tier II Requirements

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0020	The reactor designer should consider the experience in existing Light Water Reactor (LWR) and advanced reactor plants to identify design problems that have adversely affected construction costs, schedules, maintainability, or operability.	Examples of such problems include the design of masonry walls and concrete expansion anchors. Also included are such topics as the excessive use of snubbers for seismic restraints. Such issues will have applicability to all technologies. Effective decisions at the design phase can avoid repetition of such problem areas, and specific design procedures should be developed to best resolve such problems.	URD Rev 13 Tier II Chapter 1 Section 4 (EPRI, 2014a) EUR Volume 2 Chapter 14 (EUR, 2012)	Constructability	ALL	ALL	SAFE PERF ECON IMPL
2.01.0030	The reactor designer should develop a design approach that allows appropriate tolerance for construction and assembly problems, and for potential deviations in layout and location.	Lack of realistic and clearly defined tolerances for construction has resulted in significant rework in analysis and construction in older LWR plants.	URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0040	Advanced construction techniques should be used to support improved constructability, which leads to predictable construction schedules and actual construction durations that meet the objectives.	Advanced construction techniques reduce risks from the construction process and result in the performance of critical path work in environments that are more easily controlled.	URD Rev 13 Tier I Chapter 3 Section 3 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0041	Reducing the construction schedule should be prioritized above minimizing the cost of construction materials.	Designers often focus on optimizing the cost of materials. However, experience is that materials represent a relatively small cost compared to construction (direct) and support (indirect) labor. Therefore, reducing the time of construction will have a larger impact on reducing the overall cost of construction.	Recent Lessons Learned	Constructability	ALL	ALL	ECON
2.01.0050	The activities for design, construction, procurement, inspection, and testing of the nuclear plant should be thoroughly planned and included in an integrated schedule early in the project.	Thorough planning and scheduling of work is necessary to enable monitoring and control of the work and provide confidence that the schedule goals will be met. It is essential to have adequate control of the integrated project schedule so that potential problems and near critical path activities are identified early.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0051	The need for margin in fabrication and construction planning should be evaluated and explicitly identified at each step in the integrated construction schedule.	Margin may be standardized or customized based on type of component, length in manufacture, difficulty of delivery, and impact on critical path. This requirement helps minimize the consequences of unforeseen issues that may delay certain construction tasks, such as a late delivery of components that delays dependent tasks downstream in the schedule.	Industry Feedback	Constructability	ALL	ALL	IMPL
2.01.0052	The construction schedule should be optimized to reduce the interest paid on capital investments while balancing the risks of delaying critical construction tasks.	From a purely financial perspective, it is economically beneficial to wait to build structures until they are required (i.e., “critical path”), so as to minimize the interest paid on any loans required to make the purchase. However, the risk associated with any task is mitigated by performing it earlier than required, accounting for uncertainties in the time it will take to complete the task. The schedule should represent a compromise between these two concerns.	Industry Feedback	Constructability	ALL	ALL	ECON IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0053	The owner should identify and involve an Engineering, Procurement, and Construction (EPC) contractor and an operator (if they are separate entities from the owner) early on in the construction process.	Communication among companies representing the views and having knowledge of the key stakeholder organizations in the early stages of the project is crucial to project success.	Recent Lessons Learned	Constructability	ALL	ALL	IMPL
2.01.0060	Design, construction, procurement, inspection, and testing activities should be included in an integrated schedule that clearly identifies the significant activity interfaces between each of the major organizations supporting involved in construction.	Thorough planning and scheduling of work is necessary to enable monitoring and control of the work and provide confidence that the schedule goals will be met. It is essential to account for interfaces in the project schedule so that potential problems are identified early to permit timely corrective action.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0070	Each organization responsible for control and execution of work should adequately plan and schedule their activities to a sufficient level of detail to demonstrate that the validity of the overall plant schedule is supported.	Thorough planning and scheduling of work is necessary to enable monitoring and control of the work and provide confidence that the schedule goals will be met. Each organization's schedule must support the overall project schedule.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0080	A hierarchy of construction schedules should be developed to cover both high-level activities (long term) and low-level activities (near term). The schedules will involve various horizontally connected entities and must fit together in an integrated schedule.	High-level construction schedules are needed to monitor and control the overall construction effort. Low-Level schedules are needed to monitor and control individual tasks. This hierarchy only works if schedules are consistent, and low-level schedules fit appropriately in the high-level schedules.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12	Constructability	ALL	ALL	IMPL
2.01.0090	Subcontractors should develop schedules which are consistent with plant construction schedules.	For the overall project schedule to be realistic, it is important that schedule discipline be maintained by all project participants. If the subcontractors' schedules do not support project milestones, the plant schedule duration would be jeopardized.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12	Constructability	ALL	ALL	IMPL
2.01.0100	A startup schedule should be developed to define activity logic and durations at a level suitable for planning startup testing activities.	The startup schedule should be organized on a system and subsystem basis and should be developed early in the project to a sufficient level of detail to define the sequence of system testing. It is essential for the system startup requirements to be established early in the project life. Establishing these requirements assists with the designation of system and subsystem packages so that the interfaces with construction completion and transfers of responsibility are defined. This allows the assignment of startup activity dates that support the overall schedule.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0110	Prior to start of any detailed construction scheduling, and well in advance of the start of actual construction, a review of the construction sequence and techniques should be performed by a team composed of construction, design engineering, and quality control personnel to assure that the design permits optimum constructability of the plant.	The review should identify the modular construction approach to be provided for by the design and scope the specific modules to be developed. This review should utilize a physical model of the plant or a three-dimensional (3D) computer model, as available. Recommendations resulting from the review should be provided to the owner-operator for approval.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12	Constructability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0120	A constructability review program should be established and maintained throughout the design and construction phases. The constructability review team should include knowledgeable personnel with broad construction experience.	The purpose of the reviews should be to evaluate design alternatives for cost and schedule effectiveness and to identify construction risks early.	URD Rev 13 Tier II Chapter 1 Section 7	Constructability	ALL	ALL	IMPL
2.01.0130	At a minimum, the constructability review should include: • Construction plan and time schedule; • Measures for site preparation; • Site layout; • Bills of quantities of materials and of civil works.	This requirement establishes the minimum amount of information required for the constructability review to be complete and useful for planning purposes.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0140	The constructability review and construction plan should be adapted to the specific location selected for the plant's construction, taking into account national regulations, local construction requirements/codes and standards, geographic limitations, competition for construction resources, labor relations, and infrastructure support (ports, highways, rail access).	Site-specific characteristics can impact the ease and cost of construction. The general construction plan may need to be updated to account for local concerns.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0150	The EPC contractor (referred to for the rest of the document as "EPC") should prepare procedures for purchase of materials and subcontractor work, including preparation of subcontract packages, bidding, award, and administration of subcontracts.	A systematic program for managing suppliers and subcontractors is essential to a successful construction program. The subcontractors' understanding of work scope and required performance standards are paramount to timely final acceptance of completed construction work. Experienced field contract administrators can provide constructive input to assure satisfactory contractor performance.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 12 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0160	A site material control program should be developed to meet all the reactor designer's specified requirements for equipment storage and protection.	To track and protect equipment and materials to prevent delays to construction caused by material that is not yet on site, misplaced, degraded, improperly stored, etc.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0170	The site material control program should describe plans for warehousing: protection, storage, and surveillance of components and material; receiving inspection: identification, location, and retrieval of stored material; and handling equipment.	To track and protect equipment and materials to prevent delays to construction.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0180	The site material control program should be in place prior to accepting applicable deliveries at the construction site.	To track and protect equipment and materials to prevent delays to construction.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0190	The construction plan should include a description of the advanced construction techniques and practices which will be implemented.	Examples of advanced construction techniques and practices include: • Maximum use of automated welding; • Pretest modules, subsections, and equipment assemblies prior to installation; • Composite steel and concrete structures which minimize the need for temporary shoring and use the permanent steel forming; • Flat wall attachment embedments for support of structural beams from concrete walls in lieu of blockouts; • Additive manufacturing; • Powder metallurgy • Hot Isostatic Pressing (PM-HIP); • Electron beam welding.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0199	The EPC chosen by the owner-operator to build the plant should have a significant amount of previous experience serving as an EPC for large industrial construction projects.	Recent nuclear construction experiences have shown that the experience of the EPC is critical to keeping the project on schedule and on budget. The prior experience of the specific individuals that will be working on the project, and not just the organization as a whole, should be considered.	Recent Lessons Learned	Constructability	ALL	ALL	IMPL
2.01.0200	Early in the project, the EPC should coordinate the planned construction practices with the reactor designer to assure the design features will accommodate the approaches planned.	Lesson learned from construction experience.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0210	The plant should be designed to maximize the benefits that can be obtained through use of modular construction techniques.	Examples of the types of modules which have been previously developed for LWRs and represent the minimum level of effort expected are as follows: • Basemat reinforcing steel assemblies; • Main condenser and feedwater heaters received pre-tubed; • Main control panel assemblies; • Reactor vessel pedestal structural steel; • Reactor vessel nozzle support ring; • Containment vessel or liner plate; • Refueling pool and used fuel pool liner plates.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0211	On-site construction effort should be optimized to the extent practical.	Off-site construction can be more cost-effective than on-site, depending on the specific project. The availability of skilled craft workers and the need for costly incentives are concerns that can be reduced by minimizing on-site work.	Industry Feedback	Constructability	ALL	ALL	IMPL
2.01.0220	A list of module types which will be investigated for application in the plant should be scoped at an early stage of the plant design.	Planning for modular construction early in the design process facilitates the design of the plant layout.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0230	Module types should be classified as to whether the module will be fabricated entirely in an off-site shop, fabricated in major elements off site with final assembly at an on-site shop or laydown area, or will be fabricated entirely on site in a module assembly area.	Planning for modular construction early in the design process facilitates the design of the plant layout and sequencing during construction.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0240	The design should attempt to optimize the use of standardized components and processes to simplify the work.	Simplification and standardization are consistent with the ORG policy statements.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0250	The site layout design should consider access space provisions for installation and construction fit-up and for maintenance, operation, and component removal/replacement.	Some previous layouts have not provided adequate space for operation and maintenance. The resulting difficulties have caused owner-operators to incur excessive cost and reactor down time in removing interference. Allowing space to perform maintenance activities promotes long-term plant availability. Additionally, if the project is delayed during construction, components may be delivered before other components are installed, requiring more space.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0260	Pre-installation activities for modules such as receipt inspection, transfer of the module from the fabricator to the EPC, fitup verification, etc., should be identified uniquely for each module and built into the schedule.	This planning will allow for the module to be delivered on-site with sufficient time to perform the activities before the module installation date.	Recent Lessons Learned	Constructability	ALL	ALL	IMPL
2.01.0270	The module design should be 100 percent complete without design “holds” at the time each module is released for fabrication.	Completion of the module design prior to fabrication release will avoid rework of the module and fabricator excuses for schedule delays and extra charges.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0280	For complex modules to be supplied by an off-site fabricator, the reactor designer should attempt to involve the fabricator in the design process on an advisory basis.	Involvement of the module fabricator in the early planning will permit incorporating fabrication ideas that will result in the most cost effective product. Shipping considerations, fabrication tolerances at the module interfaces, and the facility’s accessibility provisions for operations and maintenance should be addressed.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0290	The design should consider routing of construction services including compressed air, water for flushing, filling and hydro testing, and electric power such that they can be incorporated in the plant for use during the life of the plant, as applicable.	Incorporation of construction service lines within the plant design can reduce the cost to realign the services during the construction phase and improve accessibility by reducing the number of obstacles.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0300	All temporary services including those which are buried should be removed at completion of construction.	This includes air, water, sewer and electric. Additionally, any residual construction debris on site should be disposed of in regulatory approved site landfill areas. Buried services and debris can hinder excavation for future modifications and/or site remediation. This is an industry decommissioning lesson learned. Identifying and disposing of construction debris can be costly and time-consuming many years after construction.	URD Rev 13 Tier II Chapter 1 Section 7	Constructability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0310	While modular construction techniques can provide advantages in construction, these techniques should not, by themselves, be relied upon to simplify construction efforts.	Large LWR construction experience has shown that modular construction can simplify construction processes but that it requires careful management and does not eliminate all complexities of on-site work. Over-crediting modularity for simplification has resulted in significant project delays on some LWR construction projects.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0320	Construction planning should consider the modules on the critical path and should include measures to mitigate late module deliveries.	This is a lesson learned from construction experience in large LWR projects. Designs with many modules on the critical path, each with a unique supply chain, present risks to the critical path.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0330	Construction sequencing should clearly identify pre-requisites for each major phase or module placement. Though each technical detail may not be reflected in schedule dependencies, construction activities should include dedicated checks for pre-requisites.	Failure to meet pre-requisites for a major construction activity may result in very large re-work efforts to address any single issue (e.g., cable or pipe which should have been laid prior to lifting a large component in place).	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0340	The EPC should prepare a crane access study which demonstrates adequate crane coverage of the power plant structures during the various phases of construction. The swing, reach, capacity, number, type, and maintenance schedules of cranes should be included.	Heavy lifting capability, permitting vertical installation of components, usually provides the most flexibility in scheduling. Experience reported by Japanese and U.S. plants indicates that primary reliance on lifting equipment into place with large cranes results in a faster construction sequence. For some plants (i.e., factory-assembled, rail-transportable technologies) the crane access study may be a simple plan for installing the plant and making up cooling and electrical connections.	URD Rev 13 Tier II Chapter 1 Section 7	Constructability	ALL	ALL	IMPL
2.01.0350	Crane availability and arrangement should support lifts during construction without any one crane's availability affecting the critical path.	Heavy lifting capability, permitting vertical installation of components, usually provides the most flexibility in scheduling. Experience reported by Japanese and U.S. plants indicates that primary reliance on lifting equipment into place with large cranes results in a faster construction sequence. For some plants (i.e., factory-assembled, rail-transportable technologies) the crane access study may be a simple plan for installing the plant and making up cooling and electrical connections.	URD Rev 13 Tier II Chapter 1 Section 7	Constructability	ALL	ALL	IMPL
2.01.0360	Appropriate and achievable construction tolerances should be developed during the design and included on construction drawings and specifications for dimensions, locations, and clearances for all structures, systems, and components (SSCs).	The lack of appropriate and achievable tolerances has been a problem in some previous projects. This has contributed to delays and cost overruns. Construction tolerances should be in addition to clearances required for design considerations, such as thermal growth due to pipe rupture or in-plant fires.	URD Rev 13 Tier II Chapter 6 Section 2	Constructability	ALL	ALL	IMPL
2.01.0370	The building design and arrangement should accommodate and facilitate the selected construction sequence.	The design must be evaluated for constructability throughout the design process and especially during the early, formative stages.	URD Rev 13 Tier II Chapter 6 Section 2	Constructability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0380	Consideration should be given to separation of safety- and non-safety-related areas with the objective of achieving lower costs in non-safety-related areas.	Consideration should be given to physical separation (i.e., space and barriers) as well as separation in design requirements, construction activities, and quality assurance for components of different quality, seismic, or safety classifications. Study of construction costs of nuclear power and conventional facilities indicates a potential savings when safety- and non-safety-related work is distinctly separated. Similar savings may be achieved by careful management of the design and construction activities to avoid application of unnecessary requirements in non-safety-related areas. Confidence in the ability to achieve the latter and the impact on plant design of a physical barrier must be weighed against the identified potential savings through physical separation.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 11	Constructability	ALL	ALL	ECON IMPL
2.01.0390	The construction work should be organized by quality level consistent with the quality determined by the design.	Required construction quality is determined by the design and relevant codes and standards. Increases in required construction quality levels increase construction cost and decrease constructability. The proper construction quality level will have an impact on the constructability.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
2.01.0400	Component installation should only proceed in a space when construction work is completed and certified.	Clean installation conditions are not possible if the construction work and the installation work are taking place at the same time and in the same compartment. However, the construction work can occur in parallel with the installation work if the compartments are properly separated from each other. Modular construction may be considered.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0410	Installation openings for major components should be arranged so as to be available even when construction sequencing is altered.	If the installation of major components is dependent on the sequencing of other major construction items, it produces little to no float on the construction critical path.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0420	The construction management organization should be consistent with the roles and duties of the Quality Assurance (QA) program.	Quality assurance during construction should be ensured by the construction management organization. Creating construction management roles which easily translate to QA responsibilities helps ensure QA programs are effectively implemented during construction and commissioning.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0430	During the erecting and testing stage, each contractor should periodically supply data and reports corresponding to the progress of his own on-site activity, as defined by the EPC.	This requirement provides information important for accurately tracking construction progress.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0440	The EPC contract should require appropriate review points in subcontractors' construction plans to allow necessary inspections and audits by the owner-operator.	This requirement ensures that the owner-operator is ultimately responsible for acceptable quality of the construction. It also provides opportunities to identify mistakes during construction.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0450	The EPC should ensure that support facilities are available to allow occupancy by appropriate personnel prior to the first equipment being commissioned.	Necessary personnel should be located on-site before equipment is commissioned in order to properly support its commissioning and operation.	Recent Lessons Learned	Constructability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.01.0460	During the construction phase, all documents and training materials necessary for the safe execution of work should be provided with sufficient time for preparation of each construction activity.	Personnel performing construction activities need to be properly prepared in order to effectively and efficiently perform their work.	Recent Lessons Learned	Constructability	ALL	ALL	IMPL
2.01.0470	A complete systematic program of pre-operational and commissioning tests and activities should be developed and incorporated into the construction schedule.	The construction schedule should include commissioning tests and activities to ensure that they are all completed and to capture the time required to perform them. At later stages, the commissioning of installed systems will dominate the critical path items.	IAEA NS-G-2.9, Section 3.2 (IAEA, 2003) URD Rev 13 Tier II Chapter 6 Section 2	Constructability	ALL	ALL	IMPL
2.01.0480	All conditions experienced during the performance of the commissioning test program (including intermediate steps) should be analyzed beforehand.	The owner-operator should be assured of safety in every test condition prior to physically placing the plant in that condition. Care should be taken to ensure that transient/intermediate steps are included in the analyses.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0490	The owner-operator and/or reactor designer should systematically verify that construction activities have been performed in accordance with design requirements through the use of on-site walk-throughs, inspections, and written reports.	Personnel most familiar with the design should verify that the as-found construction meets the requirements of the design.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0500	The commissioning test program should ensure that all equipment is installed and operable per the design requirements.	The intent of the commissioning test program is to verify that as-found construction meets the requirements of the design.	Recent Lessons Learned	Constructability	ALL	ALL	IMPL
2.01.0510	The commissioning test program should include integrated system (i.e., whole-system) tests necessary to validate performance.	The commissioning test program should capture any potential interaction between components in the integrated system. Piecemeal testing may neglect this interaction.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0520	Commissioning test procedures should be designed to ensure they are executable and should identify required instrumentation, personnel, power, and access for the test.	Inaccurate or incomplete procedures will delay testing and increase construction costs.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0530	The commissioning test program should include the involvement of operations personnel to ensure they gain familiarity with the equipment and operating procedures.	Since operations personnel will need to understand the operation of installed equipment, the commissioning test program provides an opportunity to witness and participate in equipment operation prior to full plant operation.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
2.01.0540	Design documentation should be provided to the owner-operator throughout the construction and commissioning process as a contractual requirement and tracked in the construction plan.	Experience in construction has demonstrated that vendor documentation should be provided prior to closing working relationships. Design documentation is more difficult to obtain after the fact. This documentation includes design drawings, construction as-builts, system and component requirements documents, etc.	USNRC RG-1.232 (USNRC, 2018)	Constructability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.02.0010	Cyber security considerations should be appropriately incorporated into all stages of the design process.	Retroactive application of cyber security requirements is costly, time-consuming, and in some cases, infeasible.	USNRC RG 5.71 (USNRC, 2010a) IAEA Nuclear Security Series no. 17 "Computer Security at Nuclear Facilities" IAEA, Vienna, 2011 (IAEA, 2011) URD Rev 13 Tier II Chapter 10 Section 3 EUR Volume 2 Chapter 10 IEEE Standard 7-4.3.2-2003 (IEEE, 2003) IEEE Standard 7-4.3.2-2010 (IEEE, 2010)	Cyber Security	ALL	ALL	SEC/NP
2.02.0020	Special consideration for cyber security should be given to those non-safety related digital devices that can cause transients or trips, that are important in maintaining plant reliability, or that represent unacceptable licensing or management risk.	Some non-safety systems have the potential to interrupt operation or damage equipment if compromised.	USNRC RG 5.71 IAEA Nuclear Security Series no. 17 "Computer Security at Nuclear Facilities" IAEA, Vienna, 2011. URD Rev 13 Tier II Chapter 10 Section 3 EUR Volume 2 Chapter 10 IEEE Standard 7-4.3.2-2003 and -2010	Cyber Security	ALL	ALL	SEC/NP
2.02.0030	Cyber security features should be incorporated at the interfaces to safety systems, rather than as an integral part of the safety system.	Safety system complexity should be controlled, which requires cyber security features to, for the most part, be provided at the boundaries to the safety systems rather than within the safety systems.	USNRC RG 5.71 IAEA Nuclear Security Series no. 17 "Computer Security at Nuclear Facilities" IAEA, Vienna, 2011. URD Rev 13 Tier II Chapter 10 Section 3 EUR Volume 2 Chapter 10 IEEE Standard 7-4.3.2-2003 and -2010	Cyber Security	ALL	ALL	SEC/NP
2.02.0040	The Human-Machine Interface (HMI) architecture and design should be based on an overall defensive strategy that defines multiple security levels. The most intensive security measures should be concentrated on the most critical inner level, and on connectivity between the levels.	RG 5.71 and NEI 08-09 promote the use of several defensive levels, or "rings", that range from the Control and Safety System networks themselves (for which the most rigorous security measures must be applied) to the Site Local Area Network (LAN) and Corporate Networks (for which security measures should be balanced against flexibility and performance). Generally, the safety systems and non-safety controls would be placed in the most secure internal layer, to maximize protection of the systems required to ensure safe, reliable operation. Use of firewalls, careful selection of protocols, physical isolation between defensive levels and, for the innermost level(s), restrictions to uni-directional data flow (from within the most to a less critical security level) can reduce the risk of a cyber security breach that could impact the functioning of a critical plant system.	USNRC RG 5.71 NEI 08-09 (NEI, 2010) IAEA Nuclear Security Series no. 17 "Computer Security at Nuclear Facilities" IAEA, Vienna, 2011. URD Rev 13 Tier II Chapter 10 Section 3 EUR Volume 2 Chapter 10 IEEE Standard 7-4.3.2-2003 and -2010	Cyber Security	ALL	ALL	SEC/NP

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.02.0050	The HMI defensive strategy should employ multiple methods for protecting communications between defensive levels, and for access to Critical Digital Assets (CDAs).	Because of the dynamic nature of cyber security threats, it is important that multiple approaches be applied. Defense-in-depth approaches may include a combination of: • Prevention (i.e., block harmful access); • Detection (e.g., through intrusion detection systems); • Deterrence (raising the effort and sophistication level for an intruder); • Mitigation (rapid and effective recovery if an event occurs). Multiple techniques should be used including: • Physical access or isolation; • Strong authentication methods analysis and filtering of incoming packet streams.	URD Rev 13 Tier II Chapter 10 Section 3	Cyber Security	ALL	ALL	SEC/NP
2.02.0060	The HMI defensive strategy should be updated when new threats are identified or when new defense-in-depth approaches are identified.	Because of the dynamic nature of cyber security threats, it is important that defensive strategy evolves to keep up with the nature of the threat.	URD Rev 13 Tier II Chapter 10 Section 3	Cyber Security	ALL	ALL	SEC/NP
2.02.0070	An ongoing cyber-security program should be developed to address design changes and evolving needs throughout the life of the plant.	Development of a cyber security program plan provides a description of how the owner-operator will meet regulatory requirements. The HMI needs to be designed in a manner that ensures that the HMI system can meet regulatory requirements. Cyber security threats are constantly evolving, and operational digital systems evolve more rapidly than their analog predecessors. The owner-operator must have knowledge and resources to deal with these changes over time to prevent cyber security risks from inadvertently increasing. When considering whether or not to implement a firmware, software or programmable logic upgrade, the owner-operator must be prepared to balance its potential for reducing cyber security risk against the effort and potential disruption to deploy it. Patches intended to plug potential security breaches should be applied promptly.	URD Rev 13 Tier II Chapter 10 Section 3	Cyber Security	ALL	ALL	SEC/NP
2.02.0080	Digital system design and development processes should address cyber security from requirements development through design, construction, testing, and installation.	Cyber security is a key modern issue that needs to be considered throughout the plant's lifetime.	USNRC RG 1.152 (USNRC, 2006)	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0090	The owner-operator and reactor designer should perform a cyber security assessment to identify potential cyber security vulnerabilities in the relevant phases of the system life cycle, and the results of the analysis should be used to establish security requirements for the system (hardware and software).	The assessment should be able to determine whether QA processes allow for undocumented software changes, whether installation or operation procedures allow for unauthorized access to digital systems, and whether software tools are controlled to the level of quality commensurate with their use.	USNRC RG 1.152	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0100	A security gap analysis should be completed to identify required actions to retire cyber security risks.	The gap analysis should review cyber security risks associated with design, development, testing, and maintenance practices for the reactor designer's software and hardware, application-specific software and hardware, and Commercial Off-the-Shelf (COTS) software and hardware.	USNRC RG 1.152	Cyber Security	ALL	ALL	IMPL SEC/NP

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.02.0110	Communications from digital safety systems to non-safety systems should only be performed in a "one-way" manner (i.e., no input should be received by safety systems from non-safety systems).	Safety systems should be isolated from remote cyber attacks to ensure that they will not be prevented from performing their safety functions.	USNRC RG 1.152 IEEE 7-4.3.2-2003 and -2010	Cyber Security	ALL	ALL	SEC/NP
2.02.0120	Remote access to any of the safety related systems should not be possible.	Safety systems should be isolated from remote cyber attacks to ensure that they will not be prevented from performing their safety functions.	USNRC RG 1.152 IEEE 7-4.3.2-2003 and -2010	Cyber Security	ALL	ALL	SEC/NP
2.02.0130	The Verification and Validation (V&V) process of the overall digital system should ensure the correctness, completeness, accuracy, testability, and consistency of the system cyber security requirements.	Cyber security is a key modern issue that needs to be considered throughout the plant's lifetime.	USNRC RG 1.152	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0140	The reactor designer should implement best practices in cyber security procedures and standards to minimize opportunities for tampering with digital systems, and mitigate consequences.	This is consistent with a "Safeguards by Design" philosophy, applied for cyber security. Best practices in information security avoid the creation of vulnerabilities by design.	USNRC RG 1.152 IAEA SSG-39 (IAEA, 2016)	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0150	Cyber security features (e.g., intrusion detection software, virus protection software, access control software) should be designed and tested to ensure that they do not interfere with the performance, effectiveness, reliability or normal operation of digital systems.	Added security features can increase the complexity of digital systems, and can reduce system reliability. Active computer security features can compete for resources and increase complexity. Consideration should be given to the application of passive security features at all times. Cyber security features such as intrusion detection systems should be implemented peripherally to the safety systems. Implementation of cyber security features directly in the safety system should be avoided.	USNRC RG 1.152 IAEA SSG-39 IEEE 7-4.3.2-2016 Section 5.9.3 (IEEE, 2016a)	Cyber Security	ALL	ALL	PERF IMPL
2.02.0160	Digital system testing should be performed at the earliest opportunity on integrated system functionality.	This demonstrates that appropriate cyber security measures were implemented on the integrated system. Performing testing at the earliest opportunity provides sufficient time to address issues in the design.	NEI 08-09	Cyber Security	ALL	ALL	SEC/NP
2.02.0170	Digital system design should ensure that periodic testing and monitoring, review of system logs, and real-time monitoring can be performed to continually validate system functionality and to maintain assurance of continued cyber security measures.	The success of cyber security measures needs to be verifiable.	NEI 08-09	Cyber Security	ALL	ALL	SEC/NP
2.02.0180	Modifications to digital systems should be subject to the same quality and V&V requirements as the original systems.	Alterations and/or replacements of digital systems need to perform the same function as the original, so the same quality and V&V requirements must apply to the new systems.	NEI 08-09	Cyber Security	ALL	ALL	IMPL
2.02.0190	When modifications to digital systems shift functionality between systems (e.g., two legacy systems of different quality levels combined in a single new system), an analysis should be performed to determine the appropriate quality level, cyber security, and V&V requirements.	Alterations and/or replacements of digital systems need to perform the same function as the original, so the same quality and V&V requirements must apply to the new systems.	NEI 08-09	Cyber Security	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.02.0200	Appropriate measures should be taken to protect computer systems throughout their entire lifetime (including storage at site prior to operation of the system, accounting for uncertainty in delivery time, and full operating life of the system) against physical attack, intentional and non-intentional intrusions, viruses, etc.	Cyber security is a key modern issue that needs to be considered throughout the plant's lifetime.	IAEA SSG-39	Cyber Security	ALL	ALL	SEC/NP
2.02.0210	Digital safety systems should not be connected to any external networks unless justification can be made to show that the connection is necessary and safe.	The safety of the connection to an external network must be assured prior to exposing digital safety systems.	IAEA SSG-39	Cyber Security	ALL	ALL	SEC/NP
2.02.0220	The cyber security plan should be updated as necessary to account for the overall Instrumentation and Controls (I&C) architecture and individual I&C systems, and changing cyber security threats.	Even during the course of a nuclear power plant's construction, some updates are likely to be available or required for hardware, firmware, or software. Additionally, the cyber security threats to which the plant is subjected are likely to change.	IAEA SSG-39	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0230	Cyber security protection should include appropriate physical, logical, and administrative controls.	Any single physical, logical, or administrative control cannot by itself thwart cyber security threats.	IAEA SSG-39	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0240	The cyber security plan should incorporate current industry best practices.	Guidance on cyber security has been established (e.g., NEI 08-09) that provides best practices developed from experience.	NEI 08-09	Cyber Security	ALL	ALL	IMPL SEC/NP
2.02.0251	To the extent possible, instrumentation and controls of safety systems should be designed such that cyber security is not a concern for safety systems, and only represents a risk to operations.	Reducing cyber security to an operations/economic concern lessens or eliminates the regulatory burden associated with cyber security, and opens up more possibilities in regards to the use of digital controls and automation in the plant.	Industry Feedback	Cyber Security	ALL	ALL	SAFE PERF
2.02.0261	Upon removal from service, the licensee should determine and perform the required activities to protect the information of the retired Programmable Digital Device (PDD).	Information obtained from a retired digital system could be used to breach similar systems installed in the same plant or other plants. Diagnostic data pertaining to mechanical and electrical plant systems could also be used to sabotage those systems.	IEEE 7-4.3.2-2016 Section 5.9.4.8	Cyber Security	ALL	ALL	SEC/NP
2.03.0010	Digital systems should be developed, verified, and tested in compliance with accepted international standards as appropriate.	Widely-accepted international standards for digital systems ensure these systems meet minimum expectations for redundancy, independence, fault tolerance, etc.	IEEE 1012-2016 (IEEE, 2016b) IEEE 603-2009 (IEEE, 2009) IEEE 7-4.3.2-2003 and -2010 IEEE 1074-1997 (IEEE, 1997)	Instrumentation and Controls	ALL	ALL	PERF
2.03.0020	The design should include features which facilitate planning, designing, operating, maintaining, and training for the design and modification of control rooms and other human-system interfaces in a way that takes advantage of digital system and human-system interfaces technologies, reflects practical constraints associated with modernizing existing control rooms and I&C systems, and addresses issues concerning hybrid and fully digital control room human-system interfaces for the foreseeable future.	Human Factors Engineering (HFE) should be an integral part of the engineering design process for any new nuclear power plants to ensure that personnel roles and responsibilities are properly defined. HFE is also an important part of the licensing process for new builds and is required by regulation for new builds and operating plants.	EPRI TR 3002004310 (EPRI, 2015b)	Instrumentation and Controls	ALL	ALL	ECON IMPL
2.03.0030	The reactor designer and owner-operator should plan to proactively address the digital I&C obsolescence risks during the design phases by considering the already identified technical, functional, supply chain, and vendor issues, while using the existing knowledge base developed for maintaining the installed digital I&C equipment.	Obsolescence of digital I&C equipment is inevitable (essentially guaranteed with the licensed lifetime of the plant). The owner-operator needs an overall strategic plan that can mitigate the obsolescence.	EPRI TR 3002002852 (EPRI, 2014b)	Instrumentation and Controls	ALL	ALL	PERF ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0040	The obsolescence of the digital I&C systems installed as part of an advanced reactor design should be proactively managed using methods that include virtualization, equivalent changes, repair/refurbishment, defensive purchasing of spares, or an incremental/full replacement strategy.	Obsolescence of digital I&C equipment is inevitable (essentially guaranteed with the licensed lifetime of the plant). The owner-operator needs an overall strategic plan that can mitigate the obsolescence.	EPRI TR 3002002852	Instrumentation and Controls	ALL	ALL	PERF ECON
2.03.0041	The design and implementation of I&C systems and equipment should be done to facilitate backfitting, replacements and modifications and make them economically feasible.	At present, lifetime of I&C systems and equipment is considerably shorter than the lifetime of a nuclear plant. This means that it is necessary to replace I&C systems and equipment at least once during the plant lifetime. Also, the state-of-the-art of I&C technology is changing continuously and obsolescence of equipment is a continuous concern.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
2.03.0050	An HMI should be provided to promote error-free normal operations and quick, accurate diagnosis of off-normal conditions.	Allows for safe operator control.	mPower DSRS Chapter 7 and 18 (USNRC, 2013) Kemeny Commission Report on the Accident at Three Mile Island (Kemeny Commission, 1979) URD Rev 13 Tier I Chapter 3 Section 1	Instrumentation and Controls	ALL	ALL	SAFE PERF
2.03.0051	HMIs dedicated to purposes other than operation should be separated from the operating facilities.	This requirement simplifies plant operation and improves human factors.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
2.03.0060	The HMI design should be established by a defined process which begins at the same time as the rest of the plant design process.	Experience has shown that conventional design methods cannot be expected to provide good human-system interfaces. Even if all the design requirements are identified, it is unrealistic to expect them to be met in a simple and practical manner unless the design process is systematic and consistent.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0070	The HMI design process should be applied consistently to all the interfaces between the plant and its operators and support staff, and should not depend on the particular system involved.	Non-uniformity in the design approach across different systems and for different operating modes has resulted in poor operator interfaces, employing different conventions, different alarm and display philosophies, non-standardized hardware, etc. This requirement is intended to prevent such non-uniformity in the plant. Although the design process is uniform, there may be regulatory, review or documentation requirements on hardware or software that differ between safety and non-safety system.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0080	The HMI design process should explicitly consider the potential for and the consequences of failures of plant and HMI system components.	Experience shows that major challenges to an HMI design come from failures or malfunctions of equipment. Unless the design specifically considers these malfunctions, the availability and reliability of the plant will probably be adversely affected (i.e., tolerance of the system to faults needs to be designed into the system).	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	SAFE PERF
2.03.0090	Any of the functions and tasks which result from the operator coping with equipment failures should be identified as part of the HMI design bases.	Experience shows that major challenges to an HMI design come from failures or malfunctions of equipment. Unless the design specifically considers these malfunctions, the availability and reliability of the plant will probably be adversely affected (i.e., tolerance of the system to faults needs to be designed into the system).	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	SAFE PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0100	All control systems should be analyzed to assure they are stable and provide the required steady-state and transient response for all operating conditions, including abnormal conditions. These analyses should be made part of the HMI documentation.	Experience in existing plants shows that a significant number of control problems are traceable to a lack of basic design analyses. This requirement is intended to ensure that debugging, extensive adjustment, and modifications are not required on the final systems in the field. Operating experience shows that some parameters can exceed normal operating ranges under certain conditions. The HMI should anticipate these conditions and provide the ability to monitor and control parameters when necessary.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0110	Control system analyses should assume the most conservative HMI signal propagation delays for all data communications paths.	Experience in existing plants shows that a significant number of control problems are traceable to a lack of basic design analyses. This requirement is intended to ensure that debugging, extensive adjustment, and modifications are not required on the final systems in the field. Operating experience shows that some parameters can exceed normal operating ranges under certain conditions. The HMI should anticipate these conditions and provide the ability to monitor and control parameters when necessary.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0120	The HMI design should be based on the evaluation of the costs to the owner-operator over the total life of the plant.	Cost evaluations of alternate HMI designs should adequately and consistently include consideration of the costs to the owner-operator of such items as: • Operation, maintenance and repair, including radiation exposure and contamination control; • Scheduled and unscheduled plant shutdowns; • Training of operators and technicians; • Startup and surveillance testing; • Analysis and simulation; • Replacement. The initial cost of many parts of the HMI is only a small part of the eventual cost to the owner-operator. Improvements in reliability, operability, testability, and maintainability will be reflected in higher plant availability throughout the plant life and designs which have improvements in these areas may well be the least cost option for the owner. There has been a tendency to focus cost comparisons on the initial hardware costs, since these are relatively easy to establish. This requirement is intended to emphasize that the simplistic view of costs in terms of only the initial hardware is not acceptable for the advanced plant design.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	ECON
2.03.0130	The HMI design should explicitly consider and define the actions of the operators required to operate and control the plant. These actions should be within the capability of all operators.	Experience has shown that operator actions have been a major factor in most reactor incidents. This requirement is intended to ensure that the operator’s part in the plant control and operation is as carefully planned as the electronic hardware and that the actions are well within the capability of all the probable operators.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0131	The HMI should be designed to be operated by different groups of staff.	The HMI is not only task-oriented, but also has a collective dimension encompassing all the operating staff and multiple cultures, which has to be considered in the design process. The categories of users and their mutual links are important inputs for determining the flow of information.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
2.03.0132	The HMI should be designed to preclude unintentional operator actions.	Unintentional control actions can be detrimental to plant operation.	IEEE 7-4.3.2-2016 Section 5.8.2	Instrumentation and Controls	ALL	ALL	PERF
2.03.0140	The capability for continuous on-line self-testing of hardware should be provided for as much of the HMI as is practical. This testing should not affect the system functionality and should be performed on the module, as opposed to the system.	These tests may include, but are not limited to, Random Access Memory (RAM) and Read Only Memory (ROM) failure checks, arithmetic processing unit failure checks, data link buffer checks, heartbeat indications, and Central Processing Unit (CPU) reset of watch-dog timers. Continuous on-line self-testing provides continuous monitoring of overall system availability and functionality by allowing rapid identification of hardware failures.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	PERF
2.03.0150	Coverage of automated tests of HMI hardware should be sufficient to reduce or eliminate the need for periodic functional tests.	Functional tests can be complex, require considerable labor and equipment out-of-service time, and can result in spurious actuations that either affect plant availability or deter on-line testing.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	PERF
2.03.0160	The HMI should be designed to simplify and reduce the amount and difficulty of the maintenance required over the lifetime of the plant.	Experience has shown that HMI maintenance can be a significant burden on the owner-operator’s staff or can be so difficult that errors are prevalent and the plant reliability is reduced. Ease of maintenance must be designed into the HMI. It cannot be added after the design is complete.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	PERF IMPL
2.03.0161	The number of different types of HMI dedicated to operation should be minimized for both centralized and localized facilities.	Consistent with the ORG's "Simplification" policy. The distribution between localized and central control depends on task analysis factors.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
2.03.0170	Calibration, maintenance, and repair of HMI modules should not interfere with plant operation.	Most unscheduled maintenance activities should be addressed without requiring a forced shutdown.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	PERF ECON
2.03.0180	The HMI design should incorporate features that reduce the time and effort required to fabricate and install the HMI equipment; however, these features should not adversely impact the ability to operate, test, maintain, and repair the equipment.	Ease of construction and installation of the HMI is important to meeting cost and schedule goals; however, these must not overshadow the owner-operator’s long term needs for ease of operation and maintenance.	URD Rev 13 Tier II Chapter 10 Section 3	Instrumentation and Controls	ALL	ALL	ECON IMPL
2.03.0190	Data important to plant performance should be collected during operation and stored for performance evaluation, training purposes and possible machine learning.	Allows for long-term trending of key parameters so that performance can be monitored and used to educate an automated control system.	URD Rev 13 Tier II Chapter 2 Section 3	Instrumentation and Controls	ALL	ALL	PERF
2.03.0200	The reactor designer should consider using modern technologies for data transmission.	Such technologies could streamline the plant's data network, increasing operational efficiency. Examples include: • Fiber optic networks; • Wireless transmitters; • Distributed antenna systems.	Industry Feedback	Instrumentation and Controls	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0211	The owner-operator should develop a plan for the plant's data and diagnostic infrastructure early in the design process.	Advanced plants are projected to have more monitoring and diagnostic capabilities than existing plants. This will require a more sophisticated data infrastructure that will involve additional hardware and software. It may be economically beneficial to lease data and diagnostic systems, particularly for micro reactors.	Industry Feedback	Instrumentation and Controls	ALL	ALL	PERF
2.03.0221	The number of sensors deployed in an advanced reactor should be optimized.	Increasing the use of sensors can have many benefits, such as allowing for automation, staff reduction, and reduction of personnel radiation exposure. However, increasing the prevalence of sensors in the plant can lead to reliability issues (particularly for associated cables) and an increased maintenance burden. Wireless sensors can mitigate some of these concerns. However overall, sensors should only be used where there is a strong basis for improving maintenance, operability, or reliability. First-of-a-kind (FOAK) units may need more sensors than mature designs for extra monitoring, trending, etc.	Industry Feedback	Instrumentation and Controls	ALL	ALL	PERF ECON
2.03.0231	Functions that are assumed to malfunction independently in the safety analysis should not be affected by failure of a single PDD.	Two safety functions are not independent if a single PDD failure can cause both malfunctions.	IEEE 7-4.3.2-2016 Section 5.1	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0241	Functions should be configured (e.g., functionally distributed) such that a single PDD malfunction or software error does not result in spurious actuations that are not enveloped in the plant design bases, accident analyses, Anticipated Transient Without Scram (ATWS) provisions, or other provisions for abnormal conditions. This includes spurious actuation of more than one plant device or system as a result of a single PDD malfunction or software error.	Spurious actuations caused by PDD failures must be accounted for in plant analyses.	IEEE 7-4.3.2-2016 Section 5.1	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0251	Software should be developed, modified, or accepted in accordance with a software QA plan.	Software development is unique relative to other plant quality activities such that a separate set of procedures is required to ensure software is developed to a quality commensurate with the importance of the function. The software QA plan should address all software that is resident on the PDD at run time (i.e., application software, network software, interfaces, operating systems, and diagnostics) and software tools used for system development and maintenance. Guidance for developing software QA plans can be found in IEC 60880 ED. 2 (2006-05), and IEEE Std 730-2002.	IEEE 7-4.3.2-2016 Section 5.3.1	Instrumentation and Controls	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0261	The use of software quality metrics should be considered throughout the software life cycle to improve performance and assess whether software quality requirements are being met.	This provides an objective means of auditing software quality to ensure it will perform its function. The following life cycle phase characteristics should be considered: • Correctness/Completeness (Requirements phase); • Compliance with requirements (Design phase); • Compliance with design (Implementation phase); • Functional compliance with requirements (Test and Integration phase); • On-site functional compliance with requirements (Installation and Checkout phase); • Performance history (Operation and Maintenance phase).	IEEE 7-4.3.2-2016 Section 5.3.1.1	Instrumentation and Controls	ALL	ALL	PERF IMPL
2.03.0271	The basis for the software quality metrics selected to evaluate software quality characteristics should be included in the software development documentation.	Documenting a clear basis for the use of specific software quality metrics will provide confidence that those metrics adequately evaluate the software's performance, and that software quality is maintained. IEEE Std 1061 – 1998 provides a methodology for the application of software quality metrics.	IEEE 7-4.3.2-2016 Section 5.3.1.1	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0281	Software tools used to support the software life cycle process of a PDD should be incorporated into the secure development and operational environment and controlled under the CMIS.	Only controlled software tools should be used to support the development of a safety-related PDD.	IEEE 7-4.3.2-2016 Section 5.3.2	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0291	PDD V&V processes should be used to confirm that the development products of an activity conform to the requirements of that activity, and that the system performs according to its intended use and user needs.	This requirement adopts the IEEE Std 1012-2012 terminology of process, activity and task, in which software V&V processes are subdivided into activities, which are further subdivided into tasks. The term V&V effort is used to reference this framework of V&V processes, activities, and tasks. This determination of suitability should include assessment, analysis, evaluation, review, inspection, and testing of products and processes.	IEEE 7-4.3.2-2016 Section 5.3.3	Instrumentation and Controls	ALL	ALL	SAFE IMPL
2.03.0301	PDD V&V processes should address the hardware as it affects software and system, integration of the digital system components, and the interaction of the resulting PDD system with the nuclear plant.	V&V processes need to address hardware as well as software in order to ensure the PDD will adequately perform its function.	IEEE 7-4.3.2-2016 Section 5.3.3	Instrumentation and Controls	ALL	ALL	SAFE IMPL
2.03.0311	The PDD V&V activities and tasks should include system testing of the final integrated hardware, software, and interfaces.	Unit tests of hardware and software should be used to gain confidence in individual parts of the PDD, but final testing should occur with the integrated configuration to ensure the individual parts function together.	IEEE 7-4.3.2-2016 Section 5.3.3	Instrumentation and Controls	ALL	ALL	SAFE IMPL
2.03.0321	The PDD development activities and tests should be verified and validated by independent individuals or groups with appropriate technical competence, other than those who developed the original design.	Independent verification and validation is required to prevent conflict-of-interest.	IEEE 7-4.3.2-2016 Section 5.3.4	Instrumentation and Controls	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0331	A configuration management system should be in place to control software related activities.	The minimum set of software activities for configuration management should address the following: • Identification and control of all software designs, implementation, changes, functional data (e.g., data templates and databases), interfaces, and documentation (user, operating, and maintenance documentation); • Control of development activities for the supplied safety system software; • Control and retrieval of qualification information associated with software designs and implementation; • Software configuration audits; • Status accounting. IEEE Std 828-2005 provides guidance for the development of software configuration management plans.	IEEE 7-4.3.2-2016 Section 5.3.5	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0341	I&C qualification testing should be performed with the system functioning with software and diagnostics representative of those intended to be used in actual operation.	The equipment used for qualification testing must be representative of the equipment to be installed in the plant.	IEEE 7-4.3.2-2016 Section 5.4	Instrumentation and Controls	ALL	ALL	IMPL
2.03.0351	A hazards analysis should be performed to identify and address potential hazards of the PDD system.	A PDD should not present an unacceptable risk or hazard to the system or plant. A hazards analysis can reduce the risk associated with a PDD's potential adverse impacts to surrounding systems.	IEEE 7-4.3.2-2016 Section 5.5.1	Instrumentation and Controls	ALL	ALL	SAFE IMPL
2.03.0361	If reliability requirements warrant self-diagnostics, then PDD software should incorporate functions to detect and report PDD system faults and failures in a timely manner.	A typical set of self-diagnostic functions includes the following: • Memory functionality and integrity tests (e.g., programmable read only memory checksum and random access memory tests); • Computer instruction set tests (e.g., calculation tests); • PDD peripheral hardware tests (e.g., watchdog timer and keyboard tests). The following are self-diagnostic features that should be incorporated into the system design: • Self-diagnostics during PDD system startup; • Periodic self-diagnostics while the PDD system is operating; • Self-diagnostic test failure reporting.	IEEE 7-4.3.2-2016 Section 5.5.3	Instrumentation and Controls	ALL	ALL	PERF
2.03.0371	If self-diagnostic functions are integrated into the safety PDD system, these functions should be subject to the same V&V processes as the safety functions.	Self-diagnostics are a means to provide timely detection of failures. Self-diagnostics are not required for systems in which failures can be detected by alternate means in a timely manner.	IEEE 7-4.3.2-2016 Section 5.5.3	Instrumentation and Controls	ALL	ALL	SAFE IMPL
2.03.0381	Data communication between safety divisions or between safety and non-safety systems should not inhibit the performance of the safety function.	Non-safety systems must not interfere with safety systems.	IEEE 7-4.3.2-2016 Section 5.6	Instrumentation and Controls	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0391	PDD safety functions should be separated from non-safety functions such that the non-safety functions cannot prevent the safety system from performing its intended functions.	Non-safety systems must not interfere with safety systems. In PDD systems, software performing safety functions and software performing non-safety functions may reside on the same PDD and use the same PDD resources.	IEEE 7-4.3.2-2016 Section 5.6	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0401	PDD safety systems should be designed such that no input from non-safety systems is required for the system to perform its safety functions.	Safety systems must not depend on non-safety systems. Data input (e.g., setpoints and scaling) from a non-safety system that receives verification equivalent to the quality of the safety system is acceptable for use in a safety system.	IEEE 7-4.3.2-2016 Section 5.6	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0411	Safety-related software should be protected from alteration while the safety system is in operation.	Alteration during operation could have unintended and unanalyzed consequences. Hardwired interlocks or physical disconnection of incoming data transmission from the maintenance/monitoring equipment is a preferred method to control these changes.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0421	Credible communication faults should not prevent performance of required safety functions.	The minimum lists of credible faults that should be considered include the following: • Messages may be corrupted due to errors in communications processors, errors introduced in buffer interfaces, introduced in the transmission media, or from interference; • Messages may be repeated at an incorrect point in time; • Messages may be sent in the incorrect sequence; • Messages may be lost, which includes both failures to receive an uncorrupted message or to acknowledge receipt of a message; • Messages may be longer than the receiving buffer, resulting in buffer overflow and memory corruption; • Messages may contain data that is outside the expected range; • Messages may occur at a high rate that degrades or causes the system to fail (i.e., broadcast storm). It should be assumed that non-safety systems will have multiple and continual failures.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0431	Data used by multiple safety divisions should be considered a common source of failure that may adversely affect those multiple divisions.	A common source of input data can impact multiple systems and should be accounted for as a common cause failure.	IEEE 7-4.3.2-2016 Section 5.6.4.3	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0441	The Measurement and Test Equipment (M&TE) used for PDD safety systems should not adversely affect the safety system functionality.	Safety system functionality includes the entire safety system functionality and is not limited to the channel or division under test.	IEEE 7-4.3.2-2016 Section 5.7	Instrumentation and Controls	ALL	ALL	SAFE
2.03.0451	Safety-related controls and displays should be provided via safety-related operator workstations or hardwired devices such as switches, relays, indicators, and analog signal processing circuits.	The HMI is important to preventing failures and maintaining reliability.	IEEE 7-4.3.2-2016 Section 5.8	Instrumentation and Controls	ALL	ALL	SAFE PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0461	If the digital platform for the safety system was dedicated for generic use, the licensee and safety system developer should perform and document an assessment of the unused features and justify that their retention do not adversely impact the safety function, or disable or remove those functions.	COTS digital devices are not designed specifically for the application of interest and may contain additional capabilities or features that must not interfere with the intended function of the device in the desired application.	IEEE 7-4.3.2-2016 Section 5.9.4	Instrumentation and Controls	ALL	ALL	PERF
2.03.0471	The PDD safety system hardware and software configuration should not change while the safety system's division is performing its safety function.	Configuration changes during operation introduce failure mechanisms. This does not preclude automated changes in setpoint values or logic based on plant conditions, such as changes in reactor mode.	IEEE 7-4.3.2-2016 Section 5.9.5	Instrumentation and Controls	ALL	ALL	PERF
2.03.0481	Software and hardware identification, including version control, should be provided and used to verify that the correct software is installed in the correct hardware component.	Software can be difficult to manage, as various versions of the same code can exist, with minor differences that are hard to detect but can have a large impact on performance. Additionally, similar hardware may require different software. For these reasons, identifying the correct software and version for installation on the correct hardware is important.	IEEE 7-4.3.2-2016 Section 5.11	Instrumentation and Controls	ALL	ALL	PERF
2.03.0491	Software should be proven to meet reliability goals.	The method for proving reliability may include combinations of analysis, field experience, or testing. Software error recording and trending may be used in combination with analysis, field experience, or testing.	IEEE 7-4.3.2-2016 Section 5.15	Instrumentation and Controls	ALL	ALL	PERF
2.03.0501	Emphasis should be placed on the prevention and limiting of Common Cause Failure (CCF) rather than mitigation strategies for PDDs.	The use of PDDs in safety systems, has led to concerns that software design errors could lead to CCF, which might in turn disable one or more safety functions in redundant divisions of a safety system. Good software design practices go a long way to reducing the number of software design errors. These good software design practices cannot completely eliminate CCF. However, CCF can be reduced to a reasonable and adequate level in some extremely simple systems or systems using well-established mature code with extensive operating experience of a specific environment and application.	IEEE 7-4.3.2-2016 Section 5.16	Instrumentation and Controls	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.03.0511	Testing on PDDs not considered susceptible to CCF should be conducted on the PDD integrated with test hardware representing the target hardware.	A PDD is not considered susceptible to CCF if the PDD is shown to be deterministic in performance, has documentation of all functional states and all transitions between the functional states, and is testable based on the following criteria: • Testing every possible combination of inputs; • For PDDs that include analog inputs, the testing of every combination of inputs should include the whole operational range of the analog inputs; • Testing every possible executable logic path (this includes non-sequential logic paths); • Testing every functional state transition; • Test monitoring for correctness of all outputs for every case. It is possible that PDDs include unused inputs. If those inputs are forced by the module circuitry to a particular known state, those inputs can be excluded from the "all possible combinations" criterion.	IEEE 7-4.3.2-2016 Section 5.16	Instrumentation and Controls	ALL	ALL	PERF
2.03.0521	A dedicated control system should be in place for the turbo-generator system to promote automation, operational flexibility, and safety.	For electricity generating plants, the turbine and generator are important systems for plant operation and require thorough instrumentation and controls to ensure proper operation.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	SAFE PERF
2.04.0010	The design should minimize the dependence on active engineered systems to protect the owner-operator's investment.	Reducing the active components required to operate the plant simplifies the design, reduces costs, and reduces the probability of equipment failure.	URD Rev 13 Tier I Chapter 3 Section 1 EUR Volume 2 Chapter 1	Investment	ALL	ALL	ECON
2.04.0011	The number of "safety-related" and "important to safety" components and systems in the plant should be minimized.	The administration of quality assurance requirements and cost of nuclear safety-grade components are a large driver for the costs of nuclear power. Minimizing the number of plant components for which these requirements must be applied would greatly reduce plant costs. Additionally, appropriately categorizing components "non-safety-related" makes it easier to get them serviced or replaced (since relatively few vendors maintain nuclear QA programs), and reduces the risk associated with regulator fines and shutdowns.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0020	The plant should have sufficient resilience against postulated events so as to be capable of resuming operation in a reasonable time frame following postulated events.	This requirement provides safety margin, protects the owner-operator's investment, and ensures operation can be quickly resumed following an event. The acceptable timeframe for restoration depends on the owner-operator's needs.	URD Rev 13 Tier II Chapter 1 Section 2	Investment	ALL	ALL	SAFE PERF ECON
2.04.0030	Even in plants which have been designed to provide adequate safety function without any active power sources, the design should provide a non-safety related alternate on-site power source.	This requirement provides protection of the owner-operator's investment in the event of a loss of normal Alternating Current (AC) power/station blackout. Alternate AC power sources can provide the means for powering equipment that prevents unnecessary cycling of safety-related equipment or simplifies plant recovery.	mPower DSRS Chapter 8 URD Rev 13 Tier II Chapter 1 Section 2	Investment	ALL	ALL	SAFE ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0040	The capital cost of the commercially deployed unit should be competitive with the lowest priced, equivalent scale generating method in the market in which the owner-operator intends to compete.	Only a few reactors of a specific type may be built. Therefore, economies of scale cannot be relied upon for economic competitiveness. Some markets may include government subsidies or other benefits that spur investment in first of a kind plants.	EPRI TR 3002008041 (EPRI, 2016a)	Investment	ALL	ALL	ECON
2.04.0050	The lifetime levelized cost of the commercially deployed unit should be competitive with the lowest priced, equivalent scale generating method in the market in which the owner-operator intends to compete.	Only a few reactors of a specific type may be built. Therefore, economies of scale cannot be relied upon for economic competitiveness. Some markets may include government subsidies or other benefits that spur investment in first of a kind plants.	EPRI TR 3002008041	Investment	ALL	ALL	ECON
2.04.0051	The nature of the economic market (e.g., regulated vs. free) for a particular combination of mission and region, and the impact a new plant will have on it, should be considered in early economic analyses.	It is important to fully understand the economics of a proposed plant before proceeding with the project. Market behavior can change dramatically from region to region, even within one nation. For example, the electricity market near large population centers in a nation may be government-regulated, while the market in rural areas of the same nation are free to fluctuate with supply and demand.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0052	Economic analyses of the relative benefits of investing in nuclear technologies versus competing technologies should include the environmental impacts, societal impacts, and costs of land utilization.	Competing "carbon-free" energy sources such as wind power and solar power use much more land than nuclear power for the same output. This is a major consideration that should be taken into account in energy-related decision making processes. Usually multiple scenarios (e.g., carbon costs) are evaluated.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0053	The economic analyses should be continuously updated throughout the life of the plant.	Lifetimes for advanced plants may be from 40 to 80 years. Changing environmental regulations, and other factors, necessitate that economic analyses be living documents such that the owner can make informed decisions regarding life extensions, new units, changes in business plan, etc.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0060	The reactor designer and owner-operator should investigate the major plant staffing areas (engineering, operations, maintenance, outage, training, security, chemistry and emergency preparedness) for the purpose of staff optimization.	A key barrier for the deployment of any nuclear reactor design is represented by the Operating and Maintenance (O&M) costs. Staff Optimization (not staff reduction) is a crucial initiative, while maintaining the safety and reliability of the nuclear reactor.	EPRI TR 3002007071 (EPRI, 2016b)	Investment	ALL	ALL	PERF ECON
2.04.0070	The reactor designer and owner-operator should define the information needs early in the project and document the needs in a detailed information turnover specification that is jointly agreed between the EPC organization and the owner-operator.	New nuclear power plants are being designed, procured, and constructed differently, depending much more on the use, management, maintenance, and exchange of electronic information than those built previously. An improved information turnover process will translate into significant cost savings over the life of the plant.	EPRI TR 3002007425 (EPRI, 2016c)	Investment	ALL	ALL	ECON IMPL
2.04.0080	The reactor designer should be capable of providing a reasonably detailed cost estimate for the entire project, based on the reference design and estimation of differences with this cost due to inflation and prices of materials, civil works, and labor cost.	This requirement provides for information important for obtaining an accurate estimate of construction costs. The estimate should include reasonable expectations for cost growth based on experience with industrial facilities of comparable size, complexity, or technology maturity.	Industry Feedback	Investment	ALL	ALL	ECON IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0081	The cost estimate should apply the criteria in GAO-09-3SP (GAO Cost Estimating and Assessment Guide) appropriate for the current stage of the design.	If all reactor vendors used a standard cost model, the owner-operator could more easily evaluate the various design options. It also provides reassurance to investors and public service commissions as to validity of estimates.	GAO-09-3SP (USGAO, 2009)	Investment	ALL	ALL	ECON IMPL
2.04.0082	The owner should hire a third party organization with applicable experience to verify a vendor's cost estimate.	Obtaining an unbiased perspective on the accuracy of a cost estimate will give the owner confidence in project cost estimates.	Industry Feedback	Investment	ALL	ALL	ECON IMPL
2.04.0083	The owner-operator should identify the most economically critical aspects (e.g., equipment, resources) of operating a specific reactor design for a specific mission and estimate the associated costs and uncertainties for the life of the plant before committing substantial resources.	Performing this exercise will allow the owner-operator to gauge the likelihood that operating costs will increase significantly during the lifetime of the plant and to prevent or mitigate such increases, ultimately minimizing risk.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0090	Passive plants should be designed to withstand a complete loss of bulk AC power without exceeding equipment design limits for a length of time appropriate to the specific plant.	Protection for both safety-related and non-safety-related equipment should be assured in the event of a loss of AC power.	USNRC RG 1.232 mPower DSRS Chapter 8 URD Rev 13 Tier II Chapter 1 Section 3	Investment	ALL	ALL	ECON
2.04.0100	A single point vulnerability analysis should be performed early in the design phase to eliminate or, if unavoidable, manage single point vulnerabilities.	Vulnerability analyses provide insights that can be used to increase design margins for plant systems that are primary contributors to operational and safety risks. Many electrical, mechanical, and instrumentation and control components in the Balance-of-Plant (BOP) are not protected by redundant backup systems like the safety equipment. As plants age, the potential for sudden failure of BOP systems increases. Malfunctions may have minimal safety consequences, but in today's competitive electricity marketplace, their economic significance has grown.	URD Rev 13 Tier II Chapter 1 Section 3 Programs to increase plant reliability by reducing Single Point Vulnerabilities (SPVs) have mainly focused on qualitative reviews of critical plant equipment, identifying those most prone to fail.	Investment	ALL	ALL	SAFE ECON
2.04.0110	The reactor designer should implement design methods that minimize unnecessary conservatism in the design.	Design methods should be based upon realistic and accepted values and techniques rather than overly conservative assumptions. Minimizing unnecessary conservatism can reduce construction cost and schedule.	URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 12	Investment	ALL	ALL	ECON IMPL
2.04.0120	Optimized design should be based on life-cycle cost estimates that account for both the initial hardware and construction costs, realistic component replacement costs, and the operations and maintenance costs over the life of the plant (including decommissioning).	Experience and good judgment are very valuable in deciding when to apply advanced techniques. The level of engineering effort expended in design optimization should reflect plant standardization objectives that justify increased analysis and design efforts to achieve a reduction of installed hardware and plant operating cost.	URD Rev 13 Tier II Chapter 1 Section 4	Investment	ALL	ALL	ECON IMPL
2.04.0130	The EPC should be able to define construction time and deployment time with acceptable accuracy.	Capital costs typically define the economic case for nuclear reactors. Predictable timelines provide additional confidence that projected costs are accurate.	Industry Feedback	Investment	ALL	ALL	ECON IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0131	The owner-operator should identify targets for durations between key milestones early in the project and provide an economic basis. The reactor designer, EPC, and all sub-contractors should be aware of the targets and the construction and commissioning schedules should support the targets (with margin). A probabilistic assessment of schedule duration should be performed.	This ensures that schedule expectations are set up front and that plans and contingencies are in place to meet expectations. Schedule overruns result in budget overruns. Key durations include: • Start of ground work to hot testing; • Authorization to proceed with construction to First Nuclear Concrete (FNC); • FNC to mechanical completion/hot testing; • Hot testing to fuel load; • Fuel load to commercial operation.	Industry Feedback	Investment	ALL	ALL	ECON IMPL
2.04.0140	The plant should be designed to operate for a period of time that justifies the initial capital investment.	This is necessary to the economic viability of the plant.	URD Rev 13 Tier I Chapter 3 Section 2 EUR Volume 2 Chapter 2	Investment	ALL	ALL	ECON
2.04.0141	The reactor designer should provide the owner with assurance of organizational and financial stability, and that stability will last for the foreseeable future.	The owner assumes a large financial risk when they move forward with construction of a plant. If the reactor designer were unable to continue supporting the project at some point during construction or commissioning, the owner-operator could be impacted financially.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0142	Backup plans should be in place to mitigate the impact of a key supplier failing to complete a key construction/design task.	This is a risk-mitigation measure. Any source of risk that could cause the project to halt should be identified and mitigated.	Recent Lessons Learned	Investment	ALL	ALL	IMPL
2.04.0143	When beginning construction on the first unit at a particular site, the owner-operator should allocate land for the placement of additional units that may realistically be added in the future.	It is typically more economical to add a unit to an existing site than to build a new unit at a different location, due the ability of neighboring units to share services, transmission, and personnel.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0144	If multiple units in a staggered build (i.e., all units are not built at the same time) are planned to share services (e.g., dry fuel storage, service water, fire water), the shared services should be designed to be shareable from the start, rather than retrofitted with each new unit.	Initially designing sharable services with the capability to service future units will be more cost effective than redesigning the services with each addition. This may require installing certain systems for all units during construction of the initial unit (e.g., I&C cabling for shared control room, buried service water piping).	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0145	Transmission lines and systems should be designed with margins such that additional capacity may be added easily in the future.	Transmission can limit the scalability of an entire site if not designed with future scaling in mind.	Industry Feedback	Investment	ALL	GR	ECON
2.04.0150	The design should consider current and future natural resource availability and allow for flexibility where required for the long-term economic viability of the plant.	If the economic viability of the plant relies on the availability of a particular natural resource at a specified cost, then changes to the availability or cost of the resource could threaten the plant's ability to generate profit. Allowing for flexibility in the design lessens this risk. This is particularly important when considering nuclear fuels.	Industry Feedback	Investment	ALL	ALL	ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0151	The owner-operator should ensure an adequately diverse supply chain exists for investment critical materials and components (e.g., nuclear fuel, replacement components).	Previous experience has shown that the Original Equipment Manufacturers (OEMs) for components in nuclear power plants should not be relied upon to provide maintenance or replacement components for the entire plant life. The owner-operator should have a supply chain for critical components that is robust such that if one or multiple suppliers go out of business or stop servicing the component, the owner-operator still has alternate sources. Advanced plants have the potential to use more specialized nuclear fuels than the existing fleet, making the fuel supply chain particularly important.	Recent Lessons Learned	Investment	ALL	ALL	PERF
2.04.0152	When possible, the owner-operator should avoid placing constraints on the supply chain.	Building a supply chain based on political considerations (e.g., requiring local or domestic suppliers) can increase costs compared to supply chains without such limitations.	Industry Feedback	Investment	ALL	ALL	IMPL
2.04.0153	Components and materials should not be sourced from a company or country with a reputation for supplying counterfeit goods.	This helps ensure a quality supply chain.	Industry Feedback	Investment	ALL	ALL	IMPL
2.04.0154	The regulatory and political risks (specific to the desired region) of an advanced reactor using higher assay low enriched uranium fuel than existing reactors should be considered and mitigated in the siting and pre-construction phases.	Many advanced reactor designs use High Assay Low Enriched Uranium (HALEU) nuclear fuel (5% to <20% enrichment) that has higher enrichment than fuel used in currently operating reactors. The regulator will need to license the plant to operate with the desired fuel enrichment prior to operation. Therefore, the owner-operator should reach agreement with the regulator on fuel enrichment for potential sites within the regulator's jurisdiction before making significant investment.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0160	The design should protect investment critical equipment from hazards.	Siting decisions will likely preclude sites that have proximity hazards, but certain hazards cannot be eliminated. Consideration of a wide range of hazards will allow for increased siting versatility for the plant. Examples include: • Airplane crash; • Ship collision; • Industrial plant accident; • Pipeline accident; • Surface vehicle accident; • Toxic or hazardous gas release; • Propane or other detonable fluid explosion; • Internal fire; • Sabotage; • Flooding. Additionally, some equipment used in specific missions or reactor types may have unique hazards that must be considered. Designing for these hazards can help avoid damage to expensive equipment.	USNRC RG 1.232 mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 2 URD Rev 13 Tier II Chapter 1 Section 4	Investment	ALL	ALL	ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0161	"Investment critical" components and systems (i.e., those representing a large investment or those that could lead to damage of components or systems representing a large investment) that do not have operating experience in a similar application should be proven to adequately perform their function through "proof-of-concept" testing prior to the start of construction.	FOAK components and systems represent a risk to the plant's economic performance because their failure modes may not be understood as well as components with significant operating experience. In-depth separate-effects or, if needed, prototype testing can help prove to investors that the FOAK aspects of a design do not present an unacceptable economic risk.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0162	For reactor designs that have not been constructed in the past, advanced reactor developers should minimize risk through demonstrations of constructability, operability, maintainability, and reliability.	A potential owner-operator is not going to make the initial investment without proof that the design can be built on a predictable schedule for a predictable cost and that the technology will operate as intended. This requires that the designer demonstrate constructability and operability through a series of demonstrations. Demonstrations may be partial, and may involve the nuclear or non-nuclear portions of the plant. Ideally, this would involve building a series of demonstration reactors that scale up at each step, minimizing the risk and gradually increasing confidence in the full-scale reactor. However, this scenario may be economically impractical.	Recent Lessons Learned	Investment	ALL	ALL	ECON
2.04.0163	Advanced reactors should utilize Probabilistic Risk Assessment (PRA) methodologies for investment protection in addition to safety to allow the owner-operator to quantify the risks.	Traditionally, PRA has been applied to public safety considerations (i.e., defining the risk of releasing radioactive material to the environment). However, defining the economic and operational risk associated with failure of critical equipment is also important and can allow stakeholders to have more confidence in the plant's robustness.	Industry Feedback	Investment	ALL	ALL	PERF ECON
2.04.0164	Hazard analysis should be used to identify project risks.	Project risk management differs from hazard analysis in that hazard analysis is focused solely on the technical aspects of system failure mechanisms and their effect on plant safety, rather than risks to project execution. Overlap between the project risks and hazard analyses are possible when elements are common to both.	IEEE 7-4.3.2-2016 Section 5.3.6	Investment	ALL	ALL	IMPL
2.04.0170	Automatic or manual actions taken to protect the plant in certain scenarios (e.g., actuation of pressure relief systems) should not result in the damage of equipment or components.	Protects the owner-operator's investment.	URD Rev 13 Tier II Chapter 2 Section 3	Investment	ALL	ALL	ECON
2.04.0180	The final design should include features to permit necessary component replacement within the design availability requirements and should include analyses and data necessary to support the design life of materials.	Over this life span, components will need to be replaced, and special attention will need to be paid to material issues such as fatigue, corrosion, thermal aging, and radiation embrittlement effects.	URD Rev 13 Tier I Chapter 3 Section 2 EUR Volume 2 Chapter 2	Investment	ALL	ALL	PERF ECON IMPL
2.04.0190	The reactor design should consider the ability to extend the lifetime of certain components beyond the planned plant lifetime.	A longer design life should be evaluated for certain components which are difficult to replace or maintain.	URD Rev 13 Tier I Chapter 3 Section 2 Based on experience with US LWR fleet.	Investment	ALL	ALL	PERF ECON IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0200	The design should include a clear strategy for component lifetime qualification and component replacement.	For advanced reactors with long lifetimes (e.g., 40 years and longer) unexpected component replacements can present unjustifiable costs and can result in the premature decommissioning of the plant. Owner-Operators need to understand the impact of design decisions that assume operability for the life of the plant, and tradeoffs associated with this design philosophy.	Industry Feedback	Investment	ALL	ALL	ECON IMPL
2.04.0210	The reactor designer should identify components that are intended to be replaceable and those that are qualified for the life of the plant.	For advanced reactors with long lifetimes (e.g., 40 years and longer) unexpected component replacements can present unjustifiable costs and can result in the premature decommissioning of the plant. Owner-Operators need to understand the impact of design decisions that assume operability for the life of the plant, and tradeoffs associated with this design philosophy.	Industry Feedback	Investment	ALL	ALL	ECON IMPL
2.04.0220	For advanced reactor components that are intended to be qualified for the entire life of the plant, the reactor designer should develop a component replacement strategy that identifies the impacts of an unexpected replacement.	For advanced reactors with long lifetimes (e.g., 40 years and longer) unexpected component replacements can present unjustifiable costs and can result in the premature decommissioning of the plant. Owner-Operators need to understand the impact of design decisions that assume operability for the life of the plant, and tradeoffs associated with this design philosophy.	Industry Feedback	Investment	ALL	ALL	ECON IMPL
2.04.0230	Before the first permanent concrete of the first reactor unit of a site is poured, a review of the unapproved design documentation should be conducted to ensure it has no impact on the concrete being poured.	This requirement lowers investor risk. Vendor drawings that provide the necessary technical information to enable approval of detailed plant engineering documents should be completed in order to qualify the plant engineering documents as complete.	EUR Volume 2 Chapter 13	Investment	ALL	ALL	IMPL
2.04.0240	If a plant is visible from off-site, the individual facilities and the total plant should be designed and arranged so as to present a functional and pleasing appearance from all publicly accessible locations. The result should not cause significant cost increases.	Although the advanced reactor is an industrial facility, there is nothing inherently inconsistent between the need for a pleasing external appearance and the function required of the plant. A pleasing external appearance will improve the potential for the plant to be accepted by its neighbors, whereas a plant that has an obvious presence (e.g., unsightly structures, visible plumes) will be less likely to receive approval from the public.	URD Rev 13 Tier II Chapter 6 Section 2	Investment	ALL	ALL	IMPL
2.04.0250	The interior building design should consider human factors in the selection of lighting, ventilation, furnishings, color, and the allocation of space.	Promotes good housekeeping habits and leads to good morale.	URD Rev 13 Tier II Chapter 6 Section 2	Investment	ALL	ALL	IMPL
2.04.0260	Provisions should be made (e.g., viewing galleries) to facilitate public viewing of selected plant areas by persons and groups under controlled conditions.	Advanced reactors should be good stewards of their communities. Providing a means for transparency enhances the trust and cooperation an owner-operator can achieve within the advanced reactor's community. In particular, viewing the control room and other important operating spaces should be considered.	GCRA 86-002/Rev. 3 (GCRA, 1987)	Investment	ALL	ALL	ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0270	The design life of components and structures should be based on appropriate assumptions for the duty cycles and environments to which the components and structures are exposed.	This should be the basis for determining the effective life of components and structures, including such factors as the number of transient events, the number of stress cycles, the material corrosion allowance and deterioration as a result of environmental conditions.	URD Rev 13 Tier II Chapter 6 Section 2	Investment	ALL	ALL	IMPL
2.04.0280	Safety systems designed to protect against postulated events should be credited to the maximum extent possible for mitigating the effects of severe events, to reduce the reliance on additional systems required solely for severe events.	This requirement reduces the amount of equipment needed, reducing capital, maintenance, and operating costs and increasing reliability.	URD Rev 13 Tier II Chapter 6 Section 2	Investment	ALL	ALL	SAFE ECON
2.04.0290	Nuclear island design and non-nuclear systems design progress should be made in an integrated manner, and the selection of non-nuclear technology should be made early in the design process.	The design of the non-nuclear systems will influence siting, pipe and cable routing, layout, and many other important considerations that must be addressed early in the design. Attempts to select and design non-nuclear systems after significant nuclear island design work will result in re-work and attendant costs.	EPRI TR 3002008041	Investment	ALL	ALL	ECON IMPL
2.04.0300	The design should minimize or eliminate realignments needed to accomplish investment protection functions.	Minimizing realignments for important functions provides for a simpler design and reduces the potential for errors that threaten equipment.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Investment	ALL	ALL	ECON
2.04.0310	The reactor designer and owner-operator should consider the development and implementation of a data-centric Configuration Management Information System (CMIS) versus a document-centric approach.	The use of modern digital data management tools can be useful not only across the plant life cycle, including EPC and decommissioning, but also for the management of plant configuration (control of the licensing basis, plant operation, and input and control of many plant programs). Using a CMIS to model the plant in a virtual environment will verify interface adequacy during design, minimizing issues during construction. It will also improve training and facilitate communication and turnover between the reactor designer and owner-operator/EPC. The licensee (owner-operator) is ultimately responsible as the design authority, so knowledge transfer from the reactor designer to the owner-operator is important.	EPRI TR 3002003126 (EPRI, 2014d)	Investment	ALL	ALL	ECON IMPL
2.04.0311	The CMIS should integrate supply chain, operations, and maintenance and should be used throughout the life of the project to assist in design and construction, and to maintain key knowledge and configuration data.	The use of modern digital data management tools can be useful not only across the plant life cycle, including EPC and decommissioning, but also for the management of plant configuration (control of the licensing basis, plant operation, and input and control of many plant programs). Using a CMIS to model the plant in a virtual environment can also improve training and facilitate communication and turnover between the reactor designer and owner-operator/EPC. The licensee (owner-operator) is ultimately responsible as the design authority, so knowledge transfer from the reactor designer to the owner-operator is important.	EPRI TR 3002003126	Investment	ALL	ALL	ECON IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0320	Any potential owner-operator should consider proactive methods of engaging the local community and the local environmental community.	Lessons learned from canceled nuclear projects or projects that failed to complete construction due to opposition have shown that public opinion can have a major effect on the viability of a nuclear project. Methods for engaging the community include: • Hiring a Public Relations (PR) company; • Working with local community organizations (grassroots campaign) and engaging local and national environmental organizations; • Building an official information center.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0321	The owner-operator should clearly define the reactor's risks to the surrounding public and environment and the recovery effort associated with postulated events. The owner-operator should communicate this information to the public.	Defining the risks associated with a nuclear plant will allow the public to be knowledgeable and be able to make an informed comparison of the risks of the nuclear plant to those of other industrial facilities. Many advanced reactor designs have dramatically reduced postulated events and recovery requirements compared to traditional reactors and it is crucial that the public recognizes these benefits. Ideally, an advanced plant would be able to make use of existing non-nuclear off-site emergency plans (e.g., local fire department).	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0330	Any prospective non-nuclear operator should consider and mitigate the reputational risk associated with adopting a nuclear technology.	The reputation of a corporation can have a significant effect on financial performance. A non-nuclear operator should have a plan in place to deal with the potential reputational risk before beginning a nuclear project so as to protect the operator's assets. Methods include: • Hiring a PR company • Public outreach on benefits of using nuclear energy; • Joint strategy with stockholders; • Corporate communication.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0331	A prospective non-nuclear owner should consider hiring an experienced nuclear operator.	If the individuals and organizations responsible for operating the plant have prior nuclear operating experience, operation will likely be more successful.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0332	A potential owner-operator organization should develop and maintain an integrated risk matrix or registry, or a similar risk assessment tool, to ensure the risk associated with the advanced reactor project is within acceptable limits.	An advanced reactor project represents a significant investment of resources for the potential owner-operator, with an associated risk. Certain organizations will be in a more favorable position to assume this risk than others. Potential owner-operators need to consider the size of their organization, their previous experience, their current portfolio, and other factors before deciding to move forward with an advanced reactor project. Lifetimes for advanced plants may be from 40 to 80 years. Many factors, such as environmental regulations, resource availability, and advancements in competing technologies, may change during that time to effect the risks. Therefore, the risk matrix needs to be maintained.	Industry Feedback	Investment	ALL	ALL	ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0340	Any potential owner-operator should consider joining nuclear industry trade groups to take advantage of industry experience in nuclear operations.	Membership in industry organizations helps to minimize risks associated with operations and provides support for public relations. Such organizations include: • Nuclear Energy Institute (NEI); • Institute of Nuclear Power Operations (INPO); • World Association of Nuclear Operators (WANO); • Electric Power Research Institute (EPRI).	Industry Feedback	Investment	ALL	ALL	PERF ECON
2.04.0350	In the case that the plant Owner and Operator are separate entities, the division of responsibilities must be defined early in the project.	Having an Operator that is distinct from the Owner can complicate the organizational structure of the project. Each organizational interface has the potential to create miscommunication. Clearly defined roles can mitigate this risk.	Industry Feedback	Investment	ALL	ALL	IMPL
2.04.0351	The reactor size (i.e., output magnitude) should be appropriate for the owner-operator's desired mission and application.	An undersized reactor can lead to an inability to meet demand. An oversized reactor can lead to inefficiency and waste energy. Modular reactors in multi-unit configuration can allow for more flexibility in sizing the overall plant to meet immediate demand and allow for future demand growth.	Industry Feedback	Investment	ALL	ALL	PERF
2.04.0352	Secondary missions should be evaluated.	Nuclear plant power is relatively cheap once the plant is built, so using reactor power for alternative purposes when full output is not required would potentially improve the economics of the plant. For example, a plant could perform desalination processes (e.g., reverse osmosis, thermal) in conjunction with a primary mission if access to salt water is available. Certain locations could have a large market for potable water (e.g., the western United States). The water could also be used for plant operation, thus minimizing water demand. Additionally, providing water and/or minimizing the plant's water use would be beneficial for obtaining public acceptance. Hydrogen production is another option for a secondary mission.	Industry Feedback	Investment	ALL	ALL	PERF ECON
2.04.0360	Advanced reactors designed for process heat applications should be capable of operating at acceptable costs and with acceptable reliability for the load profile established by the end user.	The desired load profile is of particular concern in process heat applications.	Industry Feedback	Investment	ALL	PH	ECON
2.04.0369	A reactor intended for process heat applications could be sited in close proximity to potential customers.	The plant should be located in a strategic point where external facilities with sufficient generation capacity and consumption can be potential customers. The owner-operator should enter into long term energy supply agreements with the industrial facilities to achieve the required internal rate of return on equity.	"Next Generation Nuclear Plant Project Evaluation of Siting an HTGR Co-generation Plant on an Operating Commercial Nuclear Power Plant Site," INL/EXT-11-23282 (INL, 2011b)	Investment	ALL	PH	ECON
2.04.0370	For non-electricity-generation missions, the plant should be built so there is a clear regulatory boundary between the nuclear plant and any non-nuclear systems (e.g., hydrogen production plant, chemical processing plant, etc.).	If an industrial facility that is supplied with steam (or some other product) from a nearby nuclear plant becomes subject to a nuclear regulatory body, the increased regulatory burden could offset the economic benefits of the nuclear energy source, making the project less economically viable.	Industry Feedback	Investment	ALL	PH RP	ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0381	Metrics to represent the levelized cost of delivering the plant's product to its customers should be developed for non-electricity-generation missions (e.g., production heat).	For traditional electricity generation reactors, Levelized Cost of Electricity (LCOE) is used to perform cost analyses. Similar metrics are needed for alternative missions.	Industry Feedback	Investment	ALL	PH RP AT	ECON
2.04.0391	The design should allow siting at most sites available in a geographic area designated as the reactor designer's target market.	It is desirable for the design to be deployable in a variety of environments. However, it is infeasible to make the design deployable in all environments (i.e., seismic fault lines, sinkhole areas, etc.).	URD Rev 13 Tier I Chapter 3 Section 1 EUR Volume 2 Chapter 13	Investment	ALL	ALL	ECON IMPL
2.04.0400	Siting should consider the communities, industrial facilities, and commercial zones in the vicinity of the potential site, and how the area is likely to change during the life of the plant.	As is true with any industrial or commercial endeavor, it is important to consider the impacts a new plant may have on existing nearby entities, and the impacts nearby entities may have on the plant. Since plants can have relatively long lifetimes, potential evolutions of the locality should also be considered.	United States National Environmental Policy Act (NEPA)	Investment	ALL	ALL	ECON IMPL
2.04.0411	When a new nuclear plant is being considered to replace the output of an existing plant, the owner-operator should consider siting at/near the existing site to preserve the local community that has often been built up to support the existing plant.	This requirement is consistent with the ORG's "good neighbor" policy.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0421	When considering the deployment of a reactor, the owner-operator should consider collocating small nuclear reactors with renewable energy sources (e.g., wind, solar).	One challenge of renewable energy sources is that they vary in output significantly depending on the weather, season, time of day, etc. A nuclear plant could offset these variations. Additionally, collocating the two energy sources would allow for a shared transmission infrastructure and dual use of land.	Industry Feedback	Investment	ALL	GR OG	IMPL
2.04.0431	The owner-operator should site the reactor balancing economic, practical, safety, and emergency response considerations.	Historically, nuclear power plants have been sited in remote locales, far from large and medium sized population centers. The development of Small Modular Reactors (SMRs) and other advanced designs may allow reactors to be sited closer to population centers. This would lead to cost savings associated with transmission, and other benefits. Being able to place a reactor closer to population centers would be especially beneficial for areas where building new transmission is difficult. Additionally, micro reactors may even be sited at substations, contributing to the decentralization of power. Despite the potential benefits of siting reactors near population centers, other factors must also be considered before making the decision, such as reactor size, Emergency Planning Zone (EPZ), and public acceptance.	Industry Feedback	Investment	ALL	ALL	ECON
2.04.0441	The area around a plant that could be affected in the event of an emergency (e.g., EPZ) should be minimized.	Minimizing the EPZ (or equivalent term) could allow the plant to be placed closer to population centers, minimizing the costs associated with building transmission. Minimizing EPZ is also beneficial for public acceptance and decreases regulatory burden. Ideally, the EPZ should be within the site property boundary. Many advanced SMR designs have a small EPZ based on inherent design attributes/features.	Industry Feedback	Investment	ALL	ALL	SAFE ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.04.0451	Supply chain considerations for nuclear fuel should be taken into account when siting a particular reactor type in a specific region.	Since many advanced reactors use fuels that are different from those used in existing reactors, the supply chain infrastructure for the fuel is an important consideration. For example, nations/regions that are able to source traditional fuel through a domestic/local supply chain may not be able to do so for an alternative fuel type without years of preparation, and switching to a non-domestic supply could have political impacts.	Industry Feedback	Investment	ALL	ALL	ECON IMPL
2.04.0461	The availability of existing transmission infrastructure and the barriers to building new transmission should be considered when siting a reactor.	Transmission infrastructure represents a large capital investment with many potential societal, environmental, and political concerns. The costs (or other barriers, such as environmental constraints) associated with building new transmission could make a site infeasible for an advanced reactor.	Industry Feedback	Investment	ALL	GR	ECON
2.04.0471	The water consumption (primarily used for ultimate cooling) necessary to operate the plant should be minimized.	Historically, the siting of nuclear plants has been heavily constrained by the need to have a large body of water nearby to provide the ultimate source of cooling. Reducing water requirements could greatly increase the number of viable sites for a certain reactor design, and thus increase deployability. Additionally, reducing water requirements reduces the plant's impact on the surrounding environment, which is consistent with the ORG's "good neighbor" policy.	Industry Feedback	Investment	ALL	GR OG RP	PERF ECON
2.05.0010	The design should limit off-site consequences due to postulated events and severe events.	Off-site consequences should be minimized to assure the safety of the public. Different reactor designs may use different metrics for measuring defense in depth (for example, core damage frequency for reactors with solid fuel pins), but the minimization of off-site consequences is universal. For many designs, this will allow for minimization of the EPZ which provides several benefits.	EPRI TR 3002008041	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0020	Estimates of off-site consequences should be based on mechanistic estimates of radionuclide release, unless more bounding analyses prove to be acceptable.	Off-site consequences should be minimized to assure the safety of the public. Different reactor designs may use different metrics for measuring defense in depth (for example, core damage frequency for reactors with solid fuel pins), but the minimization of off-site consequences is universal. Specifying the evaluation of off-site consequences for postulated events and severe events is not intended to preclude the use of probabilistic methods in developing the reactor's safety case.	NUREG 1465 (USNRC, 1995)	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0030	The design should prevent breaching of fission product barriers for a minimum of 30 days with the assumption of no operator action and no off-site power.	This reduces the chance for radioactive releases in an event. Owner-Operators are interested in nuclear reactors whose safety cases rely on the most minimal assumptions for active components, operator response, and external assistance. The Fukushima-Daiichi event demonstrated that supporting infrastructure and off-site power may not be available for an extended period of time after an event.	IAEA Report by the Director General: The Fukushima Daiichi Accident (IAEA, 2015)	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0040	The design should minimize the dependence on active engineered safety systems to achieve safety requirements (see definition of active component).	Reducing the active components required to demonstrate safety simplifies the design and usually enhances the probabilistic safety metrics.	URD Rev 13 Tier I Chapter 3 Section 1 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0050	The design should rely on passive systems or phenomena to remove heat to an effectively infinite heat sink (i.e., environment) during postulated events.	These passive systems and postulated events will differ for each reactor design.	EUR Volume 2 Chapter 8	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0060	The design should maintain the ability for an intentional operator action to establish safe shutdown during postulated events and severe events.	The specific events are different for each reactor technology. These events can include reactivity insertion events (e.g., water ingress into the reactor vessel for a High Temperature Gas Reactor [HTGR], voiding in a Sodium Fast Reactor [SFR], and core cooling [volume contraction] in a Molten Salt Reactor [MSR]).	EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0070	The design should minimize the plant's vulnerability and susceptibility to initiating events.	This enhances the plant's safety case.	URD Rev 13 Tier I Chapter 3 Section 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0071	The safety of the reactor should not be impacted by the status of the BOP.	Components and systems that do not impact reactor safety should be clearly delineated to allow for a graded approach to applying quality standards to BOP SSCs. Procurement cost, maintenance cost, administration of quality assurance requirements, and extent of required safety analysis are greatly reduced when an SSC's safety category is appropriately assigned.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0080	The design should minimize or eliminate realignments needed to accomplish safety functions.	Minimizing realignments for important functions provides for a simpler design and reduces the potential for errors that challenge safety systems.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0090	Simplification should be emphasized in plant design so as to enhance accident resistance and reliability.	Simplification is considered essential to all aspects of plant design. It is particularly important to minimize the occurrence of initiating events which could lead to more serious transients and accidents.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0100	Ample margin should be designed into the plant so as to reduce the likelihood of exceeding limiting conditions of operation, reduce the frequency of trips, and improve accident resistance.	Design margin will provide a more forgiving and resilient plant, which enhances the success of operator response and allows recovery from initiating events more readily without the need for actuation of active equipment or separate, quick acting engineered safety systems. Using ample margin may allow the plant to accommodate material failures or changes in licensing without having to complete a modification or component replacement. Key design margin requirements include: • Greater margins for accommodating operating transient conditions through characteristics such as larger coolant/heat sink inventory and longer response time to transient conditions; • Provide sufficient margin to reduce the likelihood of exceeding limiting conditions of operation; • Provide significant margin between normal operating range and reactor trip set points.	mPower DSRS Chapter 7 USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0110	The design should rely on natural feedback mechanisms and other inherent safety features to demonstrate that postulated events do not result in unmanaged adverse consequences.	Inherent safety features, such as natural reactivity feedback mechanisms, reduce the complexity of the design and reduce the chances for system failures to impact the safety of the plant.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0120	The reactor designer should define and analyze the postulated events that are to be accommodated in the plant design.	The design basis analyses should be used to show that fuel design limits or off-site release criteria are met and that design features are adequate to protect the owner-operator's investment. Applied in order to verify: • The functional adequacy of major plant systems and components, including the sizing and the number of cycles of operation; • The structural adequacy of plant systems, components and structures, including reactor vessel internals; • The operational adequacy of plant procedures.	URD Rev 13 Tier II Chapter 1 Section 2 The selection of, and protection against, design basis accidents is common to existing licensing paradigms. Probabilistic methods can be used to support the safety case, even to develop the key metrics against which the design is judged, but showing protection against design basis events will continue to objectively demonstrate the safety case.	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0130	The reactor designer should perform best estimate analyses to support the generation of normal, transient, and emergency operating procedures and operator training material.	Plant operating procedures must reflect a true representation of plant performance and not be based solely on licensing design basis analyses.	mPower DSRS Chapter 13 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 14	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0140	The plant should be designed to allow the operator significant time to evaluate the plant conditions and decide what, if any, manual action is needed.	This requirement minimizes the demands on the operator and provides increased time for operator diagnosis and response. Many plant designs will not credit operator actions for postulated events for long periods of time. However, designing the plant to provide operators with time for evaluation and action may provide additional margin to safety criteria and may enhance the operators' ability to prevent equipment damage or to reduce the chances for challenges to safety systems.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0150	The interactions of safety related systems with each other and with non-safety systems should be evaluated to show that these interactions are unlikely to result in unintended effects on the function of one or more safety systems.	The evaluation should consider mechanical, electrical/magnetic, chemical, and digital interactions.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0160	The plant should be designed so as to prevent operator override of safety system functions as long as a valid safety system actuation signal exists. In cases where operator overrides are desirable (as determined in design analysis), it should be demonstrated that the override function prevents challenges to safety limits or equipment damage and that the function can be well controlled through the use of procedures or interlocks.	Operator overrides introduce the possibility for operators to incorrectly prevent necessary safety actions. However, some operator overrides may be necessary to prevent inappropriate safety system actuation or continued safety system operation from causing damage to plant components. In applications which warrant such operator overrides, the design must carefully control them, to ensure that they cannot be implemented when a valid safety system signal is present and needed.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0170	If a plant must depend on active safety systems, the design must demonstrate the defense-in-depth of the systems' power supplies.	If dependency on active safety systems cannot be avoided, then power supplies for such systems should be independent, diverse, and redundant such that postulated events are unlikely to disable all credited safety features.	URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0180	The plant should have the capability of achieving safe shutdown with safety related equipment only, for all identified postulated events, assuming the most limiting single failure.	Defines conditions associated with safe shutdown and minimum requirements for safety related equipment.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0190	The reactor designer should identify all initiating events that are significant contributors to the risk of fission product release.	The intent is to ensure the events analyzed are complete for an advanced plant with potentially unique features. Insights from risk assessments may be useful in identifying an appropriate set of initiating events.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0200	The list of initiating events should be classified into postulated events and severe events.	Classification of the postulated events and severe events determines what falls within the design basis, and the acceptance criteria to be applied to each analysis.	NUREG-0800 Chapter 15 (USNRC, 2017)	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0210	Postulated events should be classified by their frequency of occurrence.	Appropriate frequency classifications for postulated events are important for determining the safety significance of plant systems, and provide a framework for PRA inputs. Suggested classifications are as follows: • Moderate Frequency - Those events any one of which may occur during a calendar year for a particular plant; • Infrequent events - Those events any one of which may occur during the life of a particular plant; • Limiting Faults - Those events that are not expected to occur over the lifetime of the plant but are postulated because their consequences would include the potential for release of significant amounts of radionuclides.	URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0220	The reactor designer should identify potential single equipment failures which could occur coincident with identified postulated events.	Single equipment failures that are selected should be those that are limiting for the initiating event, given specified fuel, reactor boundary, and containment limits (i.e., consistent with the single failure criterion).	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0230	Once a site is identified as a possible location for the deployment of an advanced reactor, the reactor designer and owner-operator should start a rigorous and comprehensive process of selecting and scoring this potential site, using different siting criteria, in order to evaluate its suitability.	To deploy a new nuclear reactor, the applicant must receive permits from the regulator for the construction and operation of the reactor. In addition to the regulatory requirements, the approved site must also satisfy business objectives for the project, allow for plant operation, and comply with process requirements for the consideration of alternative sites. Engagement of the public is also a necessary element in this process.	EPRI TR 3002005435 (EPRI, 2015a)	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0250	Before making the final decision during the site selection process, the reactor designer and owner-operator should consider the suitability of the site from the perspectives of the business plan for the new nuclear plant, existing knowledge for the site under consideration, and other specific site characteristics (e.g., ownership, seismic and meteorological).	To deploy a new nuclear reactor, the applicant must receive permits from the regulator for the construction and operation of the reactor. In addition to the regulatory requirements, the approved site must also satisfy business objectives for the project, allow for plant operation, and comply with process requirements for the consideration of alternative sites.	EPRI TR 3002005435	Licensing and Safety Analysis	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0260	The reactor designer should develop the technical basis for severe accident management, including the Emergency Procedure Guidelines (EPGs) to assure reactor protection, meet off-site dose limits, and mitigate the effects of radionuclide release.	The experiences of Three Mile Island (TMI) point out the need for a severe accident management program.	mPower DSRS Chapter 19 URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0270	The reactor designer should use the plant specific PRA and other relevant information to confirm that the plant design is compatible with the EPGs and severe accident management program.	The experiences of Three Mile Island (TMI) point out the need for a severe accident management program.	mPower DSRS Chapter 19 URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0280	The reactor designer should clearly articulate a defense in depth strategy for containing fission products early in the design process.	Advanced reactors utilize different fission product barriers and have different sources of fission products, depending on the design. The strategy for containing fission products should include successive physical barriers, just as large LWRs have traditionally done. Since these barriers are often different than those traditionally used in LWRs, they should be very clearly articulated for the benefit of the owner-operator and the regulator.	NUREG-0800 3.8.1-3.8.3 URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0290	Severe accident risk should be evaluated using PRA, and it should be demonstrated by the reactor designer that the off-site risk is consistent with the regulators health objectives.	Events with severe off-site consequences should be very remote in probability. This requirement will also help to achieve long-term public acceptance of nuclear power. This requirement is also consistent with regulator quantitative health goals.	mPower DSRS Chapter 19 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0300	The scope of the PRA should include internal and external events (excluding seismic events and sabotage) and including assessment for reduced and shutdown operating conditions.	Events with severe off-site consequences should be very remote in probability. This requirement will also help to achieve long-term public acceptance of nuclear power. This requirement is also consistent with regulator quantitative health goals.	mPower DSRS Chapter 19 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0310	Critical equipment that could be exposed to hazardous temperature, pressure, or radiological conditions as a result of postulated events (e.g., located inside containment) should either be protected from those events or qualified to operate under the hazardous conditions that can result from them.	Components, including instrumentation and control equipment, that are located inside containment and are required to function following postulated events should be protected from hazards that can result from those events.	URD Rev 13 Tier II Chapter 3 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0320	For passive plant designs, functional containment sufficient to meet off-site dose limits should be maintained for at least 30 days without the need for off-site assistance. Beyond 30 days, only simple operator action and minimal off-site assistance should be necessary to maintain required functional containment.	Provides for low leakage during severe events and reduces reliance on off-site assistance.	mPower DSRS Chapter 8 URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0330	Design analyses should use proven methods and reasonably conservative assumptions.	Unrealistic assumptions can reduce plant safety, increase plant costs, and limit plant operation. Analysis costs can be reduced by performing enveloping calculations. However, the impact of these enveloping calculations on plant costs and operations should be justified. Conservatism should be consistent with regulatory requirements. Conservatism assumed in safety margin analyses should be justified by the reactor designer.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1 Appendix B	Licensing and Safety Analysis	ALL	ALL	SAFE ECON

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0340	The design should allow for simplification and standardization of emergency planning.	Utilities have repeatedly expressed concern about emergency response features (such as early notification of and evacuation planning for the public) which are intrusive on the public and increase costs and investment risk without commensurate safety benefits. The intent is to retain the on-site plan and certain off-site emergency response actions, but demonstrate that early notification and evacuation planning for the public are not necessary to assure adequate public safety.	NUREG-0654/FEMA-REP-1, Rev. 1 (USNRC, 2011) URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE ECON
2.05.0350	During the EPZ size determination phase, the reactor designer and owner-operator should consider demonstrating a reduced risk profile for their advanced reactor to the regulator, and should propose the use of advanced warning systems during events and emergency situations.	An EPZ is designed to protect communities near the nuclear facility from radiation exposure in the event of an accident. The selected EPZ represents a zone within which food products, livestock, and water would be monitored to protect the public from radiological exposure through consumption of contaminated foodstuffs.	EPRI TR 3002008037 (EPRI, 2016d)	Licensing and Safety Analysis	ALL	ALL	SAFE ECON
2.05.0351	Emergency planning should consider the ability of communities and individuals to evacuate the EPZ, taking into account local weather and other considerations.	Advanced reactors may be sited at locations with geographic factors that are not considered for existing plants. For example, an advanced reactor could be placed in a rural area with heavy snowfall and limited mobility in the winter, in which case any local population may not be able to evacuate. Limiting off-site consequences reduces this concern.	EPRI TR 3002008037	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0360	The reactor designer should account for natural occurring phenomena.	The plant should not lose the capability to perform designed safety functions as the result of naturally-occurring phenomena. Consideration of a wide range of natural phenomena will allow for increased siting versatility for the plant. Examples include: • Earthquakes; • Hurricanes (severe winds); • Floods (heavy rains); • Tornado winds or missile strike; • Blizzards (ice storms and heavy snows); • Tsunami or seiche.	USNRC RG 1.232 mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 2 URD Rev 13 Tier II Chapter 1 Section 4	Licensing and Safety Analysis	ALL	ALL	SAFE IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0370	The reactor designer should account for man-made hazards.	Siting decisions will likely preclude sites that have proximity hazards, but certain hazards cannot be eliminated. Consideration of a wide range of hazards will allow for increased siting versatility for the plant. Examples include: • Airplane crash; • Ship collision; • Industrial plant accident; • Pipeline accident; • Surface vehicle accident; • Toxic or hazardous gas release; • Propane or other detonable fluid explosion; • Internal fire; • Sabotage; • Flooding.	USNRC RG 1.232 mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 2 URD Rev 13 Tier II Chapter 1 Section 4	Licensing and Safety Analysis	ALL	ALL	SAFE IMPL
2.05.0380	The design should demonstrate that chemical hazards (e.g., fires, inert gas engulfment) resulting from postulated events do not pose a threat to the public or degrade the operators' ability to respond to the event.	Advanced reactor designs introduce chemicals with potentially different hazard concerns from LWR experience. These new chemicals should be considered for possible hazards, and these hazards should be mitigated.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0390	A temperature control system should be provided for components in extreme thermal environments, or where temperature control is required for a material or substance to maintain the phase of matter required to perform its function.	A component subject to hot or cold conditions must be maintained at temperatures at which the component is proven to perform its function. Depending on the component and the environment, this may require heating or cooling for the component. Similarly, certain materials or substances must be regulated into order to maintain the desired phase (e.g., liquid sodium).	USNRC RG 1.232 NUREG-1368 (USNRC, 1994)	Licensing and Safety Analysis	ALL	ALL	SAFE IMPL
2.05.0400	The reactor designer should establish spatial separation criteria to preclude unwanted interactions between SSCs.	Spatial interactions are a part of Unresolved Safety Issue (USI) A-17, Systems Interaction.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 4	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0410	In cases where electrical components are exposed to extreme environmental conditions, the qualification basis and evaluation of risks should carefully consider whether the environmental challenges could possibly change overarching assumptions such as common mode failures, maintainability, and reliability that were based on prior experiences outside the new environments.	To demonstrate that the equipment will perform its design function on demand to meet system performance requirements when subjected to the design environmental conditions. Some advanced reactors will present new challenges for equipment, when considered under postulated event conditions.	mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0420	It is the owner-operator's responsibility to obtain the necessary licenses and permits with the support of the reactor designer.	In order for the advanced reactor project to accomplish its goals, it is necessary and appropriate to cover all licensing aspects.	URD Rev 13 Tier II Chapter 1 Section 10	Licensing and Safety Analysis	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0430	The reactor designer should assist the owner-operator in developing and implementing a licensing plan that identifies, defines, and schedules the activities required to obtain all the licenses and permits needed to construct and operate the advanced reactor.	This plan should be completed early enough to allow implementation of the plan and obtain all needed permits and licenses on a schedule compatible with the plant construction schedule. The licensing plan should be revised and updated, as appropriate, as licensing and construction of the plant progresses.	URD Rev 13 Tier II Chapter 1 Section 10	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0431	If there are multiple viable licensing paths available, the owner-operator should decide which approach to take early on in the process.	The nuclear regulator may allow for flexibility in the process used to obtain licensing (e.g., 10CFR50 versus 10CFR52 processes in the United States). The licensing approach taken can impact decision making throughout the design and construction of the plant.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0432	Licensing documents should provide enough detail on the design to form a design basis, but should also avoid over-constraining the construction and design details.	The amount of information requiring regulatory approval to change design detail should be minimized. Having some flexibility in the detailed design will allow for easier construction and operation.	Recent Lessons Learned	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0433	For plants with multiple units (including modular reactor plants), the owner-operator should interface with the regulator to determine a licensing approach in which one license can be obtained for the entire plant, rather than for individual units.	For some multi-unit plants (particularly small modular reactors), obtaining a license for each unit separately would make the plant economically infeasible. Owner-operator should consider the licensing options prior to this interface and make the case for the approach considered most advantageous from a regulatory efficiency perspective while providing each unit to operate for a 20 year period.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0440	The reactor designer should establish a set of principal design criteria for the advanced reactor that will be documented in the Safety Analysis Report.	Principal design criteria (or their equivalent) are required by regulators to demonstrate the safety of the plant and overall compliance with existing regulation. They should be based on existing high-level regulatory requirements.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 10	Licensing and Safety Analysis	ALL	ALL	SAFE IMPL
2.05.0450	The reactor designer should include design features in accordance with current regulatory requirements and guidance unless such design features are based on plant optimization that obviates the current regulatory requirements.	Current technology provides the basis for changing current regulatory requirements and guidance. In cases where existing regulation is obviated by the design, the reactor designer should be prepared to provide detailed justification for the exception.	URD Rev 13 Tier II Chapter 1 Section 10	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0460	In cases where the current regulatory requirements do not apply, the elimination of required design features should be reflected in the principal design criteria.	Current technology provides the basis for changing current regulatory requirements and guidance.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 10	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0470	The reactor designer should support the owner-operator, as requested, in preparation of a site characteristics report for the plant site chosen for the advanced reactor. The report should be formatted and completed in a manner that facilitates the approval of the various licenses and permits required for construction.	This report should cover those characteristics of the site needed to obtain the necessary licenses and permits as well as those needed to define a firm design basis for the plant. The reactor designer's support of the owner-operator is necessary to establish the plant site characteristics.	URD Rev 13 Tier II Chapter 1 Section 10	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0480	Where generally recognized codes and standards are used, they should be identified and evaluated to determine their applicability, adequacy, and sufficiency, and should be supplemented or modified as necessary to assure a quality product.	The use of existing codes and standards will require some validation given the unique characteristics of the advanced reactor's design.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0490	Appropriate records of the design, fabrication, erection, and testing of SSCs important to safety should be maintained by or under the control of the owner-operator throughout the life of the unit.	Without control of documentation, the owner-operator will have difficulty maintaining the plant.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0500	The design bases for SSCs important to safety should reflect appropriate combinations of the effects of normal and postulated event conditions with the effects of the natural phenomena.	Natural phenomena can act as initiating events. Therefore, they should be considered as occurring simultaneously with the initiating event.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0501	Safety-related components and systems that do not have operating experience in a similar nuclear application should be proven to adequately perform their safety function through "proof-of-concept" testing prior to the start of construction.	FOAK components and systems represent a risk to the integrity of the reactor design because the failure modes may not be understood as well as components with significant operating experience. In-depth separate effects or, if needed, prototype testing can help prove to a regulator that the FOAK aspects of a design do not present an unacceptable safety risk.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0510	SSCs important to safety should be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions.	This reduces the susceptibility of the plant to a fire or explosion.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0520	Fire detection and fighting systems of appropriate capacity and capability should be provided and designed to minimize the adverse effects of fires on SSCs.	This reduces the susceptibility of the plant to a fire or explosion.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0530	Each plant building should have multiple, pre-defined escape routes for personnel in the event of a fire. These routes should be designed to be protected in the case of a fire.	To prevent injury or loss of life of personnel in the event of a fire.	URD Rev 13 Tier II Chapter 6 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0540	SSCs important to safety should not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0550	The reactor core and associated structures, coolant, control, and protection systems should be designed to assure that power oscillations which can result in conditions exceeding specified acceptable design limits are not possible or can be reliably and readily detected and suppressed.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement and to generalize the design limits to which the requirement refers. In some advanced reactor designs, fuel design limits may not be the limits associated with preventing a fission product release (e.g., MSRs).	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0560	Instrumentation should be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for postulated event conditions as appropriate to ensure adequate safety, including those variables and systems that can affect the fission process and the integrity of fission product boundaries.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to emphasize fission product boundaries rather than structures specific to any one design type. Appropriate controls should be provided to maintain these variables and systems within prescribed operating ranges.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0570	The reactor coolant boundary should be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactors rely upon the reactor coolant boundary for a safety function.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE PERF
2.05.0580	The reactor coolant system and associated auxiliary, control, and protection systems should be designed with sufficient margin to assure that the design conditions of the reactor coolant boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactors rely upon the reactor coolant boundary for a safety function.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0590	A means of containing fission products should be provided to establish a low-leakage barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated event conditions require.	For some designs, the barrier considered to serve as containment may significantly differ in design from the traditional concrete containments of LWRs. However, any nuclear system must include design features that act as physical barriers to fission product release.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0600	If electric power is required for safety system operation, the power supplies should be designed, built, and tested to ensure that sufficient independence and redundancy exist in the safety-related power supplies.	This requirement is reduced from the scope of USNRC's Advanced Reactor Design Criterion 17. Since advanced reactors are expected to maximize the use of passive safety systems, explicit, detailed requirements for off-site and on-site power are avoided in the ORG.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0610	An area in the plant should be provided from which actions can be taken to operate the nuclear power unit under normal conditions and to maintain it in a safe condition under postulated event conditions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0620	Adequate radiation protection should be provided to permit access and occupancy of the control room under postulated event conditions without personnel receiving radiation exposures in excess of regulatory limits during the duration of the event.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0630	Adequate habitability measures should be provided to permit access and occupancy of the control room during normal operations and under postulated event conditions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0631	In addition to the primary control room, a remote shutdown station should be available with sufficient controls to shut down the reactor and maintain safe conditions following an accident.	A backup control room that can shut down the reactor is needed in the event the primary control room becomes inhabitable. The remote shutdown station can be on-site or off-site.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0640	The protection system should be designed (1) to initiate automatically the operation of appropriate systems, including the reactivity control systems, to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences and (2) to sense postulated event conditions and to initiate the operation of systems and components important to safety.	Automatic protection systems remove the potential for human error and ensure protective system response in time to meet the safety basis.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0650	The protection system should be designed for high functional reliability and in-service testability commensurate with the safety functions to be performed.	Including sufficient redundancy and independence allows for in-service testing, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0660	Redundancy and independence designed into the protection system should be sufficient to assure that (1) no single failure results in loss of the protection function and (2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated.	Including sufficient redundancy and independence promotes the reliability of the design.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0670	The protection system should be designed to assure that the effects of natural phenomena, and of normal operating, maintenance, testing, and postulated event conditions on redundant channels do not result in loss of the protection function, or should be demonstrated to be acceptable on some other defined basis.	Design techniques, such as functional diversity or diversity in component design and principles of operation, can be used to the extent practical to prevent loss of the protection function.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0680	The protection system should be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water, and radiation) are experienced.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0690	The protection system should be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system.	Interconnection of the protection and control systems is limited so as to assure that safety is not significantly impaired.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0700	Reactivity control systems should include a means of shutting down the reactor to ensure that, under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions, design limits for fission product barriers are not exceeded.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0710	Reactivity control systems should include a means of shutting down the reactor and maintaining a safe shutdown under design-basis event conditions, with appropriate margin for malfunctions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0720	Reactivity control systems should include a means of holding the reactor subcritical under varying ranges of shutdown temperatures.	This requirement has been adapted from the USNRC's Advanced Reactor Design Criteria (ARDCs) to account for the variation in temperature reactivity among different advanced reactor designs.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0730	The protection and reactivity control systems should be designed to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0740	The reactor coolant boundary should be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated event conditions (1) the boundary behaves in a non-brittle manner and (2) the probability of rapidly propagating fracture is minimized.	This requirement was adapted from the USNRC's Advanced Reactor Design Criteria (ARDCs) but has been modified to a "should" statement since not all advanced reactors rely on the reactor coolant boundary to perform a safety function.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0750	A system to maintain reactor coolant inventory for protection against small breaks in the reactor coolant boundary should be provided as necessary.	For reactors which must retain reactor coolant inventory to maintain the cooling of solid fuel, a means of maintaining inventory should be capable of making up for leaks due to small breaks.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0760	A system to remove decay heat should be provided. The system safety function should be to transfer fission product decay heat and other residual heat from the reactor core to an ultimate heat sink.	This requirement was adapted from USNRC's Advanced Reactor Design Criterion 34, but has been simplified. Decay heat removal will be required for any nuclear system, but safety metrics are more likely to be defined based on preventing fission product release rather than preventing physical damage to any individual structure or component (e.g., structural damage to solid fuel). Additionally, the system may not be comprised of any equipment dedicated solely for the purpose of shutdown decay heat removal and the system may not incorporate any active components, depending on the design.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0770	The containment heat removal system should be designed to permit appropriate periodic inspection of important components, to assure the integrity and capability of the system.	Examples were deleted to make the USNRC's Advanced Reactor Design Criterion 39 technology neutral.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0780	Systems to control fission products and other substances which may be released into the reactor containment should be provided as necessary to reduce the concentration and quality of fission products released to the environment following postulated events, and to control the concentration of other substances in the containment atmosphere following postulated events to assure that containment integrity is maintained.	Advanced reactors offer the potential for reaction product generation that is different from that associated with clad metal-water interactions.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0790	Atmosphere cleanup systems should be designed to permit appropriate periodic inspection and testing of important components, such as filter frames, ducts, and piping to assure the integrity and capability of the systems.	This requirement is based on the USNRC's Advanced Reactor Design Criteria (ARDCs) but has been generalized to any atmosphere cleanup systems since some designs do not rely on traditional containments. The requirement is also changed to a "should" statement to reflect variations in advanced reactors' reliance on atmosphere cleanup systems to prevent or limit radioactive releases.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0800	A system to transfer heat from SSCs important to safety to an ultimate heat sink should be provided, as necessary, to transfer the combined heat load of these SSCs under normal operating and postulated event conditions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0810	The nuclear power unit design should include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated operational occurrences.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0820	The fuel storage and handling, radioactive waste, and other systems that may contain radioactivity should be designed to ensure adequate safety under normal and postulated event conditions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0830	Radioactive systems (including fuel handling systems) should be designed (1) to permit appropriate periodic inspection and testing, (2) with suitable shielding, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability as appropriate, and (5) to prevent significant reduction in fuel storage cooling under postulated event conditions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0840	The reactor core and associated components/systems should be designed such that sub-criticality is maintained during all stages of ex-core fuel handling, including planned intermediate fuel configurations and any single failure or procedural error.	This requirement contributes to a high degree of nuclear safety during fuel-handling operations.	URD Rev 13 Tier II Chapter 4 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0850	Appropriate systems should be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0860	Means should be provided for monitoring enclosed atmospheres, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated events.	This requirement is based on the USNRC's Advanced Reactor Design Criteria (ARDCs), but has been modified to use "enclosed atmospheres" in lieu of containments since some designs do not rely on traditional containments.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
2.05.0868	Environmental impact studies should be performed for sites under consideration to ensure the plant will not have an adverse impact to the surrounding environment, or that such impacts can be reliably mitigated.	The environmental impacts of a plant to the surrounding environment are becoming a larger concern for the public and regulatory organizations. Impacts to groundwater and local wildlife are particularly important. Plants that utilize less land area are likely to have smaller impacts to the environment. This requirement is consistent with the ORG's "good neighbor" policy.	United States National Environmental Policy Act (NEPA)	Licensing and Safety Analysis	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.05.0869	The environmental impact studies should be continuously updated throughout the project.	Lifetimes for advanced plants may be from 40 to 80 years. During that time environmental regulations could change, or new local environmental considerations could arise. For example, the migration patterns of a certain species of fish could shift, causing the fish to swim past river waters impacted by the plant. This type of discovery would need to be accounted for in the plant's environmental impact studies, and mitigating actions taken if needed.	United States National Environmental Policy Act (NEPA)	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0870	Environmental requirements for decommissioning should be considered in the design.	Anticipating decommissioning requirements will inform the design and ultimately will reduce decommissioning costs.	NUREG-0586 (USNRC, 2002)	Licensing and Safety Analysis	ALL	ALL	IMPL
2.05.0880	For process heat applied to hydrogen production, the plant should be configured with the reactor modules physically separated by a specified distance from the systems and components of the hydrogen process plant.	Specifying the separation distance will require tradeoffs balancing assessed risk, the cost of the coupling heat transport system versus the distance separating the nuclear heat source and hydrogen production plant, features to mitigate potential events associated with a proximate hydrogen plant and other considerations, such as the implications of hydrogen production plant workers within the exclusion area boundary of the nuclear heat source.	EPRI TR 1009687 (EPRI, 2004) GCRA 86-002/Rev. 3	Licensing and Safety Analysis	ALL	PH	SAFE
2.05.0081	The designer and the owner-operator of a process heat reactor applied to hydrogen production plant should add a new category of safety issues to deal with the presence of large amounts hydrogen and oxygen.	The presence of oxygen or hydrogen at elevated temperatures and – at least in the case of hydrogen – stored in large volume exacerbates this safety concern. If released from the plant, the oxygen effluent is both a safety and environmental concern.	EPRI TR 1009687	Licensing and Safety Analysis	ALL	PH	SAFE
2.06.0010	The design should include features that allow for and optimize the performance of maintenance activities.	Maintenance considerations must be factored into the design in order for the plant to be maintainable.	URD Rev 13 Tier II Chapter 3 Section 2 URD Rev 13 Tier II Chapter 8 Section 3 EUR Volume 2 Chapter 7	Maintenance and Operability	ALL	ALL	PERF
2.06.0011	The plant should be designed to minimize the need for operator action.	This reduces the costs associated with training operators and improves plant reliability.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF ECON
2.06.0020	Proven diagnostic monitoring techniques should be used for leak detection, vibration, and other potential degraded component conditions.	Necessary to improve incipient failure detection of rotating equipment, high pressure systems, valves, fuel components, and other items so as to increase accident resistance and availability of the plant.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	SAFE
2.06.0030	Diagnostic monitoring techniques should, to the maximum extent possible, be incorporated into the design such that their implementation does not constitute a separate investment of manpower, material, or radiation exposure.	Improves planning and maintenance scheduling for equipment upkeep.	Industry Feedback	Maintenance and Operability	ALL	ALL	ECON
2.06.0040	Requirements for component operation and Equipment Reliability (ER) routine and diagnostic monitoring should be established during design and initial procurement.	The reactor designer and the vendors of components are the best sources of monitoring, diagnostic and preventive maintenance details for components defined as critical to plant equipment reliability. It is essential that this information be determined and documented at the initial stage of plant design and procurement.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	SAFE
2.06.0050	Current best practices in non-destructive evaluation should be used, where possible, to evaluate the condition of components both prior to installation, and during service.	Non-destructive evaluation can give confidence in the condition of components, and can inform when replacement is necessary.	EPRI TR 3002012389 (EPRI, 2017b)	Maintenance and Operability	ALL	ALL	SAFE PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0060	Necessary monitoring instrumentation and access for monitoring should be provided.	The reactor designer and the vendors of components are the best sources of monitoring, diagnostic and preventive maintenance details for components defined as critical to plant equipment reliability. It is essential that this information be determined and documented at the initial stage of plant design and procurement.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	SAFE
2.06.0070	Permanent features should be designed into the plant to facilitate connection and use of any portable equipment required for off-site assistance. These features should be designed to minimize radiation exposure during required actions to establish the connection.	Reduces demands on operator and reduces radiation exposure.	URD Rev 13 Tier II Chapter 1 Section 2 Post-Fukushima FLEX requirements NEI 12-06 (NEI, 2016)	Maintenance and Operability	ALL	ALL	SAFE
2.06.0080	All maintenance and operating procedures should be fully demonstrated and qualified by the supplier of the equipment to achieve the intended end result.	The availability and use of qualified maintenance tooling and test equipment has been shown to reduce the number of man-hours required to successfully complete required maintenance.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
2.06.0081	The design should minimize the feedback of balance-of-plant transients on reactor operation and where interactions can occur, they should be evaluated.	This simplifies operation and maintenance and reduces associated costs by designating “non-safety related” quality standards to BOP SSCs.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
2.06.0090	The components that require local manual operation, as required by plant emergency and beyond design basis procedures, such as for containment venting, should be located in plant areas that are accessible given post-accident radiation levels and temperatures.	Minimizes the probability of containment failure in the unlikely event a transient progresses to radionuclide release by providing independent means of maintaining containment integrity.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Maintenance and Operability	ALL	ALL	SAFE
2.06.0100	The plant should be designed so that occupational radiation exposure is controlled well below regulatory guidelines without unreasonably impeding plant operation.	Industry exposure values have generally decreased over time as a result of applying improved technology and operational practices.	URD Rev 13 Tier II Chapter 1 Section 3 EUR Volume 2 Chapter 4	Maintenance and Operability	ALL	ALL	SAFE IMPL
2.06.0101	Application of radiological controls should be balanced against other risks to plant personnel (e.g., medical, confined space, heat stress).	The current nuclear fleet has strict controls on radiation exposure and contamination of personnel. These practices exist to protect personnel. However, sometimes radiological controls can be enforced to the detriment of personnel safety if other hazards are present. For example, if a personnel has a medical emergency while in a radiologically protected area but is found to be contaminated, the medical emergency should be prioritized above contamination protocol, as it is the more immediate threat to personnel safety.	Industry Feedback	Maintenance and Operability	ALL	ALL	SAFE IMPL
2.06.0110	Equipment designs should include appropriate margins to provide for future modifications that can be anticipated during the plant life.	Some modifications are inevitable in plants with a long life. Existing lessons from operating nuclear power plants should be used to design and arrange plant equipment such that the impact of replacements and reconfigurations can be minimized.	URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 13	Maintenance and Operability	ALL	ALL	ECON IMPL
2.06.0120	The reactor designer should make maximum use of proven computerized design tools to improve the economy, efficiency and quality of design, and to simplify and control the exchange of information between disciplines.	Typical applications would include not only Computer Aided Design and Drafting (CADD) applications, but also interface and layout databases, as well as databases containing current analysis results.	URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 1	Maintenance and Operability	ALL	ALL	ECON IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0130	The plant design should permit the operators to take control of multiple control modules, including support processes, from within a single integrated control room using the manual mode at any time for all operating conditions.	Allows for operational flexibility.	"Key Design Requirements for the High Temperature Gas-Cooled Reactor Nuclear Heat Supply System," INL/EXT-10-19887 (INL, 2010)	Maintenance and Operability	ALL	ALL	PERF
2.06.0131	If a single control room is to be used for all units on a proposed multi-unit site, the control room should be built such that controls for additional units in a staggered build can be easily added to the control room.	Having a central control room for multiple units could be more efficient than having separate control rooms for each unit. However, construction on multi-unit sites is likely to be staggered, with each unit reaching operation at a different time. Additionally, the owner-operator may decide to add another unit after existing units have been in operation. For these reasons, a central control room needs to be designed such that units can be added without an expensive retrofit.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
2.06.0132	If a remote shutdown station is to be used for all units on a proposed multi-unit site, the remote shutdown station should be built such that controls for additional units in a staggered build can be easily added to the station.	Having a central remote shutdown station for multiple units could be more efficient than having separate stations for each unit. However, construction on multi-unit sites is likely to be staggered, with each unit reaching operation at a different time. Additionally, the owner-operator may decide to add another unit after existing units have been in operation. For these reasons, a central remote shutdown station needs to be designed such that units can be added without an expensive retrofit.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
2.06.0133	For multi-unit sites, the units should be spaced such that the protected area of the site is minimized without sacrificing maintainability and operability.	Minimizing the protected area saves resources on security and plant infrastructure.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
2.06.0140	For multiple unit plants on a single site, shared systems should be limited to auxiliary support systems such as sewer, auxiliary steam or site security.	This requirement reflects the utility experience that for multiple units on a single site, a minimum number of systems should be shared. This is especially true with systems used in normal operations. Minimizing shared systems minimizes cross-connects, operator error, and disturbance propagation.	USNRC RG 1.232 mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 6	Maintenance and Operability	ALL	ALL	SAFE PERF
2.06.0150	For any systems that are shared in case of multiple unit plants on a single site, an analysis should be made of the effect of any failure or any testing in that system that will impact the maintenance, dose rates, availability, safety or operability of other systems and the availability of each unit.	Shared systems have the potential to create unexpected interactions that can adversely affect both units.	USNRC RG 1.232 mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 6	Maintenance and Operability	ALL	ALL	SAFE PERF
2.06.0160	The reactor design should minimize the number of active components required to meet the intended function of operability and maintainability.	Reduction of number of components promotes higher plant availability; simplicity is an ORG policy statement and numerous simplification opportunities are available. However, it is not intended to compromise the redundancy required to meet safety goals, or to hinder the ability to qualify advanced component designs.	mPower DSRS Chapter 7 Appendix C URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 1	Maintenance and Operability	ALL	ALL	PERF
2.06.0170	Components that perform the same function and are not required to be separated should be collocated to the maximum extent possible.	This practice reduces the number and length of cable and piping connections required for the systems to perform their functions.	EUR Volume 2 Chapter 13	Maintenance and Operability	ALL	ALL	PERF IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0180	COTS equipment should be utilized in every application possible.	The use of COTS equipment improves simplicity of the design and reduces cost. It also improves maintainability and component replacement during the plant operating life.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
2.06.0190	Component count reduction should be balanced with component uniformity to reduce design complexity and construction cost.	For example, several applications may be able to use the same pump design if appropriate orificing is included. Similarly, a large number of identical components may be more cost effective than a smaller number of unique components with their own design criteria and supply chains.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF ECON
2.06.0200	Human factors design principles should be consistently applied throughout the design process for each operation or maintenance work space in the plant to reduce operation and maintenance errors during all plant modes.	Human errors that affect plant performance may be system-, design-, or human-induced. Human factors applications focus on eliminating from the plant the causes of human errors that exist in older plants. Examples of human factors considerations include adequate space, illumination, noise levels, and environmental controls.	mPower DSRS Chapter 18 URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF
2.06.0210	A standard set of operating and maintenance procedures and training should be developed for each plant design.	A standardized set of procedures and training should permit achieving high quality and performance in operation and maintenance activities.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF IMPL
2.06.0220	Adequate training materials and a training simulator should be available on a schedule to support plant startup.	To train and qualify the plant staff for plant startup and operation.	URD Rev 13 Tier II Chapter 1 Section 8	Maintenance and Operability	ALL	ALL	PERF IMPL
2.06.0221	The time and resources devoted to operator training should be commensurate with the difficulty and consequences of the required tasks.	In traditional nuclear plants, training operators is a long and resource-intensive process. This is appropriate because the required tasks can be complex and the consequences of inaction or erroneous action can be high. However, many advanced reactor designs have enhanced operability and safety such that the actions required of operators are simple and minimal. Spending the same time and resources on training as traditional plants would not result in equivalent value. Optimized training programs may be appropriate.	Industry Feedback	Maintenance and Operability	ALL	ALL	ECON IMPL
2.06.0230	Multiple units on a single site should have identical or similar equipment, equipment and systems layout and orientation, to the extent practical.	To minimize errors by operating and maintenance personnel and to improve the interchangeability of components.	mPower DSRS Chapter 18 URD Rev 13 Tier II Chapter 1 Section 8	Maintenance and Operability	ALL	ALL	IMPL
2.06.0240	The plant should be designed to provide pathways with a minimal number of elevation changes through the plant to selected locations where heavy tools, equipment, or replacement components must travel.	This reduces rigging equipment and resource requirements, and the potential for damaging plant equipment during rigging operations. This also improves the industrial safety aspects of equipment and material handling.	URD Rev 13 Tier II Chapter 1 Section 8	Maintenance and Operability	ALL	ALL	IMPL
2.06.0250	Equipment should be oriented to facilitate maintenance operations without the installation of temporary access platforms and ladders, particularly for high-maintenance components or those expected to be replaced on a regular basis.	This requirement simplifies the performance of operations and maintenance tasks.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0260	An equipment identification system should be developed and imposed at the design stage, made a part of the configuration control system, and maintained through procurement, installation and spare parts control. Systems and equipment should be clearly identified using this system, which should be unambiguous and common for the entire plant.	Confusion in identifying equipment has caused operation and maintenance errors and has contributed to plant events when a component mistakenly taken out of service for maintenance has been called upon to operate.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 12 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
2.06.0261	Bases for design and configuration decisions should be clearly documented in a configuration management system from the start of the project.	Without a documented basis, current and future personnel may not understand the reasoning behind certain design aspects, which could lead to uninformed decision-making. For example, a future design change could render a prior operation or maintenance requirement, or procedural step obsolete. However, without a documented basis, future personnel may not realize the requirement no longer serves a purpose and may continue to devote resources to satisfying it. Conversely, if future personnel do not understand the basis for an existing requirement, they may decide that it does not serve a purpose and nullify it. If the assumption was incorrect, the plant could suffer unforeseen consequences. Clearly documenting bases would solve both of these problems.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
2.06.0262	Changes to a system should be formally documented and approved consistent with the system configuration management plan. The documentation revisions should include the reason for the change, the affected configuration item, the impact of the change on the system including the hazards and risks analysis, and the plan for implementing the change in the system.	Clearly documenting configuration changes will allow for easier review and approval of the change, and will aide future personnel in understanding the basis for the change.	IEEE 7-4.3.2-2016 Section 5.3.5	Maintenance and Operability	ALL	ALL	IMPL
2.06.0270	The reactor designer and EPC, for purposes of design development and planning, may assume that personnel staffing for plant operation and maintenance will be defined very soon after the commitment to build a plant, encompassing the organization and divisions of responsibility for all functions, including support to be provided by other company organizations.	The approach to management and the overall philosophy of operation are important in selecting and training the operating staff for a nuclear plant.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0271	For certain plant conditions, the owner-operator should consider obtaining additional staff, permanently or temporarily.	In some plant conditions (planned or unplanned), the flexibility of the normal operating staff might not be sufficient to accommodate the situation. In such cases, the team may have to be changed in order to cope with the situation. The need for other personnel should be included in work planning and cost estimates. Some typical conditions are as follows: • Commissioning; • Testing; • Refueling; • Maintenance; • Accident conditions; • Post-accident operation.	EUR Volume 2 Chapter 10	Maintenance and Operability	ALL	ALL	IMPL
2.06.0280	Anticipated tasks, methods, personnel skills and man-hour requirements to accomplish unscheduled maintenance should be documented on a system basis.	Analysis should be based upon industrial experience (mean time between failure and mean time to repair data) for like type systems and components. Estimated man-hours should include equipment/system isolation, preparation for maintenance and return to service. Anticipated health physics man-hours should also be documented.	GCRA 86-002/Rev. 3	Maintenance and Operability	ALL	ALL	IMPL
2.06.0290	The reactor designer should include a robotic analysis to consider possible uses of robotics in maintenance activities.	The purpose of this analysis should be to identify candidate activities for use of robotic equipment which should be accommodated in the design. The reactor designer should develop a list of functions for application of robotic equipment which, based upon cost effective considerations, will dictate their incorporation at the initial design stage or likely future incorporation in the plant. Robotic systems can effectively reduce the length of time humans need stay in hostile environments (heat, radiation, humidity), augment the limitations of human strength for arduous tasks, accurately perform repetitive tasks, and perform tasks in areas inaccessible to humans.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	SAFE IMPL
2.06.0300	The reactor designer should provide a recommended spare parts list to the owner-operator for the entire plant based on equipment supplier recommendations and maintenance experience at operating nuclear plants. The spare parts list should be in sufficient detail to allow ordering of spares.	Experience reported for both nuclear and fossil plants demonstrates the need for an adequate inventory of spare parts plus an automated system to facilitate identification and location of spares as well as maintain the desired inventory of spares.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
2.06.0310	The plant arrangement should provide features to facilitate the replacement of all major plant components (including the reactor vessel and basic plant structures if economically justified).	Experience with commercial nuclear power throughout the world has shown the need for designs that facilitate the replacement of major components. From the large number of components (total or partial) that have been replaced, such as steam generators, recirculation piping, feedwater heaters, moisture separator reheaters, etc., design requirements for removal and replacement are essential if long useful plant life is to be attained.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0320	The plant design should include plans for removal, transportation, and storage of major plant components and special tools and equipment, including those that have become contaminated or activated.	Experience has shown that detailed planning is required during the design phase to assure that the plant arrangement can accommodate removal and replacement of components if and when it becomes necessary.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 11	Maintenance and Operability	ALL	ALL	IMPL
2.06.0330	The plant design should include plans for transportation and storage of spare equipment and components to be procured for future use if there is a reasonable probability that replacement equipment will not be available in future years.	Experience has shown that at the time components require replacement, sufficient space does not exist to store the old components or install the new components. Similarly, replacements can be difficult or impossible to obtain many years later for certain equipment more specialized in nature or purpose.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 11	Maintenance and Operability	ALL	ALL	IMPL
2.06.0331	Load handling systems (e.g., cranes) should be designed to consider potential for unexpected load “hang-ups.”	Large loads can get stuck or enter odd geometries during handling, making the maintenance activity more difficult for personnel.	Recent Lessons Learned	Maintenance and Operability	ALL	ALL	IMPL
2.06.0340	Components and systems important to safety should be designed to permit periodic inspection and testing.	Inspection and testing provides assurance that components and systems will be able to perform their safety function during a postulated event.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	SAFE
2.06.0350	The plant design should permit performing as many surveillance tests as possible during normal operation without lifting leads or blocking relays physically.	This greatly enhances operational flexibility, improves safety, and enhances availability. Only the remaining items that cannot reasonably be done at power should still be done with the plant shutdown, or in an otherwise reduced power status.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF IMPL
2.06.0360	Provisions should permit testing systems/subsystems or instrument loops in as close to normal operating conditions as practical.	This greatly enhances operational flexibility, improves safety, and enhances availability. Only the remaining items that cannot reasonably be done at power should still be done with the plant shutdown, or in an otherwise reduced power status.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF IMPL
2.06.0370	Surveillance testing should utilize nonintrusive techniques.	Minimizing the use of intrusive surveillance testing or techniques which result in accelerated wear or other negative consequences of maintenance will improve overall equipment reliability.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 4	Maintenance and Operability	ALL	ALL	IMPL
2.06.0380	Startup tests should be integrated system tests that demonstrate to the extent practical full system functional capability, including the capabilities of the various subsystems when aligned together.	Inherent in these tests should be checks that systems are installed as designed, that equipment interlocks are performance tested, and that temporary installations are removed or scheduled for removal prior to fuel load. Also included in these tests should be a means of capturing startup data that can benchmark system performance for future reference and comparison. A well planned startup test program is essential to a smooth plant startup and important in uncovering deficiencies which, if unattended, could hamper later plant operation.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 13	Maintenance and Operability	ALL	ALL	IMPL
2.06.0390	The startup test program plan should include clear indication of which tests may be performed piecemeal without jeopardizing the validity of the test(s).	This gives flexibility in the startup test program.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
2.06.0400	The use of hazardous and toxic chemicals within the plant should be minimized to the extent practical.	Minimization of the release of hazardous and toxic chemicals to the environment is part of the ORG “good neighbor” policy.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0410	Designs should have features that protect personnel from in-plant hazards.	This requirement helps to ensure a safe work environment. The plant design should not result in undue exposure to industrial hazards (e.g., falls, high temperatures, high voltages, etc.).	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	SAFE
2.06.0420	In applications where the use of hazardous materials is unavoidable (such as in certain advanced reactor designs in which the coolant, like liquid lead, is hazardous), the plant design should incorporate features that minimize personnel exposure to the hazards.	Minimization of the release of hazardous and toxic chemicals to the environment is part of the ORG "good neighbor" policy.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	SAFE
2.06.0421	The impact to the surrounding environment by the plant should be minimized.	Impacts to the environment include: • Emission (to air and water); • Solid waste pollution; • Heat pollution (e.g., raising the temperature of a body of water); • Noise pollution. Minimization of the release of pollution to the environment is part of the ORG "good neighbor" policy.	United States National Environmental Policy Act (NEPA)	Maintenance and Operability	ALL	ALL	PERF
2.06.0430	The owner-operator should specify the minimum number of operators required for each mode/scenario of operation.	The number of operators specified should be independent of regulation (i.e., the minimum number required to perform required actions, not meet regulations). Regulation may require larger operating staffs than those specified, but regulation is subject to change, and defining a practical minimum with a clear basis will present a clear operation strategy, with the goal of minimizing operator actions for all scenarios.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
2.06.0440	The reactor designer, supported by the vendors of individual components, should establish the preventive maintenance programs for the plant.	Preventive maintenance includes all tasks designed to determine and maintain conditions of plant systems and components (predictive, time-based and preventive). A structured process such as the EPRI Preventive Maintenance Basis Database should be followed. See EPRI 3002002951, "Preventative Maintenance Basis Database (PMDB) Web Application v3.0.1."	URD Rev 13 Tier II Chapter 1 Section 8 EPRI 3002002951, "Preventative Maintenance Basis Database (PMDB) Web Application v3.0.1." (EPRI, 2014c)	Maintenance and Operability	ALL	ALL	PERF IMPL
2.06.0450	Components should be designed to allow in-service inspection and testing.	Requirements and provisions for in-service inspection have a significant effect on operability, which must be considered in the design.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 1 EUR Volume 2 Chapter 7	Maintenance and Operability	ALL	ALL	IMPL
2.06.0460	Building design should include consideration for personnel and equipment access, simplicity of arrangement to facilitate installation during construction, and the need for adequate working space during construction, operation, and maintenance.	Overall costs, which include capital as well as operation and maintenance costs, must be considered in the sizing of plant buildings. Recent experience indicates that, in some cases, space was minimized without proper consideration of the impact on construction, maintenance, and operation.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	IMPL
2.06.0461	Plants should be designed to allow for future modifications (e.g., change in cooling method, uprating).	This requirement allows for operational flexibility.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0470	The building and component arrangement should optimize bulk quantities (excavation, concrete, piping, raceway, cable, etc.) to the extent that access for construction, maintenance, testing, inspection, and operation is not adversely impacted.	Overall costs, which include capital as well as operation and maintenance costs, must be considered in the sizing of plant buildings. Recent experience indicates that, in some cases, space was minimized without proper consideration of the impact on construction, maintenance, and operation. Reducing bulk quantities (particularly concrete) also makes decommissioning the plant easier.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	IMPL
2.06.0480	The design should consider human traffic patterns and the impact of maintenance boundaries and operations on traffic flows.	Identification of maintenance and access routes in highly congested areas will minimize the potential damage to components caused by personnel climbing over the components.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	ECON IMPL
2.06.0490	The reactor designer and owner-operator should make the information turnover process a part of the original EPC contract for a successful turnover of information regarding the configuration management information systems, asset management systems, and records management systems.	New nuclear power plants are being designed, procured, and constructed differently, depending much more on the use, management, maintenance, and exchange of electronic information than those built previously. An improved information turnover process will translate into significant cost savings over the life of the plant.	EPRI TR 3002007425	Maintenance and Operability	ALL	ALL	ECON IMPL
2.06.0491	The owner-operator should have access to all reactor design information, including information from the reactor designer and third-party vendors.	Ultimately, the owner-operator is responsible for proving to the regulator that the plant is safe to operate, and therefore needs access to all the design information. Additionally, vendors can go out of business during the lifetime of the plant, making this requirement particularly important. To protect the intellectual property of the vendors, Non-Disclosure Agreements (NDAs) or equivalent legal measures should be in place. Also, legal agreements to have a third party securely hold necessary information “in trust” should be established.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
2.06.0500	The plant arrangement should provide easily accessible shop and warehouse facilities for both contaminated and non-contaminated equipment.	Experience has shown that poor access to shop and warehouse facilities will increase down time. It is essential that equipment can be readily moved between the shop and warehouse facilities.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	IMPL
2.06.0510	The plant arrangement and building design should provide, wherever practical, for weather sheltering of equipment in order to protect against deterioration by weather and for the comfort of operating and maintenance personnel.	Because ORG plants prioritize standardization, decisions on weather protection must consider the envelope of site conditions. Experience has shown that outdoor equipment (controls, Heating, Ventilation, and Air-Conditioning [HVAC] components, etc.) evidence considerable degradation after a number of years of operation in some environments, resulting in extensive maintenance, refurbishment, or replacement. Initial higher construction costs are expected to balance these later maintenance and replacements costs.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 1	Maintenance and Operability	ALL	ALL	ECON IMPL
2.06.0520	Water chemistry and its effect on equipment condition should be considered in the design of plant cooling systems and water sources.	Raw service water (such as from a river) has the potential to cause fouling and corrosion of equipment.	URD Rev 13 Tier II Chapter 8 Section 2 EUR Volume 2 Chapter 8	Maintenance and Operability	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.06.0530	The reactor designer should ensure protection of plant components from external corrosion.	For above-ground and underground (e.g., in a trench) components, this protection is typically provided by appropriate coatings. For buried components, this protection is provided by a combination of coatings and cathodic protection, or by use of exotic alloys (titanium, 6XN, 254SMO) or nonmetallic materials such as High-Density Polyethylene (HDPE) that are resistant to corrosion.	URD Rev 13 Tier II Chapter 1 Section 4	Maintenance and Operability	ALL	ALL	ECON IMPL
2.06.0541	A Foreign Material Exclusion (FME) program should be developed and executed in construction, operation, and maintenance.	Preventing intrusion into or contamination of plant components and substances by uncontrolled materials or species will be particularly important for certain advanced reactor designs.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF IMPL
2.06.0542	The FME program should be developed before main construction begins.	FME issues during construction can cause problems well into plant operation.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
2.06.0551	Site power needs (e.g., for lights, water, machinery) during planned or unexpected outages (both short and long) should be considered and backup power sources should be supplied if needed.	Plants that are in an outage and are not generating electricity must still be inhabitable by personnel performing maintenance, and power may be needed to perform the maintenance.	Industry Feedback	Maintenance and Operability	ALL	GR OG	IMPL
2.07.0010	Materials used in the design should be specified by the reactor designer.	Materials should be deliberately specified by the reactor designer, not by other entities (e.g., supplier, regulator). This is not meant to require the reactor designer to specify the exact grade or specification for each material.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Materials	ALL	ALL	IMPL
2.07.0020	Commonality in material should be pursued where feasible.	An important objective of advanced reactor design is that it should be significantly simplified with respect to older plants. Reducing the number of material types and grades will simplify supply chains, and reduce the technical analysis and quality assurance burden.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Materials	ALL	ALL	IMPL
2.07.0030	Materials should be chosen to ensure long-term satisfactory corrosion and erosion performance of key components.	Necessary to minimize corrosive environments and equipment failures which could lead to safety system challenges and loss of availability.	mPower DSRS Chapter 5 and 6 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 6	Materials	ALL	ALL	SAFE
2.07.0040	Materials should be chosen to minimize worker dose during normal operation and shutdowns.	The selection of materials can significantly impact the deposition of activation products that lead to radiation exposure for plant personnel. Materials selection also impacts the shielding properties of reactor plant equipment.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 6	Materials	ALL	ALL	SAFE
2.07.0050	Fuel qualification should demonstrate the acceptability of the fuel over a range of conditions that could be experienced during normal operation and postulated event conditions.	Some advanced reactor designs use fuels without significant operating experience, making fuel qualification an important aspect of the design of these reactors.	Industry Feedback	Materials	ALL	ALL	SAFE
2.07.0051	The owner-operator should identify a licensed means of transporting new fuel to the plant early on in the project.	Advanced reactors may use different fuels than what is currently used in LWRs and new means of transporting the fuel may need to be designed and licensed. Regulatory guidance in different nations may be applicable.	Industry Feedback	Materials	ALL	ALL	SAFE IMPL
2.07.0060	Manufacturing processes should demonstrate fuel failure rates that support acceptable limits for fission product release and internal contamination of reactor plant systems.	Minimizing fuel defects improves the efficiency of maintenance operations and minimizes personnel exposure to radioactivity. This may include a maximum acceptable fuel failure rate.	mPower DSRS Fuel System design URD Rev 13 Tier II Chapter 1 Section 3 EUR Volume 2 Chapter 1	Materials	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.07.0070	The purity of critical fluids (including the heat transfer fluid) should be maintained throughout normal operation to mitigate the effects of corrosion from impurities.	Due to many advanced reactors operating at high temperatures, the corrosion rates are increased. Therefore, the purity of the heat transfer fluid is often important to maintaining the design conditions for plant equipment.	Industry Feedback	Materials	ALL	ALL	PERF
2.07.0080	The reactor designer should implement chemistry controls on certain materials in particular applications.	To prevent undesirable effects of impurities.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Materials	ALL	ALL	SAFE
2.07.0090	The design should prevent interactions between materials or substances that may create undesirable reactions if they come into contact, and mitigate such reactions as appropriate.	Some advanced reactor designs use materials or substances that may react violently with air, water, etc. Liquid sodium coolant is an example.	USNRC DC-1330	Materials	ALL	ALL	SAFE
2.07.0100	The design of the reactor coolant boundary should reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated event conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.	This requirement was adapted from the USNRC's Advanced Reactor Design Criteria (ARDCs) but has been modified to a "should" statement since not all advanced reactors rely on the reactor coolant boundary to perform a safety function.	USNRC RG 1.232	Materials	ALL	ALL	SAFE
2.07.0110	The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC) specifications may be appropriate but should not be considered sufficient to demonstrate adequate performance if the service conditions cannot be supported by code cases and applicable experience. Additional documented experience or analysis may be required.	Materials which meet code requirements may provide safe service but may not provide problem-free service. Hence, the reactor designer may need to place requirements on materials which go beyond a given code's minimum requirements (e.g., corrosion effects may limit the use of some code materials).	URD Rev 13 Tier II Chapter 1 Section 5 Sims R. 2010. Roadmap to Develop ASME Code Rules for the Construction of High Temperature Gas Cooled Reactors (HTGRS). STP-NU-045, ASME (Sims, 2010)	Materials	ALL	ALL	PERF IMPL
2.07.0121	A plan should be in place for the permanent disposal of all radioactive waste streams early on in the project. This plan should not rely on external factors beyond stakeholders' control.	Regulations will require that radioactive waste is adequately disposed. Waste management is important to the general public and is a critical aspect of proving the viability of the design. The experiences of the existing United States nuclear fleet with the Yucca Mountain nuclear waste repository show that waste management plans should be independent of politics, or that a suitable alternative plan should be identified.	Industry Feedback	Materials	ALL	ALL	IMPL
2.07.0131	A plan should be in place for the permanent disposal of all non-radioactive hazardous waste early in the project.	Many advanced reactor designs use hazardous materials (e.g., liquid sodium) in operation. Waste management of these substances needs to be considered.	Industry Feedback	Materials	ALL	ALL	IMPL
2.08.0010	The number of radiological control points required to access the plant should be minimized.	To simplify and improve security.	URD Rev 13 Tier II Chapter 1 Section 8	Physical Protection and Proliferation Resistance	ALL	ALL	IMPL
2.08.0020	The security plan should be developed to optimize the effectiveness of the security force and simplify the actions required to secure the site perimeter.	Large security forces have been required in some nuclear power plants to accommodate "added on" security features and requirements. Simpler, more agile security forces can respond more quickly and take advantage of inherent security features in the plant design.	EPRI TR 3002008041	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.08.0030	Controlled security access locations to vital areas should be provided at vital area boundaries.	Access control programs and the fitness for duty programs have substantially reduced the insider threat, and design features will not add significant protection against this threat.	URD Rev 13 Tier II Chapter 6 Section 2	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
2.08.0040	The reactor designer should incorporate physical protection measures into the design of the plant, such as placing vital equipment within vital areas, installing intrusion detection and assessment systems, etc.	This requirement protects against external threats.	URD Rev 13 Tier II Chapter 6 Section 2 This requirement reflects compliance with regulatory requirements in 10CFR73.55(c).	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
2.08.0050	Physical security should be provided to support cyber security systems.	Physical security measures can deny access to critical digital assets.	URD Rev 13 Tier II Chapter 10 Section 3	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
2.08.0051	The plant layout near key assets should be designed with enough space to allow for additional physical barriers.	The desire to enhance physical protection while minimizing the size of the guard force requires the flexibility to add barriers if security requirements escalate over time or are more stringent in other countries.	Industry Feedback	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
2.08.0060	The design should have features that prevent the removal of fissile material from the plant.	Consistent with the ORG's "Threat Protection" policy, and international goals for non-proliferation.	"Proliferation Resistance and Physical Protection of the Six Generation IV Nuclear Energy Systems," Generation IV International Forum, GIF/PRPPWG/2011/002 (GIF, 2011)	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
2.08.0070	System design should minimize the need for future modifications or other processes that could expose it to tampering.	This is consistent with a "Safeguards by Design" philosophy. Best practices in information security avoid the creation of vulnerabilities by design.	USNRC RG 1.152	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
2.08.0080	Advanced reactors designed for the production of radioisotopes should include considerations for extracting the radioisotopes without providing undue access to fuel.	Steps to remove radioisotopes should not introduce the potential for fissile isotopes to be diverted.	Industry Feedback	Physical Protection and Proliferation Resistance	ALL	RP	IMPL SEC/NP
2.09.0010	The reactor designer should ensure that mechanical and electrical equipment is qualified for use in the operating environment under which it will be required to perform its design function.	To demonstrate that the equipment will perform its design function on demand to meet system performance requirements when subjected to the design environmental conditions.	mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4	Quality Assurance	ALL	ALL	PERF
2.09.0020	A quality assurance program should be established and implemented in order to provide adequate assurance that SSCs will satisfactorily perform their required functions, according to the level of quality assigned.	A quality assurance program is critical to achieving both safety and economic goals.	USNRC RG 1.232	Quality Assurance	ALL	ALL	SAFE PERF
2.09.0030	The assumptions of the PRA should be documented such that they can be periodically validated throughout the plant's life.	The PRA contains assumptions regarding system, structure, and component reliability and availability. Plant operation and maintenance must be consistent with these assumptions to avoid increasing plant risk.	mPower DSRS Chapter 19 URD Rev 13 Tier II Chapter 1 Section 2	Quality Assurance	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.09.0040	The reactor designer, EPC and owner-operator should each define and document a plan which specifies the Quality Assurance Program requirements for all the safety-related activities, and SSCs making up the advanced reactor. This plan should be provided at the plant proposal stage.	This requirement assigns the reactor designer, EPC and owner-operator the responsibility for defining a plan to implement the QA responsibility they are assigned. Providing the plan at the proposal stage will ensure that conflicts or open items will be resolved prior to awarding the contract.	mPower DSRS Chapter 17 URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	SAFE IMPL
2.09.0050	The construction prime contractors should be responsible for monitoring the performance of subcontractors.	To ensure ownership of work performed by subcontractors.	mPower DSRS Chapter 17 URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	IMPL
2.09.0060	The reactor designer, owner-operator, EPCs, and suppliers should ensure the Quality Assurance Program is consistent with the appropriate regulator-endorsed requirements.	NQA-1 provides a single consolidated source document for QA requirements. NQA-1 is a second generation standard, resulting from a consolidation of American National Standards Institute (ANSI)/ ASME N45.2 and the seven programmatic N45.2 series standards, which provides an adequate basis for compliance with 10CFR50 Appendix B and ASME Code Section III requirements.	USNRC RG 1.28 mPower DSRS Chapter 17 URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	IMPL
2.09.0061	Vendors for nuclear safety-related components should have prior experience delivering components in accordance with a nuclear QA program.	The nuclear industry is a unique environment for procuring components due to the regulation and associated QA requirements. Suppliers familiar with manufacturing components for use in other industries may not have the experience needed to provide a nuclear safety-related component on budget and on schedule.	Recent Lessons Learned	Quality Assurance	ALL	ALL	IMPL
2.09.0062	If new manufacturing or test facilities are used to source nuclear safety-related components, the owner-operator should audit the facility's QA program to ensure it meets the applicable standards.	The nuclear industry is a unique environment for procuring components due to the regulation and associated QA requirements. Suppliers familiar with manufacturing components for use in other industries may not have the experience needed to provide a nuclear safety-related component on budget and on schedule.	Industry Feedback	Quality Assurance	ALL	ALL	IMPL
2.09.0070	Plant diagrams should be prepared and maintained on a structure, system or component basis, as appropriate, showing the boundaries where the quality program (or various levels of the quality program) applies.	Experience has shown diagrams are particularly useful for the purpose of clarifying the boundaries of the quality levels in the plant. The diagrams should be in sufficient detail to allow quality level determinations for individual components and for the interfaces between components and systems of different quality levels.	mPower DSRS Chapter 17 URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	IMPL
2.09.0080	To the maximum extent possible, QA manuals and procedures should be based on those already successfully used in comparable nuclear facilities.	The use of proven QA manuals and procedures helps ensure that lessons learned previously are retained in advanced reactors. Changes and new practices that help improve the efficiency of the QA process or address shortcomings are recognized and encouraged.	URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	IMPL
2.09.0090	Prior to initiating work, contractors should formally agree to comply with the owner-operator's QA program.	To ensure a consistent QA program is applied to all work performed for the project.	URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.09.0100	The owner-operator and its agent should define the organizational interfaces and detailed responsibilities of the reactor designer, EPC, major contractors, and the owner-operator personnel participating in the design, construction and/or support of the plant. This definition should be provided at the time of plant order.	The complexity of nuclear power plants and the involvement of several important organizations require detailed control of the design, construction, and support functions.	mPower DSRS Chapter 17 URD Rev 13 Tier II Chapter 1 Section 9	Quality Assurance	ALL	ALL	IMPL
2.09.0110	The reactor designer should give special attention to the design control and review processes.	Design control errors are significant contributors to problems in older plants. Accordingly, special emphasis must be placed on systematic design control and review requirements.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0120	The owner-operator should have the right to monitor and review the design control and review process in depth to assure that requirements are being met.	Design control errors are significant contributors to problems in older plants. Accordingly, special emphasis must be placed on systematic design control and review requirements.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0130	The owner-operator should have the right of access to the reactor designer’s or contractor’s calculations, design reports, design review reports, verifications, test procedures and results, and similar documents (including works in progress).	The review and audit of design work in depth is important in assessing the overall adequacy of the design work.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0140	On a case basis, the owner-operator should have the right to request additional design work (at a stated level of detail) where it appears to be warranted.	The review and audit of design work in depth is important in assessing the overall adequacy of the design work.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0150	The owner-operator or its agent should have the right to audit the reactor designer’s and contractor’s facilities and those of their subcontractors.	To ensure work is performed in accordance with the owner-operator's QA program.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0160	Prompt action should be taken to correct items and conditions found by auditors in the reactor designer's or contractor's facilities to be in nonconformance with the applicable requirements.	To ensure work is performed in accordance with the owner-operator's QA program.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0170	The reactor designer should prepare system, equipment, and component specifications which invoke quality requirements consistent with the owner-operator’s overall quality assurance program.	To ensure work is performed in accordance with the owner-operator's QA program.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0180	The advanced reactor quality assurance program should address past problems in nuclear construction.	Construction quality has caused problems at a number of existing plants and is an important area for improvement in advanced reactors. All applicable industry experience should be sought to avoid repetition of past problems.	URD Rev 13 Tier II Chapter 1 Section 9 NUREG 1055 (USNRC, 1984) provides descriptions of previous problems in construction quality assurance for the existing fleet of LWRs.	Quality Assurance	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.09.0190	Reactor designers and/or major contractors, (e.g., supplier for Nuclear Island, steam turbine supplier, etc.), should define specific technical requirements for the storage, handling, installation, and testing of their equipment and should perform frequent, periodic inspections at the construction and storage sites to assure their equipment is stored, handled, installed, and tested in accordance with the technical requirements.	Written reports of the findings of these inspections should be provided to the owner-operator and to its representatives, such as the Construction Site Manager or the Storage Site Manager. Depending on the importance of the findings, the owner-operator's Management should be notified orally, without delay. These reports should define and request specific action to correct any non-compliances. This requirement is based on lessons learned from existing plants which indicate that storage, handling, and protection of equipment during construction must be carefully monitored and controlled to prevent problems which may not show up until after equipment is stored or placed in service.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 15	Quality Assurance	ALL	ALL	IMPL
2.09.0200	The Quality Assurance Program for construction should require frequent interviews with a representative sample of the construction workers, inspectors, supervisors, etc. as the work progresses. These interviews should be carried out and documented with those actively working on the job as well as with those who are leaving the work.	The intent of these interviews is to assure that quality problems are promptly detected and investigated so that re-inspection and rework, if necessary, can be completed expeditiously. Utility experience has shown that interviews of the type required are effective in identifying and correcting potential problems before they become major.	URD Rev 13 Tier II Chapter 1 Section 9 EUR Volume 2 Chapter 13	Quality Assurance	ALL	ALL	ECON IMPL
2.09.0210	The purchasing organization procuring COTS software or previously developed software should perform acceptance tests on the digital configuration in which the software is to be applied.	Modern digital systems may rely upon several commercial products (e.g., distributed control systems, user interface environments, and programmable logic) whose source code may be proprietary and unavailable for review. The purchasing organization must be held accountable for commercially available software products in a similar manner as for hardware components. EPRI 1011710 provides guidance for applying commercial dedication principles to digital systems and software, and EPRI 1001045 provides guidance on application of commercial grade dedicated equipment.	URD Tier II Chapter 10 Section 6 EPRI 1011710 (EPRI, 2005b) EPRI 1001045 (EPRI, 2000)	Quality Assurance	ALL	ALL	IMPL
2.09.0220	The purchasing organization procuring COTS software or previously developed software should consider the operating experience and vendor support of the product(s) in similar applications. Such experience need not be limited to the nuclear industry.	Modern digital systems may rely upon several commercial products (e.g., distributed control systems, user interface environments, and programmable logic) whose source code may be proprietary and unavailable for review. The purchasing organization must be held accountable for commercially available software products in a similar manner as for hardware components. EPRI 1011710 provides guidance for applying commercial dedication principles to digital systems and software, and EPRI 1001045 provides guidance on application of commercial grade dedicated equipment.	URD Tier II Chapter 10 Section 6 EPRI 1011710 EPRI 1001045	Quality Assurance	ALL	ALL	IMPL
2.09.0230	The purchasing organization procuring a commercial-grade item should perform a dedication process consistent with EPRI 3002002982 before accepting the item for performance of a safety function.	Commercial-grade dedication provides reasonable assurance that the item being procured will perform its safety functions.	EPRI 3002002982 (EPRI, 2014e)	Quality Assurance	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.09.0240	When dedicating a commercial-grade item for nuclear safety service, the item's critical characteristics (i.e., those important design, material, and performance characteristics that, once verified, will provide reasonable assurance that the item will perform its safety function) should be verified upon receipt of the item.	Commercial-grade dedication provides reasonable assurance that the item being procured will perform its safety functions. Verifying critical characteristics is an important aspect of commercial-grade dedication.	EPRI 3002002982 USNRC 10CFR21	Quality Assurance	ALL	ALL	IMPL
2.10.0010	The design should minimize the amount of time, effort, and resources needed to make the plant available to support its mission after plant safety features are activated.	This minimizes the adverse effects plant trips have on availability.	URD Rev 13 Tier II Chapter 2 Section 3	Reliability and Availability	ALL	ALL	PERF
2.10.0020	Margin and flexibility should be provided in the design to allow for maintenance to be performed on individual components without significant impact to plant operation.	This helps minimize the impact maintenance has on availability.	URD Rev 13 Tier II Chapter 2 Section 4	Reliability and Availability	ALL	ALL	PERF
2.10.0030	Non-safety auxiliary systems should be provided in areas that may lead to increased operational flexibility and availability.	Having auxiliary systems that can be relied upon to perform non-safety functions can greatly improve operational flexibility and availability. Auxiliary Steam is one example.	URD Rev 13 Tier II Chapter 2 Section 7	Reliability and Availability	ALL	ALL	PERF
2.10.0040	Conditions causing spurious actuation of components or systems should be avoided.	Unnecessary actuation of components and systems results in excessive wear, decreased reliability, and increased maintenance.	URD Rev 13 Tier II Chapter 1 Section 3 EUR Volume 2 Chapter 1 EUR Volume 2 Chapter 10	Reliability and Availability	ALL	ALL	PERF
2.10.0050	The design should minimize or eliminate realignments needed to perform major plant evolutions (e.g., startup and shutdown).	Minimizing realignments for important functions provides for a simpler design and reduces the potential for errors that reduce plant availability.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Reliability and Availability	ALL	ALL	PERF
2.10.0060	The plant should be designed to recover from a single failure of a reactivity control system with minimal impact to operations.	Plant availability should be maintained despite this type of single failure. This includes designs that may require shutdown but can be rapidly recovered and designs that can continue to operate at reduced power. The acceptability of the operational impact should be commensurate with the mission of the reactor.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 3	Reliability and Availability	ALL	ALL	PERF
2.10.0070	The waste management system and waste forms should allow for on-site storage capacity sufficient to avoid reactor operational impacts over the anticipated economic life of the plant.	History has shown that the assumption of used nuclear fuel removal from commercial nuclear plants has led to unforeseen complications of plant operations and refueling due to accumulation of inventories and the need to implement alternative on-site storage solutions. Loss of full and partial core reserves in used fuel pools has threatened the ability to refuel and restart LWRs in the United States.	Commercial LWRs store used fuel on-site in the US. The waste form and on-site fuel storage capacity allow for several refueling outages (or even full plant life) without reliance on off-site facilities.	Reliability and Availability	ALL	ALL	PERF
2.10.0080	The reactor designer should develop and implement Design Reliability Assurance Program (D-RAP) during the design phase based on PRA methods and industry experience.	The D-RAP will encompass SSCs whose reliability has a significant effect on the safety of the reactor or significantly challenges the reactor safety systems or plant availability for power production. The ORG is committed to a reliability program. It is intended that the owner-operator consider the SSC reliability and documented basis when developing operations and maintenance programs for plant SSCs.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	SAFE PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.10.0090	The D-RAP should provide basic information for consideration by a future owner-operator for plant reliability assurance activities.	The ORG is committed to a reliability program. It is intended that the owner-operator consider the SSC reliability and documented basis when developing operations and maintenance programs for plant SSCs.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	SAFE PERF
2.10.0100	Preparation of the D-RAP should generate the detailed plant technical information and process structure to satisfy the requirements of the United States Nuclear Regulatory Commission (USNRC) Maintenance Rule, the Plant Equipment Reliability program (as described in INPO-AP-913) and the preventive maintenance details required by the EPRI Preventive Maintenance Database.	The reactor designer should work closely with potential owner-operator to detail the requirements of these plant programs. This should be accomplished early in the plant design process. Over the last 2 decades several programs and processes have been developed by the USNRC, NEI, INPO and EPRI to establish and sustain plant SSC reliability. Generation of the technical details and process structure for these is most effectively and efficiently accomplished early in plant design and at the start of a project. These then become engineering documents that are maintained throughout the project. Refer to EPRI 3002002951, “Preventative Maintenance Basis Database (PMDB) Web Application v3.0.1,” or latest version for information on the PMDB.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	PERF
2.10.0110	The reactor designer should prepare analyses showing the adequacy of plant system designs and recommended maintenance activities, spare parts, surveillance tests and test intervals needed to support the SSC reliability and availability assumptions of the PRA.	This analysis should be consistent with the PRA required by the ORG. Furthermore, the reliability and availability analyses should be carried out as an integral part of the design process to influence the design options and allow appropriate cost/benefit trade-offs during the design of the plant. This analysis should be performed by the reactor designer sufficiently ahead of procurement and construction to minimize the impact of potential design changes and ensure that SSC reliability assumptions are met. This requirement applies to SSCs whose reliability has a significant effect on the safety of the reactor or that affect plant availability. Analyses relating system and component reliability to plant availability are necessary for making adequate decisions about plant system design. Availability analysis is a useful method for evaluation of system performance and provides an indication of areas for potential optimization. The objective is to assure integration of the requirements into the design as it is prepared, not after the design is complete.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	PERF
2.10.0120	The reliability and availability models should use standard techniques. The models and data used should, to the extent possible, be consistent with the models and data used in the PRA.	Standard techniques are available to ensure a consistent approach. These include fault tree analysis and use codes such as CAFTA. Reliability block diagram techniques (which are also supported by CAFTA) could also be used.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.10.0130	The reactor designer should prepare a review of operating experience from plants of the same type (or similar type, as appropriate).	Based on this review, the reactor designer should identify significant causes of failures to SSC functions having a significant effect on reactor safety or probabilities associated with them or resulting in forced plant outages. This review should identify the types of past problems, how they are covered by the reactor plant design, where the design parameters, or materials or environments are outside the ranges previously considered proven by nuclear plant experience. This review should determine appropriate design actions to reduce the contribution of these causes. The results of this review should be translated into appropriate system design features and design recommendations for consideration by the owner-operator in managing reliability activities. The purpose of this requirement is to emphasize the need to use the lessons learned by the commercial nuclear industry over the past decades. This data will also be useful in the "machine learning" phase, for possible transition to automation.	URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 14	Reliability and Availability	ALL	ALL	PERF ECON
2.10.0140	The PRA methodology used by the reactor designer should provide for importance measures for SSCs according to their risk significance and for identification of the dominant failure modes of these SSCs.	PRA insights support establishing a prioritization methodology to minimize plant risk for both design considerations and plant operation and maintenance considerations. Additionally, this approach should provide the capability to predict contribution to risk for a single SSC of concern while considering the total complement of equipment available to perform the function.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	PERF ECON
2.10.0141	Very low PRA probability results should be used with caution.	PRAs are valuable comparative risk tools, but probabilities below approximately 1E-8 per reactor year are so low as to be dominated by uncertainty and events not modeled.	Industry Feedback	Reliability and Availability	ALL	ALL	PERF ECON
2.10.0150	The reactor designer should assure that the dominant modes of failure identified by PRA are appropriately addressed in the plant design consistent with their risk significance.	PRA insights support establishing a prioritization methodology to minimize plant risk for both design considerations and plant operation and maintenance considerations. Additionally, this approach should provide the capability to predict contribution to risk for a single SSC of concern while considering the total complement of equipment available to perform the function.	mPower DSRS Chapter 17 and 19 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	PERF ECON
2.10.0160	For those portions of the design which are not sufficiently detailed, PRA assumptions (e.g., interface requirements) to be maintained by each of the participants in the design and construction process should be defined by the reactor designer to facilitate a PRA that can be used for supporting plant operation. These assumptions should be included as part of the final design documentation.	It is anticipated that the PRA will be developed in parallel with the plant design to provide insights to the reactor designer to support design certification. For portions of the plant design which are not sufficiently detailed, control requirements will be established by the reactor designer to maintain validity of the PRA. The PRA will assume that the plant will be built in accordance with the detailed design and PRA assumptions. In order to obtain a realistic assessment of the important contributors to core-damage frequency and risk, it is intended that the PRA use best-estimate methods, data, and assumptions to the extent that they are available and it is practical to do so.	URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 17	Reliability and Availability	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.10.0170	The plant should be designed such that known failure mechanisms will not prevent the plant from achieving its design life or meeting the availability and reliability goals.	Examples include: • Embrittlement of carbon steel; • Cyclic fatigue because of vibration, thermal expansion, etc.; • Cracking in pumps, valves, turbines, etc.; • Mechanical aging of fans, relays, and other components; • Thermal aging of electrical components; • Radiation aging of in-core and near core electrical components. The long design life of plants places a premium on assuring that the known, long-term damage mechanisms in present LWRs are carefully designed against. Accordingly, some of the known, long-term degradation mechanisms which have been a problem in existing LWRs are highlighted here, and the plant designer is specifically cautioned to take them into account.	mPower DSRS Chapter 4 and 6 URD Rev 13 Tier II Chapter 1 Section 6	Reliability and Availability	ALL	ALL	ECON
2.10.0180	The reactor designer should demonstrate that known failure mechanisms are addressed by the design or are not applicable to the design.	The extensive experience in LWR plants and other industries offers lessons learned to enhance future designs.	EPRI TR 3002008041	Reliability and Availability	ALL	ALL	SAFE PERF
2.10.0190	Known failure mechanisms specific to the advanced reactor type should be addressed or mitigated by the design.	Lessons learned in advanced reactor operation should be applied to the maximum extent possible to prevent recurrence of past problems.	Industry Feedback	Reliability and Availability	ALL	ALL	SAFE PERF
2.10.0191	Equipment qualification testing should demonstrate that the performance requirements have been met in the presence of all defined environmental and plant input and output stressors.	Equipment qualification is required for commercial grade items as well as equipment produced under a nuclear quality assurance program.	IEEE 7-4.3.2-2016 Section 5.4	Reliability and Availability	ALL	ALL	IMPL
2.10.0200	The plant should be designed to meet a pre-defined set of duty cycle limits based on the anticipated service. This should include a minimum number of events for (1) load rejections, (2) load ramps, (3) initiation of emergency systems, (4) normal operating cycles (i.e., startups and shutdowns), and (5) duty cycles specific to the plant's mission.	HTGRs are anticipated to meet a broader set of missions than traditional reactors, including those that require load following. This expectation, coupled with many new materials development, means that cyclic stresses on plant equipment are especially important to consider. The design should account for the expected number of duty cycles to ensure continued operation for the design life of the plant.	GCRA 86-002/Rev. 3 DOE-GT-MHR-100248 (UI, 1995)	Reliability and Availability	ALL	ALL	PERF
2.10.0201	The plant's planned outage (e.g., for refueling) intervals and durations should be established by the reactor designer and should be adequate for the owner-operator's desired mission.	Advanced nuclear plants have the potential to reach higher availabilities than the existing fleet by reducing the intervals and durations of planned outages. Some applications (such as the remotely deployable nuclear battery) may not have planned outages at all.	Industry Feedback	Reliability and Availability	ALL	ALL	PERF
2.10.0202	The owner-operator should consider the effect that both planned and unexpected outages (both short and long) will have on the plant's customer, and provide a temporary alternative means of serving the plant's mission during the outage if required.	Some advanced reactors may serve smaller markets (e.g., nuclear battery, process heat for a chemical plant) than the existing fleet. The effect of an outage on these markets could be more severe. While these reactors may be designed so that planned outages are not necessary for refueling or maintenance, unexpected outages must still be considered. Regardless of application, the owner-operator should consider all outage scenarios to ensure the customer's needs will be met.	Industry Feedback	Reliability and Availability	ALL	ALL	ECON

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.10.0210	The plant should be designed to follow a load profile that is appropriate for the specific application of the plant.	The ability to load follow effectively increases the operational flexibility of the plant. An example of a possible target 24-hour load cycle profile is given below: Starting at 100% power, power ramps down to 50% in two hours, power remains at 50% for two to ten hours, and then ramps up to 100% in two hours. Power remains at 100% for the remainder of the 24-hour cycle.	URD Rev 13 Tier I Chapter 3 Section 2 EUR Volume 2 Chapter 2 EUR Volume 2 Chapter 8	Reliability and Availability	ALL	GR OG	PERF
2.10.0211	The plant's minimum turndown rating (i.e., minimum viable output divided by rated output) should be adequate for the owner-operator's desired mission.	Advanced nuclear plants may need to have more flexibility in technically and economically viable operating output ranges (electricity or heat) than the existing nuclear fleet to compete with alternate energy sources, such as solar and wind.	Industry Feedback	Reliability and Availability	ALL	GR OG PH	PERF
2.10.0212	The time required to start the plant and reach rated operation should be minimized.	Traditional nuclear reactors are slow to start and ramp up to rated load. Rapid plant startup would allow advanced plants to have increased availability, and would give them the flexibility to quickly meet a sudden demand.	Industry Feedback	Reliability and Availability	ALL	ALL	PERF
2.10.0213	BOP systems should be designed upfront to perform load following tasks as defined by the owner-operator.	Designing for load following will be more cost effective than retrofitting these capabilities.	Industry Feedback	Reliability and Availability	ALL	GR OG PH	ECON
2.10.0214	The reactor designer should consider the use of energy storage systems to increase the plant's flexibility in meeting demand.	Energy storage systems would allow the plant to store excess product (e.g., electricity, heat) during low demand intervals that could be used during peak demand intervals without changing the power output of the reactor. This would allow for load following while minimizing the plant rated output because the storage would allow the plant to offset peak loads. Methods for energy storage include: • Electric Batteries (lithium-ion or redox flow); • Pumped-Hydro; • Thermal storage; • Hydrogen Production (electrolysis or steam reformation); • Compressed Air Storage.	Industry Feedback	Reliability and Availability	ALL	GR OG PH	PERF
2.10.0215	The reactor should operate at a temperature appropriate for the technology and the application.	Certain advanced missions require higher-grade heat than what is needed for traditional large-scale electricity generation, and certain advanced reactor designs are capable of supplying steam at temperatures well above what is possible with a traditional LWR. To avoid operating primary plant materials in excess of the qualified range, electric superheating on secondary plant output should be assessed.	EPRI TR 1009687	Reliability and Availability	ALL	ALL	PERF
2.10.0220	The plant should be designed so that it may be remotely dispatched for load following.	This is consistent with utility desires and expectations. Though current regulation may not allow remote dispatching in all cases, the ability to meet this expectation is still a desired feature.	URD Rev 13 Tier I Chapter 3 Section 2	Reliability and Availability	ALL	GR OG	PERF
2.10.0221	Electricity generation plants should output power at voltage levels compatible with the available transmission.	Transmission infrastructure places a constraint on the voltage output by the plant.	Industry Feedback	Reliability and Availability	ALL	GR OG	PERF

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.10.0222	Electricity generation plants should stabilize frequency fluctuations to have a minimal impact on the desired application.	Frequency fluctuations can have adverse impacts on the local infrastructure.	Industry Feedback	Reliability and Availability	ALL	GR OG	PERF
2.10.0230	For large-scale electricity generation, the design should permit plant to be used for normal frequency restart of the grid.	This is consistent with utility desires and expectations since it enhances the flexibility of the plant and provides an added benefit to the grid.	URD Rev 13 Tier I Chapter 3 Section 2	Reliability and Availability	ALL	GR	PERF
2.10.0240	If grid restart capability is required by the plant's mission, the plant should be able to continue operation in case of a loss of off-site power.	Continued operation in case of a loss of off-site power presents design challenges that should be addressed early in the design process in order to be fully integrated into the design. The reactor designer should identify isolation strategies, reduced power operation strategies, and equipment needs.	Industry Feedback	Reliability and Availability	ALL	GR	PERF
2.10.0250	Advanced reactors should be able to maintain operation during grid perturbations without prolonging or exacerbating the transient.	This is consistent with utility desires and expectations since it enhances the availability of the plant and provides an added benefit to the grid.	Industry Feedback	Reliability and Availability	ALL	GR	PERF
2.10.0260	The reactor designer should provide plant design features to assure that the off-site risk associated with a station blackout event satisfies the safety goals (e.g., USNRC quantitative health objectives) of the appropriate competent authority.	The purpose of this criterion is to minimize challenges to safety systems to mitigate or reduce the likelihood of failure during a station blackout event.	URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 1	Reliability and Availability	ALL	GR	ECON
2.10.0270	The reactor designer should perform an evaluation of potential system failures that will result in reactor trips that shows the expected trip frequency to be consistent with or lower than maximum allowable trip rates set by the owner-operator.	Because human errors cause a large fraction of reactor trips, emphasis should be placed on the human factors aspects of operation and surveillance testing. This will help assure careful consideration of the trip requirement during the design process. The purpose of this criterion is to minimize challenges to safety systems.	URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 8	Reliability and Availability	ALL	GR OG	ECON
2.10.0280	The plant should be designed so that the frequency and duration of forced outages are equal to or smaller than LWR experience.	This requirement is necessary to assure that sufficient plant reliability is designed into the plant to assure the overall plant availability requirement is met with reasonable planned maintenance activities.	URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 2	Reliability and Availability	ALL	GR OG	ECON
2.10.0290	The plant should be designed so that the frequency and duration of major outages are equal to or smaller than LWR experience.	This requirement is established to assure that an allocation of the unavailability is designated for the occasional situation requiring an extended (major) outage for repairs or replacement of a large component.	URD Rev 13 Tier II Chapter 1 Section 6 EUR Volume 2 Chapter 2 EUR Volume 2 Chapter 18	Reliability and Availability	ALL	GR OG	ECON
2.10.0300	Advanced reactors considered for the production of radioisotopes should be designed to minimize the complexity of steps to insert and remove irradiation targets from the core, and provide controls that limit the reactivity transient of target movement.	Consistent with the ORG's "Simplification" policy.	Industry Feedback	Reliability and Availability	ALL	RP	PERF ECON
2.11.0010	Seismically-rugged non-safety related equipment that has the potential to serve as a backup to necessary safety related equipment should be shown to have seismic capacity to withstand an appropriate seismic event.	Analysis has shown that significant benefit is obtained if a backup, diverse means is provided to meet safety functions.	URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Seismic and Structural	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.11.0020	The reactor designer should classify the SSCs of the plant with respect to the nuclear safety function they are relied upon to perform.	Safety Classification is based upon considerations of both probabilities of failure and severity of consequences. Further design work (e.g., Probabilistic Risk Analysis) may result in revisions to some safety classifications. This classification should be developed early in the design phase, to the extent practicable.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0030	The reactor designer should classify the SSCs of the plant with respect to their ability to withstand the effects of a seismic event, as required by the governing regulatory agency.	Allows for the application of sets of seismic design rules to each category according to the requirements of the particular country where the plant will be built.	USNRC RG 1.232 mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0040	The structural design of the plant, including design, fabrication and installation of SSCs, should comply with all codes and standards pertinent to the nuclear power industry.	To expedite all phases of design, construction and licensing, it is imperative that all applicable codes and standards be identified and agreed upon at the outset.	mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 1	Seismic and Structural	ALL	ALL	SAFE
2.11.0050	The reactor designer should list all applicable codes and standards, including revision. However, licensing basis documentation should allow maximum flexibility to use updated codes and standards (e.g., allow use of a more recent revision if the revision is authorized by the regulator for subsequent plants).	To expedite all phases of design, construction and licensing, it is imperative that all applicable codes and standards be identified and agreed upon at the outset. Some older nuclear power plants have been challenged by ambiguity as to the applicable version of various codes and standards. Flexibility to use a newer version of a code or standard accepted for later plants eliminates the need to process licensing basis changes for technically accepted versions.	mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 1	Seismic and Structural	ALL	ALL	SAFE
2.11.0060	Applicable structural design and construction codes and industry technical standards that conflict with regulatory positions should be resolved by the reactor designer with the regulator, and the resolution should be fully documented.	Since most nuclear codes and standards have been written specifically for LWR power plants, advanced reactors are likely to include design elements which deviate from these codes and standards. Such deviations must be well documented and justified in order to satisfy regulatory requirements.	mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 1	Seismic and Structural	ALL	ALL	SAFE
2.11.0070	The reactor designer should define the plant’s operating structural loads for all SSCs based on all normal operating modes as well as structural loads resulting from postulated events.	Overall plant design and reliability will be enhanced by concentrated efforts during design to define all plant operating loads.	URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0080	The reactor designer should consider and minimize the magnitude of structural loads due to all operating conditions, including plant transients.	Overall plant design and reliability will be enhanced by concentrated efforts during design to minimize all plant operating loads.	URD Rev 13 Tier II Chapter 1 Section 4 EUR Volume 2 Chapter 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0090	The reactor designer should consider the potential structural effects of in-plant hazards due to the environmental conditions associated with plant operations under normal conditions and postulated events.	In-plant hazards can interfere with plant operation and safety and need to be addressed in the plant design. Examples of such hazards are pipe rupture, internal flooding and fires, the generation of missiles, and chemical reactions, depending on the particular design.	USNRC RG 1.232 mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0100	The reactor designer should consider the effects of appropriately combined loads on plant SSCs.	It is reasonable to expect that plant SSCs will experience loading from multiple sources. A combination of these loads should be considered in the plant design.	mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier II Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
2.11.0110	To the extent practical, seismic testing and environmental qualification should be performed at the system rather than component level.	System level qualification allows for qualification under more realistic conditions and definition of system level acceptance criteria and error bounds, which is preferable to accounting for cumulative error effects when component qualification procedures are used.	USNRC RG 1.232 mPower DSRS Chapter 3 URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0120	Equipment should be seismically qualified using testing, analysis, a combination of testing and analysis, or by experience data. The qualification should demonstrate both the structural integrity and the required functional operability of the equipment.	The requirements and qualification methodology specified are similar to those in current practice, but include provision for qualification of equipment based upon experience data.	IEEE Standard 344 (IEEE, 2013) URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE
2.11.0130	The intensity of the design effort and the application of elaborate analytical techniques for the structural and mechanical design of the plant should be consistent with the importance and complexity of the SSCs involved.	For example, the analytical models used for the seismic analysis of SSCs should be of sufficient detail to assure that the response spectra remain valid during the design duration. Elaborate or complicated analyses should be held to a minimum to simplify any reanalysis necessitated by as-built configuration changes.	URD Rev 13 Tier II Chapter 6 Section 2	Seismic and Structural	ALL	ALL	ECON IMPL

5.5 Tier III Requirements

The following pages present the ORG Tier III Requirements.

Table 5-5
ORG Tier III Requirements

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.01.0040.010	Advanced manufacturing and construction techniques used in non-nuclear industries should be considered for use in advanced reactors.	Recent advances in manufacturing and construction techniques have been applied across many industries. Nuclear projects could benefit greatly from the experiences in other industries. Examples of such techniques include: • Additive manufacturing (3D printing); • Powder metallurgy; • Robotic welding; • Modular techniques; • Modeling and simulation.	Industry Feedback	Constructability	ALL	ALL	IMPL
3.01.0040.020	The reactor designer should consider using COTS used in non-nuclear applications, where possible.	Recent advances in construction techniques have been applied across many industries. Nuclear projects could benefit greatly from the experiences in other industries. Examples of such components include: • Digital Control Systems; • Digital Instrumentation; • Valves.	Industry Feedback	Constructability	ALL	ALL	IMPL
3.01.0130.010	The construction plan should take into account the placement of concrete pumping stations.	Cure times, routing of concrete movements, and access to concrete pumping stations can be impacted by the pumping station locations.	EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
3.01.0210.010	Reactor components should be shop-built, including heat treatment, to the degree practical, and instrumentation required to monitor components during shipment and storage should be provided.	Materials and special processes are best controlled in a shop environment. However, based on component size and local (site-specific) shipping limitations, it may be necessary to perform final welding and post-weld heat treatment at the site.	URD Rev 13 Tier II Chapter 4 Section 2 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	IMPL
3.01.0210.020	The module sizes should consider shipping limitations for weight and clearance as well as the capacity of heavy lift cranes on site.	The EPC must be able to transfer modules from manufacturer to site.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	ECON IMPL
3.01.0210.030	The external building openings and temporary openings in walls and floors should be sized and located with consideration to module installation sequence and size.	The EPC must be able to install the module on site.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 13	Constructability	ALL	ALL	SAFE IMPL
3.01.0240.010	Consistent with the overall simplification policy, the different types and sizes of valves, pumps, other components and systems, and the different types of instrumentation, control, and power equipment used should be minimized (while standardized as much as possible). However, each component must be selected to meet the required function for each specific application.	Overall plant simplicity is an ORG policy statement. Proper selection and coordination of this effort can greatly simplify and reduce the maintenance effort and the number of spare parts that must be stocked. The need to balance standardization with ingenuity must also be considered.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 4	Constructability	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.01.0240.020	The reactor designer should consider using standardized gate valve, globe valve, and butterfly valve designs that several vendors can manufacture.	Provides flexibility in the event that quality issues are experienced with a specific valve vendor.	URD Rev 13 Tier II Chapter 1 Section 12	Constructability	ALL	ALL	PERF
3.01.0240.030	Heat exchangers should be built to the Tubular Exchanger Manufacturers Association (TEMA) R Standard.	The subject standard supports a 60-year design life.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 4	Constructability	ALL	ALL	PERF
3.01.0310.010	Components with complex welded geometries (e.g., condensers) should be designed to accommodate shop prefabrication.	Maximizing the opportunities for shop pre-fabrication can aid in construction sequencing. The condenser especially has complex welded geometry. Shop fabrication on this component is beneficial.	URD Rev 13 Tier II Chapter 2 Section 4	Constructability	ALL	ALL	PERF
3.01.0470.010	SSCs should be tested during and following fabrication for compliance with service requirements.	Examinations and tests help assure the critical process steps are controlled.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Constructability	ALL	ALL	IMPL
3.01.0490.010	The reactor designer could consider making digital video documentation of walk-throughs and inspections.	Constitutes a more complete documentation of the inspection than other methods.	Industry Feedback	Constructability	ALL	ALL	IMPL
3.02.0140.010	The developer should document the standards and procedures that will conform with the applicable security policies to demonstrate that the system design products (hardware and software) do not contain undocumented code (e.g., back door coding), malicious code (e.g., intrusions, viruses, worms, Trojan horses, or bomb codes), and other unwanted or undocumented functions or applications.	This requirement helps ensure that cyber security vulnerabilities are not built into the design of the digital device. Additionally, the developer should only purchase software from reputable vendors.	IEEE 7-4.3.2-2016 Section 5.9.4	Cyber Security	ALL	ALL	SEC/NP
3.02.0200.010	The safety system should not contain any removable media devices unless there are physical barriers to preclude installation of each removable media device during online operation or the design prohibits data being written from the media to the safety system during online operation.	Removable media devices provide opportunities for access by bad actors.	IEEE 7-4.3.2-2016 Section 5.9.3	Cyber Security	ALL	ALL	SEC/NP
3.02.0200.020	Non-safety engineering workstations should have timely, periodically updated virus protection software run and security patches installed prior to their connection to safety systems if the workstation has capabilities for removable external storage media or the workstation can be attached to a network other than safety systems.	Non-safety workstations could act as a medium for transferring malicious software to safety systems.	IEEE 7-4.3.2-2016 Section 5.9.3.1	Cyber Security	ALL	ALL	SEC/NP
3.02.0200.030	Any media (disk, tape, flash drive, etc.) used for data storage or transfer should be scanned for malware prior to use or should be controlled and stored in a physically protected area to prevent virus intrusion onto the media.	Data media could act as a medium for transferring malicious software to safety systems.	IEEE 7-4.3.2-2016 Section 5.9.3.1	Cyber Security	ALL	ALL	SEC/NP

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.02.0230.010	Access to permanent or portable engineering workstations and to M&TE should be limited to only a defined set of authorized employees whose job requires access to the equipment.	Limiting access to critical individuals reduces the likelihood of unauthorized access. This physical and logical access control should be based on the results of a system Secure Development and Operational Environment (SDOE) assessment. The results of the assessment may require combinations of more complex access controls, such as a combination of knowledge (e.g., password), property (e.g., key, smart-card) and personal features (e.g., fingerprints).	IEEE 7-4.3.2-2016 Section 5.9.1	Cyber Security	ALL	ALL	SEC/NP
3.02.0230.020	Vendor default passwords should be changed before the system is credited with performing its safety function.	Vendor default passwords are not secure.	IEEE 7-4.3.2-2016 Section 5.9.2	Cyber Security	ALL	ALL	SEC/NP
3.02.0230.030	Terminals used to make safety system software configuration changes should have access (e.g., keylock) and password security.	This requirement reduces the likelihood of sabotage.	IEEE 7-4.3.2-2016 Section 5.9.5	Cyber Security	ALL	ALL	SEC/NP
3.03.0010.010	The heat balance instrumentation should include as a minimum the recommended sensors shown in ANSI/ASME PTC 6 (or equivalent) for an alternative procedure for testing steam turbines.	The power industry has recognized the need for development of a cost-reduced, less complex method of accurately obtaining heat cycle information. Sufficient instrumentation should be provided to allow accurate testing of BOP components and for the calibration of nuclear instruments based on heat balance measurement.	ANSI/ASME PTC 6 (ASME, 2004) URD Rev 13 Tier II Chapter 2 Section 3	Instrumentation and Controls	ALL	GR OG	PERF
3.03.0020.010	Information from the HMI should be presented to reflect its importance in terms of the plant state or phenomena dynamics and to facilitate its analysis.	This requirement improves the human factors of the HMI.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0020.020	The operator should be given adequate feedback about the progress and completion of commands.	This requirement improves the human factors of the HMI.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0020.030	Alarms should be designed for attracting the operator's attention to unexpected events requiring an operator action, especially to disturbances regarding process control and plant behavior.	Knowledge of the operator's tasks is a basic element to be taken into account in the design of alarms, so that alarms and other information are correctly directed to the appropriate staff. The operator must not be distracted from their main tasks. In particular, attention is drawn to the I&C failures which necessitate a specific analysis to detect those to be considered as real alarms and those to be considered as information directed to the maintenance staff and only to be displayed to the operator at their request.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0020.040	The alarm processing should minimize non-significant alarms and alarms with similar meaning or alarms originating from the same event.	The purpose of the alarm is to alert the operator only if it is necessary for them to perform corrective action or to be aware of a change in the state of the plant. Excess alarms will distract operators and delay response.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0050.010	Both automatic and manual control should be provided for pressure relief systems.	Automatic control ensures timely actuation to preferentially actuate redundant safety features. Separate pressure relief devices may be more reliable than complex, multi-function components. This should be assessed by perform a Failure Modes and Effects Analysis (FMEA) or equivalent analysis.	URD Rev 13 Tier II Chapter 2 Section 3	Instrumentation and Controls	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.03.0050.020	The Plant Environmental Monitoring System (PEMS) should use a cost-effective mix of permanent and portable instrumentation to record the history of environmental stressors (e.g., temperature, humidity, radiation, pressure, and vibration) in and around all plant SSCs whose aging degradation or failure can have a significant adverse effect on safety, reliability, or operations and maintenance costs.	The environments in and around SSCs play an important role in reliable service life. In older plants, limited component environmental monitoring (e.g., measurement of only global ambient temperatures for technical specification compliance and of radiation levels to gauge personnel exposure) has not been completely effective for indicating short- or long-term hot spot areas that can cause failures from premature aging degradation of SSCs.	"*Guide for Monitoring Equipment Environments During Nuclear Plant Operation*", EPRI NP- 7399 (EPRI, 1991) URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Instrumentation and Controls	ALL	ALL	IMPL
3.03.0050.030	The reactor designer should make recommendations for a PEMS to be used by the owner-operator to ensure that plant environments are maintained within design values throughout the life of the plant.	The environments in and around SSCs play an important role in reliable service life. In older plants, limited component environmental monitoring (e.g., measurement of only global ambient temperatures for technical specification compliance and of radiation levels to gauge personnel exposure) has not been completely effective for indicating short- or long-term hot spot areas that can cause failures from premature aging degradation of SSCs.	"*Guide for Monitoring Equipment Environments During Nuclear Plant Operation*" EPRI NP- 7399 URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 14	Instrumentation and Controls	ALL	ALL	IMPL
3.03.0050.040	The clocks of the I&C systems should be synchronized to the real time. The accuracy of this synchronization should be sufficient to analyze complicated plant disturbances.	This requirement helps improve the precision of plant actions and displayed information.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0080.010	Automatic control for pressure relief systems should be designed such that a single failure will not result in the inadvertent actuation of more than one pressure relief component.	This requirement limits inventory loss due to single failures.	URD Rev 13 Tier II Chapter 2 Section 3	Instrumentation and Controls	ALL	ALL	PERF
3.03.0080.020	Failure or malfunction of any operator workstation and its restoration should not result in a plant condition (including simultaneous conditions) that is not enveloped in the plant design bases, accident analyses, and Anticipated Transient Without Scram (ATWS) provisions, or in other unanticipated abnormal plant conditions.	Events related to workstations should be accounted for in design.	IEEE 7-4.3.2-2016 Section 5.8.2	Instrumentation and Controls	ALL	ALL	SAFE PERF
3.03.0080.030	Loss of power, power surges, power interruption, reboot, and any other credible event to any operator workstation or controller should not result in spurious actuation or stoppage of any plant device or system unless that spurious actuation or stoppage is enveloped in the plant safety analyses.	Events related to workstations should be accounted for in design.	IEEE 7-4.3.2-2016 Section 5.8.2	Instrumentation and Controls	ALL	ALL	SAFE PERF
3.03.0130.010	HTGR designs should be developed with a control strategy that provides effective control of the reactor in all conditions and is reliant on direct measurement of key variables without complex operator actions.	Depending on the flux spectrum, the fuel type, and the coolant, the control strategy could rely on many different principles. The selection of an appropriate control strategy may influence specific design features.	USNRC RG 1.232	Instrumentation and Controls	HTGR GFR	ALL	SAFE PERF
3.03.0130.020	MSR designs should be developed with a control strategy that provides effective control of the reactor in all conditions and is reliant on direct measurement of key variables without complex operator actions.	Depending on the flux spectrum, the fuel type, and the coolant, the control strategy could rely on many different principles. The selection of an appropriate control strategy may influence specific design features.	USNRC RG 1.232	Instrumentation and Controls	MSR	ALL	SAFE PERF

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.03.0130.030	SFR designs should be developed with a control strategy that provides effective control of the reactor in all conditions and is reliant on direct measurement of key variables without complex operator actions.	Depending on the flux spectrum, the fuel type, and the coolant, the control strategy could rely on many different principles. SFRs have many reactivity coefficients that change over the range of operating conditions experienced by the plant and therefore require special consideration in control strategy design. The selection of an appropriate control strategy may influence specific design features.	USNRC RG 1.232 American Nuclear Society "General Safety Design Criteria for a Liquid Metal Reactor Nuclear Power Plant", ANS 54.1 (ANS, 1989)	Instrumentation and Controls	SFR	ALL	SAFE PERF
3.03.0130.040	SFR designs should be developed with a control strategy that provides effective control of the reactor in all conditions without complex operator actions.	Natural feedback mechanisms used as part of the control strategy are different than traditional LWR technologies.	Industry Feedback	Instrumentation and Controls	SFR	ALL	SAFE PERF
3.03.0132.010	No single control action (for example, mouse click or screen touch) should generate commands that change the state of plant equipment; a minimum of two positive operator actions should be required to generate a command.	This requirement reduces the likelihood of spurious or unintended operator commands.	IEEE 7-4.3.2-2016 Section 5.8.2	Instrumentation and Controls	ALL	ALL	PERF
3.03.0132.020	The design should have the provision to physically disable the control and display stations upon abandonment of the main control room to preclude spurious actuation of safety equipment that might otherwise occur as a result of the condition causing the abandonment (such as control room fire or flooding).	This requirement reduces the likelihood of spurious or unintended operator commands. The means of disabling control room control and display stations should be immune to short-circuits, environmental conditions in the control room, cyber-attack, etc., that might restore functionality to the control room operator stations and result in spurious actuations of safety equipment.	IEEE 7-4.3.2-2016 Section 5.8.2	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0140.010	The instrumentation and control system should be designed to allow the required periodic testing without placing the plant in an unacceptable one-out-of-two or one-out-of-three trip logic.	Designing the instrumentation and control schemes to support the required periodic testing without placing the plant in an easy-to-trip condition will enhance availability, operability, reliability and maintainability.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 8	Instrumentation and Controls	ALL	ALL	PERF IMPL
3.03.0160.010	The PDD safety system configuration should not require change or modification to support periodic automated or manual surveillance testing.	Modifying the system to perform maintenance and testing would be labor intensive and would provide opportunity to introduce failure mechanisms to the system, reducing reliability.	IEEE 7-4.3.2-2016 Section 5.7	Instrumentation and Controls	ALL	ALL	PERF
3.03.0160.020	Drift within I&C systems should be limited in order to minimize the need for periodic testing and calibration.	This requirement helps minimize maintenance burden and opportunity for operator error.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0160.030	All sensors should have provisions for test equipment to provide a direct input and then to receive a direct output.	This requirement facilitates calibration.	EUR Volume 2 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0170.010	The instrumentation and control system should be designed to maximize in-place calibration.	Designing the instrumentation and control schemes to support in-place calibration will enhance availability, operability, reliability and maintainability.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 8	Instrumentation and Controls	ALL	ALL	PERF IMPL
3.03.0170.020	The instrumentation and control system should be designed to allow the required periodic testing without placing the plant in an unacceptable one-out-of-two or one-out-of-three trip logic.	Designing the instrumentation and control schemes to support the required periodic testing without placing the plant in an easy-to-trip condition will enhance availability, operability, reliability and maintainability.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 8	Instrumentation and Controls	ALL	ALL	PERF IMPL

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.03.0190.010	Heat balance sensors should transmit inputs to a computerized data calculation and retrieval system installed as part of the heat cycle performance evaluation system.	The required system will permit “near real time” capability for evaluation of both steady state and transients for both on and off design plant conditions. In addition, stored data will be available for long-term trending.	URD Rev 13 Tier II Chapter 2 Section 3	Instrumentation and Controls	ALL	GR OG	PERF
3.03.0190.020	Provisions should be made to automatically detect and document the sequence of significant events (e.g., control inputs, changes in the operation of major systems and components, protective trips, etc.) that occur during plant operation.	Automatic detection of major plant events assists in data management and reconstruction of events. Automatically logging these data relieves the operators of a data-collection burden and can aid in training.	GCRA 86-002/Rev. 3	Instrumentation and Controls	ALL	ALL	PERF
3.03.0241.010	No single failure or malfunction of an I&C component should result in a turbine trip or a reactor transient.	Plant availability should be maintained despite this type of single failure.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	ALL	PERF
3.03.0291.010	Updates for commercial software (e.g., operating systems) should be implemented using the same V&V processes as the originally installed software.	Software updates may introduce new failure mechanisms for the software that must be identified and mitigated in a thorough V&V process.	Industry Feedback	Instrumentation and Controls	ALL	ALL	IMPL
3.03.0331.010	The labeling of the PDD system for configuration control should include unique identification and revision (and/or date-time stamps) for each configuration item.	Labeling and revision control are important for software configuration management.	IEEE 7-4.3.2-2016 Section 5.3.5	Instrumentation and Controls	ALL	ALL	IMPL
3.03.0341.010	The PDD functions necessary to perform safety functions and those PDD functions whose operation or failure could impair safety functions should be exercised during equipment qualification testing.	This includes, as appropriate and practicable, exercising and monitoring the memory, the logic, inputs and outputs, display functions, diagnostics, associated components, communication paths, and interfaces.	IEEE 7-4.3.2-2016 Section 5.4	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0361.010	Self-diagnostic functions should not adversely affect the ability of the PDD system to perform its safety function, or cause spurious actuations of the safety function.	Self-diagnostics are beneficial, but design must ensure they do not have unintended consequences for the system.	IEEE 7-4.3.2-2016 Section 5.5.3	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0391.010	A safety channel should not receive any communication from outside its own safety division unless that communication supports the performance of the safety function.	Receipt of information that does not support the safety function would involve the performance of functions that are not directly related to the safety function.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0411.010	Addressable constants, setpoints, parameters, and other settings associated with a safety function should only be modified when the channel is bypassed or not in service.	Alteration during operation could have unintended and unanalyzed consequences.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0421.010	Within the PDD system performing the safety function, the data received and data transmitted should be stored in separate, pre-determined locations, which are used only for data receipt or transmission.	Having pre-allocated memory locations for receipt and transmission improves reliability of communication such that memory allocated for internal computation does not interfere with receipt and transmission.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE PERF
3.03.0421.020	Communications that are needed to support a safety function, such as the sharing of channel trip decisions for the purpose of voting, should include provisions for ensuring that received messages are correct and are correctly understood, including error-detecting coding, along with means for dealing with corrupt, invalid, untimely or otherwise questionable data.	Communication interfaces between channels represent a vulnerability in digital systems that needs to be mitigated.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.03.0421.030	The effectiveness of communication error detection should be demonstrated in the design and proof testing of the associated codes, but once demonstrated is not subject to periodic testing.	Communication interfaces between channels represent a vulnerability in digital systems that needs to be mitigated.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE PERF
3.03.0421.040	Communication for safety functions should involve a fixed set of data at regular intervals, whether data in the set has changed or not.	Communication should conform to a predictable structure and routine such that data can be interpreted more easily by the receiving channel and errors in communication (e.g., a missed interval) identified.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE PERF
3.03.0421.050	Communication protocols should be designed such that the validity and timeliness of message data is included by the protocol, and checked and appropriately processed by the receiver.	Spurious, frozen, old, or invalid data could result in unintentional operation of a device if processed.	IEEE 7-4.3.2-2016 Section 5.6.4.2	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0441.010	Wireless receivers on temporarily-connected M&TE should be disabled prior to connecting to safety-related equipment.	Active wireless receiving capabilities on temporarily-connected M&TE would provide opportunity for unintended manipulation of the system. Transmission capabilities should be acceptable if the data is sent to non-safety systems.	IEEE 7-4.3.2-2016 Section 5.7	Instrumentation and Controls	ALL	ALL	SAFE
3.03.0481.010	Means should be included in the software such that the identification may be retrieved from the software using software maintenance tools.	This requirement allows the as-installed software (and version) to be verified.	IEEE 7-4.3.2-2016 Section 5.11	Instrumentation and Controls	ALL	ALL	PERF
3.03.0521.010	A device enabling the operator to modify the turbine speed setpoint should be made available by a dedicated control.	This requirement improves operational flexibility.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	PERF
3.03.0521.020	For cases when the turbo-generator is not coupled to a grid, the design should enable the speed of the turbo-generator to be adjusted between shutdown and coupling up, with accurate speed control when approaching synchronization.	This requirement assists with synchronizing the generator to a grid.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR	PERF
3.03.0521.030	Automatic controls should provide control of turbine speed and acceleration through the entire speed range with several discrete speed and acceleration rate settings.	This requirement promotes automation and reduced operator burden and increases operational flexibility.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	PERF
3.03.0521.040	Turbine and generator rotor critical speeds should be calculated and the automatic control function should be programmed to prevent holding at these speeds.	This requirement prevents structural resonance that could lead to increased fatigue and increased probability of rotor failures.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	SAFE PERF
3.03.0521.050	A protective trip system should be provided to quickly close the turbine valves in the event of an overspeed or unsafe condition.	This requirement protects the turbine equipment and decreases the probability of turbine missile generation.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	SAFE
3.03.0521.060	Automatic adjustment of generator output by a signal sent from the power control system or by a manual signal should be provided.	This requirement promotes automation and increases operational flexibility.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.03.0521.070	A single failure of a component or power source in the overspeed protection should not result in an unsafe overspeed or trip actuation of the turbine.	Plant availability should be maintained despite this type of single failure.	EUR Volume 4 Chapter 10	Instrumentation and Controls	ALL	GR OG	SAFE PERF
3.04.0020.010	Liquid-fueled reactors using emergency drain tanks should be designed so that the fuel can be recovered after draining.	Emergency drain tanks are designed to achieve subcritical geometries. After draining and subsequent cooling, the fuel should be recoverable, even if this requires electric heating to melt the fuel prior to pumping back to the primary system.	Industry Feedback	Investment	MSR	ALL	ECON
3.04.0040.010	In the trade-off between increasing nuclear fuel efficiency and decreasing capital costs, reactor designers should utilize a LCOE (or mission-equivalent metric) evaluation to prioritize the decrease of capital costs versus nuclear fuel efficiency as a driving factor in design.	As the efficiency of converting nuclear fuel to heat increases, the design and construction costs also increase, while the nuclear fuel costs decrease. For existing plants, nuclear fuel costs are small in comparison to capital costs, and that trend is likely to extend to advanced plants as well. Therefore, in most applications, optimizing a plant's energy efficiency is not going to be worth the additional capital cost. For small- and micro-scale reactors, fuel costs may be a bigger driver of overall costs, and this trade-off may need to be revisited.	Industry Feedback	Investment	ALL	GR OG PH	ECON
3.04.0060.010	The reactor designer and owner-operator should create a list of functional responsibilities for the major plant staffing areas (engineering, operations, maintenance, outage, training, security, chemistry and emergency preparedness) which will serve as a framework for any staff optimization initiatives.	A key barrier for the deployment of any nuclear reactor design is represented by the O&M costs. Staff optimization (not staff reduction) is a crucial initiative, while maintaining the safety and reliability of the nuclear reactor.	EPRI TR 3002007071	Investment	ALL	ALL	PERF ECON
3.04.0070.010	The reactor designer should assure that the manufacturer provides detailed drawings of each check valve showing dimensions and weights of all parts, clearances between moving parts, a complete list of materials, torques for all fasteners, lubricants for fasteners before assembly, and details of all locking and retaining devices.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1.*" (EPRI, 1993)	Investment	ALL	ALL	PERF
3.04.0070.020	The reactor designer should assure that the manufacturer provides detailed drawings of each valve showing dimensions and weights of all parts, clearances between moving parts, a complete list of materials, torques for all fasteners, lubricants for fasteners before assembly, and details of all locking and retaining devices.	These considerations are motivated specifically by issues with check valves, but are beneficial for all valves due to the high failure rates associated with valves as compared to other components.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Investment	ALL	ALL	PERF
3.04.0090.010	Safety systems that rely on AC power for instrumentation and control purposes, but do not involve active components, can be considered to be passive if the AC power is supplied by safety-related Direct Current (DC) power sources that rely on stored energy (i.e., batteries).	Consistent with the philosophy of passive safety system design.	mPower DSRS 8 Chapter 8 URD Rev 13 Tier II Chapter 1 Section 2	Investment	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.04.0100.010	The design should demonstrate the ability to accommodate positive reactivity additions due to postulated single failures or operator errors, with sufficient margin to the design limits.	Plant safety should not be compromised by the failure of a single component and should have sufficient margin in the reactor protection system.	EUR Volume 2 Chapter 1	Investment	ALL	ALL	SAFE
3.04.0150.010	Breeding reactors should be designed such that the design breeding ratio (or conversion ratio) is achievable with the fuel source expected to be available (e.g., depleted uranium, used LWR fuel).	Breeding is highly dependent on the fuel source, so this must be a consideration. A wide variety of reactor designs can achieve breeding, depending on the selected fuel cycle and the design.	Industry Feedback	Investment	SFR LFR MSR	ALL	PERF ECON
3.04.0150.020	The reactor designer should demonstrate that acceptable breeding ratios (or conversion ratios) are achievable if the fuel feedstock changes over the life of the plant (e.g., depleted uranium becomes unavailable).	Similar to LWRs, the economic case for breeding reactors may change over the course of the plant's life. LWRs in the U.S. saw their competitiveness change with changes in regulation and the availability of other natural resources. A wide variety of reactor designs can achieve breeding, depending on the selected fuel cycle and the design.	Industry Feedback	Investment	SFR LFR MSR	ALL	PERF ECON
3.04.0160.010	Measures should be taken to avoid the flooding of investment critical equipment during firefighting.	Firefighting water can be a significant flooding threat. Design features can avoid the accumulation of firefighting water or provide means for dewatering to avoid damage to expensive equipment.	URD Rev 13 Tier II Chapter 6 Section 2	Investment	ALL	ALL	ECON
3.04.0160.020	The Coupling Heat Transport System (CHTS) should be designed to withstand the effects of internally generated missiles.	For process heat applications, the systems involved in heat transfer constitute a significant investment. Their rupture could also result in undesirable effects outside of the impact to the plant.	EPRI TR 1009687 GCRA 86-002/Rev. 3	Investment	ALL	PH	IMPL
3.04.0170.010	Pressure relief systems should be provided to reliably allow trips from 100% power without over pressurizing BOP systems.	This requirement is established to limit BOP pressure rises during transients. Existing LWR designs indicate these requirements can be met with a turbine bypass capacity of 40-55% of the full-load turbine steam flow at full-load steam pressure.	URD Rev 13 Tier II Chapter 2 Section 3	Investment	ALL	ALL	PERF
3.04.0190.010	The reactor designer should assure that valve design features and details are selected to lengthen the service life and improve reliability.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Investment	ALL	ALL	PERF
3.04.0200.010	The CHTS should be designed for the design life of the plant or it should be designed with allowance for periodic replacement of life-limiting components.	This relates to the potential life-limiting effects of high temperature on the CHTS and refers generally to passive portions of the CHTS contacting the circuit coolant.	EPRI TR 1009687	Investment	ALL	PH	ECON

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.04.0210.010	The turbine-generator should be designed to operate for a period of time equal to or greater than the design life of the plant without necessity for an extended refurbishment outage.	At the time of bid, the turbine-generator vendor should identify major components that will require replacement before the end of the plant's design life. The estimate and basis of the expected life of these components should also be identified. Consideration should also be given in the design of appropriate equipment for a possible life extension beyond the plant design life. Replacement of the turbine generator and associated components requires a major capital investment and results in a large period of down time. To the extent practical, these components should last for the life of the plant to avoid these costs and down time. Any components requiring replacement within the plant's design lifetime should be identified upfront so that the owner-operator can evaluate their economic impact to the plant's lifecycle and plan for their eventual replacement.	URD Rev 13 Tier II Chapter 13 Section 2	Investment	ALL	GR OG	ECON
3.04.0260.010	Visitor access that provides interactive displays, informative exhibits, and viewing of the control room (and other important facilities) should be considered.	Educating the local community fosters positive public relations, which can prevent premature shutdown of the plant due to public opinion.	GCRA 86-002/Rev. 3	Investment	ALL	ALL	ECON
3.04.0260.020	The gains associated with visitor access should be balanced against the security risks and operational inefficiencies that may result from granting non-staff access to the plant.	Issues such as increased administrative burden due to badging and increased security risk should be considered when granting plant access. Some of these issues could be mitigated by providing remote viewing capability (i.e., live feed) of certain areas in the plant.	Industry Feedback	Investment	ALL	ALL	PERF SEC/NP
3.04.0270.010	Pumps in radiation areas should be provided with long life bearings and permanent type lubrication where practical.	Pumps are a significant portion of the maintenance burden on the plant staff. Minimizing and simplifying pump maintenance will help achieve the availability goals for the plant. For pumps in radioactive service, these requirements are important to meeting plant goals.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter D49	Investment	ALL	ALL	PERF
3.04.0280.010	Safety valves should be designed to function at postulated event conditions.	This requirement is intended to assure that these valves are able to function in harsh environments to mitigate events and to minimize the possibility of plant shutdown and/or safety valve maintenance because of a safety valve not opening in the specified pressure range during an operability test.	URD Rev 13 Tier II Chapter 2 Section 3	Investment	ALL	ALL	SAFE PERF
3.04.0290.010	A material gap analysis should be performed for BOP applications to ensure that the materials assumed to be available for the plant design are also available and compatible with the BOP design.	Especially for reactors operating at high temperatures (>500 °C), specialty materials will be developed, but the reactor designer must demonstrate that materials for high temperature service will be compatible with the BOP design as well.	Industry Feedback	Investment	ALL	ALL	PERF IMPL
3.04.0290.020	The design should consider a variety of BOP cycles (including steam and gas cycles), taking into account the reactor design and mission.	Steam, or Rankine cycles have traditionally been used for BOP systems in nuclear power plants. However, with many advanced reactors operating at higher temperatures and using different primary coolants than traditional LWRs, alternative BOP designs may be more efficient or have other advantages when used with an advanced reactor.	EPRI 3002003664 (EPRI, 2014f)	Investment	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.04.0352.010	In a multi-module electricity generation-process heat dual-mission HTGR plant, each modular unit should be independent.	Where the plant is applied to electricity generation only, the function of the plant is to provide power to an external electric grid (or smaller-scale electrical system). If the plant is one of many generators on the grid, its operation responds to numerous external events and circumstances. Each modular unit is also independent of others in a multi-module HTGR generating plant. For process heat, the same capability for operating independence among the reactor modules should be preserved.	EPRI TR 1009687	Investment	HTGR	GR OG PH	PERF
3.04.0360.010	If heat storage is desired or required as part of the reactor's mission, the reactor designer should consider the use of a thermally decoupled independent loop.	Using an independent loop that can easily be de-coupled from the BOP simplifies operation and can aid in leveling the load profile of the plant.	Industry Feedback	Investment	ALL	PH	PERF
3.04.0360.020	Planned maintenance on the coupling heat transport system should be achievable within the timeframe of required outages for the reactor plant and the process heat plant (i.e., the maintenance on the CHTS should not lie on the critical path during planned outages).	Optimizing maintenance practices on the coupling heat transport system will maximize the availability of the heat source.	EPRI TR 1009687	Investment	ALL	PH	IMPL
3.04.0391.010	Technical issues related to geographic phenomena (e.g., weather, terrain) should be considered in siting and mitigated in the plant design or the construction plan.	Advanced reactors may be sited at locations with geographic factors that are not considered in existing designs. Transportation of equipment through certain terrains is a particular concern. Permafrost, sand, marsh, and barge are examples of potentially challenging terrain/foundation.	EUR Volume 2 Chapter 13	Investment	ALL	ALL	IMPL
3.04.0461.010	When siting a reactor without existing transmission infrastructure, the availability of the land needed for transmission should be confirmed.	Running transmission lines that cross through land owned by different entities can be a challenge. Using land that is owned by a governmental entity can be particularly difficult.	Industry Feedback	Investment	ALL	GR	IMPL
3.04.0471.010	Advanced reactor developers should consider leaving adequate space on site for the back fitting of air condensers to allow for dry cooling in the future.	Even if the plant does not initially have dry cooling capabilities, this requirement allows the owner-operator to include dry cooling capabilities in the future if desired.	Industry Feedback	Investment	ALL	GR OG	PERF ECON
3.04.0471.020	Prior to deciding to pursue dry cooling options for large reactors, the reactor-designer should ensure high backpressure turbines are available.	Air cooling cannot cool the working fluid to as low of temperatures as water cooling, so turbine backpressures may be much higher if dry cooling is used. The emergence of dry cooled nuclear plants may necessitate development in the area of high backpressure turbines.	Industry Feedback	Investment	ALL	GR	PERF ECON
3.05.0010.010	The containment leakage should be restricted to be less than that needed to meet the acceptable on-site and off-site dose consequence limits.	USNRC used language in their Advanced Reactor Design Criteria (ARDCs) to restrict the leakage of the containment to be less than that needed to meet the acceptable on-site and off-site dose consequence limits (Ref. SRM, SECY-93-092). Therefore, the Commission agreed that the containment leakage for advanced reactors, similar to and including PRISM, should not be required to meet the "essentially leak tight" statement in GDC 16. (Ref: NUREG-1368).	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0010.020	Systems responsible for transferring heat to the ultimate heat sink should include suitable interconnections, leak detection, and isolation capabilities, with appropriate redundancy, to ensure the systems can perform their safety function(s) assuming a single failure.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0010.030	For plants that need to be transported as a fully fueled assembly (e.g., factory-assembled, rail-transportable technologies), analysis, testing, inspection, and QA measures should be implemented to ensure that the reactor will not reach criticality during transport while accounting for potential accidents.	Transporting a fully fueled reactor assembly is a technical challenge unique to certain advanced reactor designs.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0030.010	If the design includes a containment building, the containment heat removal system should be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from postulated events using passive components.	If containment structures are required to meet requirements for fission product releases, pressure and temperature conditions must be met in order to prevent leakage from exceeding the design value.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0030.020	Piping systems penetrating the reactor containment structure should be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities which reflect the importance to safety of isolating these piping systems.	This requirement is based upon the USNRC's Advanced Reactor Design Criterion 50, which specifically applies to advanced non-LWR designs that utilize a fixed containment structure.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0030.030	Each line that is part of the reactor coolant boundary and that penetrates the reactor containment structure should be provided with containment isolation valves.	This requirement is based on the USNRC's Advanced Reactor Design Criteria (ARDCs) but has been generalized to eliminate the specific exceptions for penetrations that do not require isolation valves. The requirement is also changed to a "should" statement to reflect variations in advanced reactors' reliance on containment systems to prevent or limit radioactive releases.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0030.040	Each line that connects directly to the containment atmosphere and penetrates the reactor containment structure should be provided with containment isolation valves.	This requirement is based on the USNRC's Advanced Reactor Design Criteria (ARDCs) but has been generalized to eliminate the specific exceptions for penetrations that do not require isolation valves. The requirement is also changed to a "should" statement to reflect variations in advanced reactors' reliance on containment systems to prevent or limit radioactive releases.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0030.050	The boundary of the reactor containment structure should be designed with sufficient margin to assure that under operating, maintenance, testing, and postulated event conditions (1) its materials behave in a non-brittle manner and (2) the probability of rapidly propagating fracture is minimized.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactor designs rely upon a containment structure.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0030.060	The design should reflect consideration of service temperatures and other conditions of the containment boundary materials during operation, maintenance, testing, and postulated event conditions, and the uncertainties in determining (1) material properties, (2) residual, steady state, and transient stresses, and (3) size of flaws.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactor designs rely upon a containment structure.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0040.010	For SFRs, components submerged in the sodium pool should be designed and constructed so that they promote the passive removal of entrained gas bubbles during normal operation and during evolutions that require removal or repositioning of the component.	Entrained gas is deleterious to heat transfer and reactivity stability. Design for passive removal of entrained gas reduces plant complexity and reliability by limiting active components.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	PERF
3.05.0050.010	Safety systems that rely on AC power for instrumentation and control purposes, but do not involve active components, can be considered to be passive if the AC power is supplied by safety-related DC power sources that rely on stored energy (i.e., batteries).	Consistent with the philosophy of passive safety system design.	mPower DSRS 8 Chapter 8 URD Rev 13 Tier II Chapter 1 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0090.010	Welding construction should optimize weld, number, size, orientation, and type.	The complexity and rigor of in-field modifications should be minimized.	URD Rev 13 Tier II Chapter 1 Section 5	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.020	Fluid systems should be designed to minimize the number of valves consistent with safety, functional, reliability and availability requirements.	The reactor designer should evaluate the need for each valve based on: • - System safety functions; • - System operational functions; • - Expected flow rate range; • - Design pressure drop range; • - Reliability requirements; • - Redundancy requirements; • - Code requirements; • - Regulatory requirements; • - Isolation or maintenance requirements. Simplicity is an ORG policy statement. The number of valves affects the cost of the plant, construction difficulty, and the operation and maintenance effort over the plant lifetime.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 4 EUR Volume 2 Chapter 7	Licensing and Safety Analysis	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0090.030	The reactor designer should assure that check valves are used only where necessary.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.040	The number of primary coolant boundary penetrations should be minimized to the extent practical.	Unnecessary penetrations are a potential leak path and may require additional maintenance resources.	URD Rev 13 Tier II Chapter 1 Section 12	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.050	Heat exchangers should be designed to withstand the maximum system pressure, and relief valves should be provided only if necessary (e.g., the heat exchanger can be isolated). However, relief valves should not be used to justify the use of a heat exchanger that is designed for less than system pressure.	This requirement is good engineering practice and avoids heat exchanger damage due to off normal pressure conditions which are within the capability of the system.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.060	Piping systems which require draining should be laid out so as to minimize the number of low points.	This requirement reduces the number of drain spots and associated equipment as well as the chance for system leaks.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 2 Chapter 11	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.070	Piping layouts that result in 90° elbows, miters, etc. should be minimized during the design phase.	The piping configuration can be a cause of erosion-corrosion in the steam line. Minimizing 90° elbows, miters, etc., will reduce turbulent flow conditions that are conducive to erosion-corrosion problems.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 2 Chapter 7	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.080	The arrangement of piping should minimize the local high points and low points.	The number of drains and vents should be minimized wherever practical to simplify maintenance and startups.	URD Rev 13 Tier II Chapter 8 Section 3	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.090	Any vent or drain required for construction (pressure testing or flushing) but not required for operation (including subsequent maintenance or pressure testing) should be removed or capped before startup.	Any components not necessary for the operation of the plant should be removed in accordance with the ORG simplification policy statement.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0090.100	Air cooled rectifiers are recommended for the excitation system of the main generator. If water cooling is used for the rectifiers, the water cooling circuit must be designed and installed to preclude electrical flash-over under all operating conditions, including temporarily operating without the cooling water flow.	Air cooled design is simpler and eliminates a field ground trip failure mode as a result of stator cooling water leakage.	URD Rev 13 Tier II Chapter 13 Section 4	Licensing and Safety Analysis	ALL	GR OG	PERF
3.05.0090.110	The plant design should avoid complex, dissimilar metal welds where possible.	Such welds are often susceptible to stress corrosion cracking and are difficult to analyze (possible requiring 3D finite element analysis). Avoiding these welds will save time and money.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	PERF ECON

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0100.010	Plant systems should embody sufficient robustness of design to tolerate a conservative number of spurious or inadvertent engineered safety system actuations without the need for follow-up tests or inspections to verify systems' integrity or operability.	To assure that the plant will not be damaged, particularly in the event of accidental or inadvertent initiation of part or all of the systems and that operation of the systems will not have effects which would inhibit operators from using the systems when required.	URD Rev 13 Tier II Chapter 5 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0100.020	Components should be designed with sufficient margin to allow for wear, normal corrosion and erosion experienced in plant service, etc., without affecting plant performance and incurring unnecessary maintenance for the design life of the component.	Experience has shown that design allowances of certain components have been inadequate to cover likely problems or changes in performance, augmenting the need for plant shutdown to perform repairs. Examples of major problem areas are wear of pump parts and corrosion of heat exchanger tubes.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 1 EUR Volume 2 Chapter 7	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0100.030	Margin for heat exchanger tube plugging should be provided consistent with experience in similar heat exchangers.	Providing a tube plugging margin maintains the design heat exchanger performance, even with some degraded tubes plugged. This can substantially extend the time before a tube bundle must be replaced.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0100.040	A minimum tube plugging margin of 10% should be considered in the heat exchanger design where other requirements do not take precedence.	In the absence of other data, some tube plugging margin is appropriate. Providing a tube plugging margin maintains the design heat exchanger performance, even with some degraded tubes plugged. This can substantially extend the time before a tube bundle must be replaced.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0100.050	The feedwater/condensate system should be designed with sufficient volume to accommodate fluid thermal expansion and contraction, as well as occasional loss of fluid due to atmospheric steam dumps.	Expansion and contraction of system volume occurs during changes in load. The condenser hotwell should be large enough to accommodate normal operating transients without short term reliance on condensate reject and make-up.	URD Rev 13 Tier II Chapter 2 Section 4 EUR Volume 4 Chapter 6	Licensing and Safety Analysis	ALL	GR OG	PERF
3.05.0110.010	The reactor design should include natural reactivity feedback mechanisms that result in self-controlled behavior during all credible reactivity insertion events.	This requirement establishes the "inherently safe" principle in which the reactor is self-limiting against uncontrolled power excursions.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 8	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0110.020	The MSR core should be designed such that the overall reactivity response is negative over the range of temperatures encountered in startup, normal operation, and postulated event conditions.	A negative reactivity response to an increase in temperature provides for inherent stability at operation and provides a passive means to terminate the fission process in the event of an accidental power excursion or loss of heat removal. A limited region of non-negative response is acceptable if self-terminating.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0110.030	The SFR control strategy should not rely on parameters that are loosely coupled to reactor behavior or that could be decoupled from reactor behavior in a postulated event.	Natural feedback mechanisms used as part of the control strategy are different than traditional LWR technologies.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	SAFE
3.05.0110.040	SFR designs should include means of suppressing the positive reactivity worth due to coolant voiding, whether through active systems or inherent feedback.	SFRs typically have positive sodium void worths. This void worth is suppressed with active systems like control rods, or can be suppressed through natural responses like Doppler reactivity.	USNRC RG 1.232 American Nuclear Society "General Safety Design Criteria for a Liquid Metal Reactor Nuclear Power Plant", ANS 54.1	Licensing and Safety Analysis	SFR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0120.010	The source term for postulated events should consider the entire fuel salt volume and applicable portions of fuel salt polishing systems.	Although only a fraction of the fuel salt will be considered "critical" at any point during operation, the analyses of postulated events should consider the entire volume of the fuel salt.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0150.010	Piping should not be routed over electrically energized components.	Separating pipe routes from electrical cables or cabinets reduces the potential for damaging electrical equipment in the case of a pipe leak. It also reduces the interference removal required for replacing electrical equipment.	URD Rev 13 Tier II Chapter 6 Section 4	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0150.020	Exciter coolers should be offset from the centerline of the exciter.	Cooler offset prevents exciter loss as a result of cooling water leakage.	URD Rev 13 Tier II Chapter 13 Section 4	Licensing and Safety Analysis	ALL	GR OG	PERF
3.05.0170.010	The on-site safety power distribution systems should be divided into independent divisions. The divisions should supply power to separate and functionally redundant load groups.	This requirement helps implement the concepts of redundancy and divisional separation that support Defense-in-Depth.	URD Rev 13 Tier II Chapter 11 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0180.010	The design of the reactor vessel, reactor system, and reactor building should be such that their integrity is maintained during postulated events to ensure the geometry for passive removal of residual heat from the reactor core to the ultimate heat sink and to permit sufficient insertion of the neutron absorbers to provide for reactor shutdown.	The reactor vessel and reactor system for HTGR is relied upon for effective heat removal and reactivity control during all conditions (including postulated events).	USNRC RG 1.232 “A Safety Re-evaluation of the AVR Pebble Bed Reactor Operation and its Consequences for Future HTR Concepts” (Moormann, 2008)	Licensing and Safety Analysis	HTGR	ALL	SAFE
3.05.0180.020	MSRs should use active reactivity control systems to demonstrate acceptable margin to design limits in the event of the maximum positive reactivity insertion resulting from cooldown, assuming the most limiting single failure of the reactivity control system.	While inherent negative feedback mechanisms can be relied upon to safely shut down the plant, active control features are operationally desirable.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0180.030	Penetrations of the reactor vessel should be above a specified minimum elevation required to provide cooling in a postulated event, with the exception of penetrations for specific safety purposes (e.g., a primary vessel drain in an MSR).	Locating vessel penetrations above a specified minimum level reduces the chance that a rupture could reduce coolant inventory sufficient to jeopardize cooling or pump net positive suction head.	Industry Feedback	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0190.010	The source term for postulated events should consider the entire fuel salt volume and applicable portions of fuel salt polishing systems.	Although only a fraction of the fuel salt will be considered "critical" at any point during operation, the analyses of postulated events should consider the entire volume of the fuel salt.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0190.020	The design should specify the distribution of fuel salts between the core and loops for postulated events.	The amount of fuel salt circulating outside of the core will affect the assumed source term during postulated events. Some postulated events may assume a source term in the core or in the primary system loop, which could be different.	Minimizing the Fissile Inventory of the Molten Salt Fast Reactor, E. Merle-Lucotte et. al., Advances in Nuclear Fuel Management IV (Merle-Lucotte, 2009).	Licensing and Safety Analysis	MSR	ALL	SAFE IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0230.010	During the site selection process for an advanced reactor deployment, the reactor designer and owner-operator should analyze various numerical composite ratings for each site being considered, and rank their overall suitability as nuclear power plant sites.	To deploy a new nuclear reactor, the applicant must receive permits from the regulator for the construction and operation of the reactor. In addition to the regulatory requirements, the approved site must also satisfy business objectives for the project, allow for plant operation, and comply with process requirements for the consideration of alternative sites.	EPRI TR 3002005435	Licensing and Safety Analysis	ALL	ALL	IMPL
3.05.0280.010	HTGRs should employ a defense in depth approach to fission product barriers, relying on the fuel, primary system boundary, and/or external structures to demonstrate adequate protection of the public.	This requirement supports the multi-barrier approach of a functional containment, which starts at the fuel kernel.	USNRC RG 1.232 “A Safety Re-evaluation of the AVR Pebble Bed Reactor Operation and its Consequences for Future HTR Concepts”	Licensing and Safety Analysis	HTGR	ALL	SAFE
3.05.0280.020	Tristructural-isotropic (TRISO) type fuels should be demonstrated to withstand postulated event conditions such that they can be relied upon as an effective fission product barrier, reducing the need for other barriers to demonstrate a defense in depth strategy.	A major benefit of the TRISO fuel type is the relaxation of design requirements for other fission product barriers.	Industry Feedback	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE PERF
3.05.0320.010	Passive plant containment systems for which a change of state is necessary to assure an intact containment during a severe event (e.g., containment isolation, containment heat removal) should be redundant and independent from the systems whose failure leads to radionuclide release.	Minimizes the probability of containment failure or bypass in the unlikely event a transient progresses to radionuclide release by providing independent means of maintaining containment integrity.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0330.010	The design should account for the effects of delayed neutron production occurring outside the core region.	If fuel circulation in the loops occurs on a timescale similar to delayed neutron precursor decay, then reactor kinetic behavior will be coupled to delayed neutron production in the loops. This is a feedback mechanism unique to reactors with circulating fuel.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE PERF
3.05.0380.010	HTGR designs should include sufficient monitoring to identify chemical hazards, including the leakage of heat transfer fluids that may be hazardous to plant personnel or equipment.	Though most HTGRs use heat transfer fluids that do not result in strong chemical reactions, these fluids are usually a hazard to personnel if leaked in large quantities. Other chemical hazards should be identified and monitored if applicable.	Industry Feedback	Licensing and Safety Analysis	HTGR	ALL	SAFE PERF
3.05.0390.010	The MSR design should keep molten salts from freezing, except where intended to freeze as a part of the designed functionality.	Freezing molten salt has the potential to block flow through the reactor and induce undesirable stresses on materials and mechanical components. Many molten salt designs use a "freeze plug" which melts to release the core volume into an emergency drain tank or tanks.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	PERF
3.05.0390.020	MSR designs which use solid reflector material should demonstrate that reflector materials can be adequately cooled.	Reflector materials have internal heat generation due to the slowing down of neutrons, as well as conductive and convective heating from surrounding materials and fluids. They often have lower temperature limits than other reactor materials. Cooling could be provided by the reactor coolant or by a dedicated separate cooling system.	USNRC RG 1.232	Licensing and Safety Analysis	MSR	ALL	SAFE

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0390.030	The design should keep sodium from freezing except in areas where it is deliberately allowed to freeze, and should be able to unfreeze sodium throughout all reactor systems.	Freezing sodium has the potential to block coolant flow and induce undesirable stresses on materials and mechanical components.	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE PERF
3.05.0390.040	Heating systems should be provided for systems and components important to safety, which contain or could be required to contain liquid metals or metal aerosols, to provide means for protection against freezing in vulnerable areas, and a means for thawing the metal.	Freezing in undesirable locations could jeopardize the performance of important equipment. Having the ability to prevent or thaw such freezing is important for the operability of plant equipment.	USNRC RG 1.232 NUREG-1368	Licensing and Safety Analysis	SFR LFR	ALL	IMPL
3.05.0480.010	For reactors designed to operate at high temperatures, the designer should perform the safety classification of the plant's SSCs in accordance with applicable codes and standards.	Division 5 of Section III of the ASME B&PV Code was created to address the unique concerns associated with the high operating temperatures of advanced reactors. The temperature threshold for "high" is variable, but existing codes and standards may require further development for a number of proposed reactor designs.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 4	Licensing and Safety Analysis	ALL	ALL	SAFE PERF
3.05.0480.020	Heat exchangers should be built to the TEMA R Standard.	The subject standard supports a 60-year design life.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 4	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0480.030	Steam line isolation valves and non-return valves should be of a design, size, and arrangement to comply with the requirements of ANSI/ ASME TDP-2, “Prevention of Water Damage to Steam Turbines used for Electric Power Generation: Nuclear-Fueled Plants” (or equivalent).	This is an international standard for the design and arrangement of steam valves.	URD Rev 13 Tier II Chapter 2 Section 3 ANSI/ ASME TDP-2, “Prevention of Water Damage to Steam Turbines used for Electric Power Generation: Nuclear-Fueled Plants” (ASME, 2012)	Licensing and Safety Analysis	ALL	GR OG	PERF
3.05.0480.040	The condenser should be designed in accordance with Heat Exchange Institute (HEI) Standards.	Industry accepted standards for the design of heat exchangers.	URD Rev 13 Tier II Chapter 2 Section 4	Licensing and Safety Analysis	ALL	GR OG	PERF
3.05.0510.010	Noncombustible and fire-resistant materials should be used wherever practical throughout the plant, particularly in locations with SSCs important to safety.	This reduces the susceptibility of the plant to a fire or explosion.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0510.020	The plant should use barriers and physical separation to prevent the spread of fire and to eliminate the potential for redundant systems to be subject to a common mode failure.	To prevent the spread of a fire beyond the initiating location, and to ensure redundant pieces of equipment are not both vulnerable to damage in the event of a single fire.	URD Rev 13 Tier II Chapter 6 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE ECON
3.05.0520.010	Fire protection water should be from a dedicated supply.	Older plants are experiencing continuing difficulty using a raw water system from fresh water bodies. A properly treated water source will mitigate many of these problems.	URD Rev 13 Tier II Chapter 9 Section 3 EPRI TR 109633 “*Guideline for the Evaluation and Treatment of Corrosion and Fouling in Fire Protection Systems*” (EPRI, 1999)	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0520.020	The fire protection water should be chemically treated to reduce biological fouling and filtered to reduce silt and debris.	Older plants are experiencing continuing difficulty using a raw water system from fresh water bodies. A properly treated water source will mitigate many of these problems.	URD Rev 13 Tier II Chapter 9 Section 3 EPRI TR 109633 “*Guideline for the Evaluation and Treatment of Corrosion and Fouling in Fire Protection Systems*”.	Licensing and Safety Analysis	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0520.030	Firefighting systems should be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of any SSCs.	This reduces the susceptibility of the plant to a fire or explosion.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0520.040	The design of fire detection and fighting systems should consider the total volume and location of combustible materials and provide adequate measures for fire protection.	To provide a fire protection system at each location in the plant that is consistent with the fire hazard.	URD Rev 13 Tier II Chapter 6 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE ECON
3.05.0550.010	Advanced reactor designs should include sufficient instrumentation to characterize core conditions to prevent exceeding design limits.	The use of multiple monitoring systems, both in-core and ex-core, allows for more accurate determination of core conditions, especially during events. This instrumentation should be designed to measure parameters important to the specific design. Modern analytical techniques may provide sufficient modeling of reactor conditions that instrumentation can be reduced relative to older designs.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE PERF
3.05.0550.020	The reactor core should be designed to be self-damping against power oscillations throughout core life.	The core should be designed for stability.	URD Rev 13 Tier II Chapter 4 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE PERF
3.05.0550.030	The SFR control strategy should not rely on parameters that are loosely coupled to reactor behavior or that could be decoupled from reactor behavior in an event.	Natural feedback mechanisms used as part of the control strategy are different than traditional LWR technologies.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	SAFE
3.05.0550.040	The design should consider the potential for deformation of the fuel assemblies to prevent the blockage of coolant channels.	It is important to prevent fuel failure due to local flow blockage caused by entrainment of foreign substances, fuel pin swelling, etc., since the reactor is close-packed and the specific power is high.	Industry Feedback	Licensing and Safety Analysis	SFR LFR	ALL	SAFE
3.05.0550.050	MSR fuel qualification should demonstrate that unacceptable gradients in fuel concentration, poison concentration, or concentrations of other solutes will not develop (e.g., as a result of differing molecular weights).	The fuel salt chemistry should be sufficiently homogenous to mitigate the creation of localized "hot spots" in the reactor, which would act as an increased source of radiation and heat.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE IMPL
3.05.0550.060	Consideration should be given to the placement of nozzles, etc., to prevent cover gas entrainment into the primary system from occurring during normal and postulated event conditions.	Gas bubble inflow to the core due to cover-gas entrainment will result in a positive sodium void reactivity insertion.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	PERF
3.05.0550.070	Helium should be used as the heat transfer fluid for HTGR designs.	Helium will not corrode components or equipment.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR	ALL	PERF
3.05.0550.080	For pebble bed designs, the design should include features to promote homogeneous travel of fuel particles through the reactor.	Due to the fuel particles being mobile, there is potential for the particles to develop localized areas of higher-than-normal activity and temperature. The travel of individual pebbles can be hindered by the periphery of the reactor.	“A Safety Re-evaluation of the AVR Pebble Bed Reactor Operation and its Consequences for Future HTR Concepts”	Licensing and Safety Analysis	HTGR	ALL	SAFE PERF
3.05.0560.010	Instruments for identifying fuel failures should be positioned such that they can effectively distinguish true fuel failures.	If not carefully planned, instruments that identify fuel failures may be located in an area that would inhibit their ability to distinguish fuel failures from the other sources of ionizing radiation.	EUR Volume 2 Chapter 8	Licensing and Safety Analysis	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0560.020	HTGR designs should be developed with a control strategy that provides effective control of the reactor in all conditions and is reliant on direct measurement of key variables without complex operator actions.	Depending on the flux spectrum, the fuel type, and the coolant, the control strategy could rely on many different principles. The selection of an appropriate control strategy may influence specific design features.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE PERF
3.05.0560.030	HTGR designs should include instrumentation that allows for confidence in fuel temperatures measured throughout the core.	To ensure that specified acceptable core radionuclide release design limits are not exceeded throughout the core under all conditions.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE PERF
3.05.0560.040	MSR designs should be developed with a control strategy that provides effective control of the reactor in all conditions and is reliant on direct measurement of key variables without complex operator actions.	Depending on the flux spectrum, the fuel type, and the coolant, the control strategy could rely on many different principles. The selection of an appropriate control strategy may influence specific design features.	USNRC RG 1.232	Licensing and Safety Analysis	MSR	ALL	SAFE PERF
3.05.0560.050	SFR designs should be developed with a control strategy that provides effective control of the reactor in all conditions and is reliant on direct measurement of key variables without complex operator actions.	Depending on the flux spectrum, the fuel type, and the coolant, the control strategy could rely on many different principles. SFRs have many reactivity coefficients that change over the range of operating conditions experienced by the plant and therefore require special consideration in control strategy design. The selection of an appropriate control strategy may influence specific design features.	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE PERF
3.05.0560.060	Fuel failure detection devices should be provided as appropriate.	The design of radiation detectors or other instruments that can identify fuel failures is important in evaluating and responding to events.	Industry Feedback	Licensing and Safety Analysis	SFR LFR	ALL	SAFE
3.05.0560.070	MSR designs should include reliable chemical monitoring and polishing systems to ensure that fuel/coolant salt chemistry problems can be identified and addressed in time to prevent adverse effects.	Corrosion, fuel performance, and safety all depend on maintaining salt chemistry within specified bounds.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	PERF
3.05.0560.080	Cover gas purity should be monitored, maintained, and provided with the means to remove coolant aerosols.	Cover gas purity is important for maintaining the performance of reactor systems. Aerosols can deposit on components within the reactor vessel and result in mechanical clearance and other problems.	"Operating Experience from the BN 600 Sodium Fast Reactor", O.A. Potapov (Potapov, 2015)	Licensing and Safety Analysis	SFR LFR MSR	ALL	PERF
3.05.0570.010	Analysis should confirm that the integrity of the reactor coolant boundary will be maintained against the release of mechanical energy due to a bounding re-criticality event unless analysis shows that re-criticality is not possible.	The configuration of a reactor core is not maintained in its most reactive state. Therefore, a loss of core geometry due to a severe event such as fuel melting and relocating could place the fuel in a more reactive state allowing it to achieve prompt criticality.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0570.020	The reactor helium pressure boundary should be designed, fabricated, erected, and tested so as to have an extremely low probability of unacceptable ingress of air, secondary coolant, or other fluids.	The addition of unacceptable air and fluid ingress, which is unique and critical to the HTGR design, to the USNRC's Advanced Reactor Design Criterion 14 warranted the development of an HTGR design specific criterion for the reactor helium pressure boundary.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0570.030	When the primary coolant system interfaces with a structure, system, or component containing fluid that is chemically incompatible with the primary coolant, the interface location should be designed to ensure that the primary coolant is separated from the chemically incompatible fluid by two redundant, passive barriers.	Barriers ensure that radioactive sodium does not have the potential for exposure to steam or other incompatible substances. For most SFR designs, this is accomplished with an intermediate loop. Barriers could include inert gas layers and/or mechanical boundaries. The rates and exothermic energies of chemical reactions must be evaluated by the designer to determine what constitutes "chemically incompatible."	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE
3.05.0570.040	The number of primary coolant boundary penetrations should be minimized to the extent practical.	Unnecessary penetrations are a potential leak path and may require additional maintenance resources.	URD Rev 13 Tier II Chapter 1 Section 12	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0570.050	Components which are part of the reactor helium pressure boundary should be designed, fabricated, erected, and tested to the commensurate quality standards.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0570.060	For HTGR designs, means should be provided for detecting and, to the extent practical, identifying the location of the source of the reactor helium leakage.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0570.070	Components which are part of the primary coolant boundary should be designed, fabricated, erected, and tested to the commensurate quality standards.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0570.080	For liquid metal and MSR designs, means should be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0580.010	The MSR design should keep molten salts from freezing, except where intended to freeze as a part of the designed functionality.	Freezing molten salt has the potential to block flow through the reactor and induce undesirable stresses on materials and mechanical components. Many molten salt designs use a "freeze plug" which melts to release the core volume into an emergency drain tank or tanks.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	PERF
3.05.0580.020	The design should keep sodium from freezing except in areas where it is deliberately allowed to freeze, and should be able to unfreeze sodium throughout all reactor systems. Note: Same as 3.05.0390.030.	Freezing sodium has the potential to block coolant flow and induce undesirable stresses on materials and mechanical components.	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE PERF
3.05.0580.030	The SFR design should mitigate the effect of thermal loads on the reactor coolant boundary, especially at the upper plenum.	A large temperature difference can occur within the short distance between the free sodium surface and top of the reactor vessel. This stress can become transient during reactor startup when the sodium level rises with the thermal expansion of sodium itself as it increases in temperature.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	SAFE PERF
3.05.0580.040	The reactor coolant inventory maintenance system should be designed to assure that a postulated single failure could not result in a loss of coolant inventory during normal reactor operation.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0580.050	The primary coolant system and associated auxiliary, control, and protection systems should be designed with sufficient margin to assure that the design conditions of the primary coolant boundary, including the cover gas boundary, are not exceeded during any condition of normal operation, including anticipated operational occurrences.	The cover gas boundary is included as part of the primary coolant boundary (referred to as RCPB by PRISM) per NUREG-1368 (page 3-38).	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0580.060	A gas service system should be provided to maintain the primary gas circuit inventory, store gas during depressurizations, and provide a backup supply of gas.	Maintaining gas inventory in the primary gas circuit helps to maintain coolability of the core during normal and postulated event conditions.	"Key Design Requirements for the High Temperature Gas-Cooled Reactor Nuclear Heat Supply System," INL/EXT-10-19887	Licensing and Safety Analysis	HTGR	ALL	PERF
3.05.0580.070	The MSR fuel qualification should demonstrate that expected changes in fuel salt solubility during operation are well characterized and factored into the design.	Fuel solubility may change during plant transients and some fuel may precipitate out of solution. The effects of this precipitation will change the concentration and gradient of fuel distribution in the reactor, possibly leading to adverse reactor conditions (i.e., localized hot spot).	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE IMPL
3.05.0580.080	Liquid-metal and liquid-salt-cooled reactors should use a cover gas to control pressure transients and to provide a physical buffer between coolant and materials that should not be wetted.	Some equipment cannot be submerged within the coolant pool. The cover gas provides a safe environment for this equipment. The cover gas is also capable of accommodating pressure transients, especially those resulting from thermal expansion of the coolant.	Industry Feedback	Licensing and Safety Analysis	SFR LFR MSR	ALL	PERF
3.05.0580.090	The SFR design should ensure that the sodium does not approach boiling conditions during normal operation or transients.	The sodium is expected to be liquid during normal operation, and deviations from this expectation should be addressed in the design.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	PERF
3.05.0580.100	SFR designs should include methods to limit the potential for sodium aerosols to plate out on plant components where such plating could affect functionality (e.g., narrow clearances between mechanical components).	To prevent clearance plugging and accumulation of solid sodium.	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE PERF
3.05.0590.010	External building openings and temporary openings should be designed with joints and proven structural seals that minimize the potential for in-leakage of precipitation or ground water and unplanned or unmonitored releases of radioactive materials to the environment for the life of the plant.	Providing positive, long-term controls and containment design features that minimize the unplanned, unmonitored release of radioactivity to the environment supports regulatory compliance and the ORG's good neighbor policy intent.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 13	Licensing and Safety Analysis	ALL	ALL	SAFE IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0590.020	The reactor designer should perform an evaluation of the relative costs and benefits of locating large portions of the reactor below grade.	Placing portions of the reactor below-grade can simplify structural support and containment design (e.g., airplane impact and aerosol dispersion space are minimized). However, the benefits must justify the added construction costs and time, which will be dependent on the ground (e.g., hard rock versus dirt). Building piles or walls of soil around the outside of the reactor may be a more practical method of achieving the same benefits. This requirement may not apply to designs that are small, rail-transportable, or otherwise inappropriate for below-grade construction.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	ECON SEC/NP
3.05.0590.030	The design should include a method to collect any fuel-salt leaks and divert them to an emergency drain tank.	Fuel salt leaks may occur as a result of manufacturing flaws, excessive wall temperatures and stresses, corrosion, thermal stress cycling, etc.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE PERF
3.05.0590.040	A reactor containment consisting of a low leakage, pressure retaining structure surrounding the reactor and its associated cooling systems, should be provided to control the release of radioactivity to the environment and to assure that the reactor containment design conditions important to safety are not exceeded for as long as postulated event conditions require.	USNRC used language in their Advanced Reactor Design Criteria (ARDCs) to restrict the leakage of the containment to be less than that needed to meet the acceptable on-site and off-site dose consequence limits (Ref. SRM, SECY-93-092). Therefore, the Commission agreed that the containment leakage for advanced reactors, similar to and including PRISM, should not be required to meet the "essentially leak tight" statement in GDC 16. (Ref: NUREG-1368).	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE
3.05.0590.050	Each line that penetrates the containment structure and is neither part of the reactor coolant boundary nor connected directly to the containment atmosphere should have at least one containment isolation valve (automatic or locked), unless it can be demonstrated that the containment safety function can be met without an isolation valve, while assuming failure of a single active component.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactor designs rely upon a containment structure.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR GFR	ALL	SAFE
3.05.0590.060	Radiation detectors installed for the detection of fission product releases should be designed and positioned such that operators are able to distinguish the breach of fission product barriers from other sources of radiation, such as neutron/gamma flux from normal operations.	Distinguishing radiation sources allows for the correct diagnosis of system failures.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0600.010	The on-site safety power distribution systems should be divided into independent divisions. The divisions should supply power to separate and functionally redundant load groups.	This requirement helps implement the concepts of redundancy and divisional separation that support Defense-in-Depth.	URD Rev 13 Tier II Chapter 11 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0640.010	The protection system should be designed (1) to initiate automatically the operation of appropriate systems, including the reactivity control systems, to assure that specified acceptable core radionuclide release design limit is not exceeded as a result of anticipated operational occurrences and (2) to sense postulated event conditions and to initiate the operation of systems and components important to safety.	This requirement differs from the Tier II requirement based on the USNRC's Advanced Reactor Design Criterion 20 in that the criterion is dependent on fission product release rate rather than fuel design limits. This is owing to the functional containment boundary of a TRISO fuel particle.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0640.020	The protection system should be designed to assure that specified acceptable core radionuclide release design limits are not exceeded during any anticipated operational occurrence resulting from a single malfunction of the reactivity control systems.	This requirement differs from the Tier II requirement based on the USNRC's Advanced Reactor Design Criterion 25 in that the criterion is dependent on fission product release rate rather than fuel design limits. This is owing to the functional containment boundary of a TRISO fuel particle.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0680.010	The protection system should be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, sodium and sodium reaction products, pressure, steam, water, and radiation) are experienced.	Digital protection systems can be programmed to revert to known safe states when identifying a control system failure. Defining these states carefully ensures that a control system failure does not place the plant in an unanalyzed condition. In NUREG-1368, Table 3.3 (page 3-21), (ML063410561) USNRC staff recommended adding the phrase "sodium and sodium reaction products" to the list of postulated adverse environments in the Generic Design Criteria (GDC). Therefore, "sodium and sodium reaction products" are added to the second list of examples in parenthesis in the USNRC's Sodium Fast Reactor Design Criterion 23.	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE
3.05.0700.010	The reactivity control system should be designed so the amount and rate of reactivity insertion is limited in order to ensure, when coupled with the reactor protection system, that postulated reactivity events do not result in fuel damage, fission product barrier damage, or impairment of the capability to adequately cool the core.	This requirement provides assurance that a major failure in the reactivity control system will not prevent control or shutdown of the core, and will not cause damage to the reactor fuel or the reactor boundary.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 4 Section 2	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0700.020	The reactivity control systems should be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity events can neither (1) result in damage to the reactor helium pressure boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor vessel internals to impair significantly the capability to cool the core.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0710.010	Safety-related reactivity control systems should be designed to assure that they perform their safety functions under normal, moderate frequency, infrequent and limiting fault events, including following natural phenomena like earthquakes and tsunamis (defined by applicable regulation) and man-made phenomena.	Failure of control systems to operate can lead to unacceptable consequences. Active reactivity control systems may or may not be safety-related, depending on the design.	URD Rev 13 Tier II Chapter 4 Section 2 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0710.020	Equipment at appropriate locations outside the control room should be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the plant in a safe condition during hot shutdown, and (2) with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.	Having a means of achieving safe shutdown outside the control room ensures that safe shutdown can be achieved if the control room is compromised.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0710.030	MSR designs should include an engineered means of maintaining the plant shutdown, i.e., they should not rely solely on natural feedback mechanisms for safety.	Natural feedback mechanisms or time-based safety features (e.g., a salt plug that drains to a sub-critical tank) should not be the only means of achieving a safe condition. Operators should be able to take positive action to shut-down the reactor.	USNRC RG 1.232	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0710.040	Emergency drain tanks used to achieve subcritical geometries for liquid-fueled reactors should be designed to consider conservative assumptions for post-accident conditions, including surrounding moderator and reflector materials, fuel temperature, fuel enrichment, and chemical composition.	Postulated events resulting in emergency draining could subject the fuel to other effects. For example, emergency drain tanks at low elevations could be subjected to water flooding in surrounding areas, which would result in increased reflection of neutrons and should be considered in the criticality analysis of the drain tanks. Additionally, the chemical and isotopic concentration of drained fuel should span the range of possible compositions.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0710.050	The reactivity control systems should be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity events can neither (1) result in damage to the primary coolant boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor vessel internals to impair significantly the capability to cool the core.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0720.010	Liquid-fuel MSRs should include passive features that ensure subcriticality following an event.	Such features could include, but are not limited to, automatic drains to subcritical geometries and automatic heat sink removal, which provides immediate temperature feedback. Since MSRs especially lend themselves to passive safety features (by changing the core's geometry), these methods should be employed.	B.M. Elsheikh, "Safety Assessments of Molten Salt Reactors in Comparison with Light Water Reactors," Journal of Radiation Research and Applied Sciences (Elsheikh, 2013)	Licensing and Safety Analysis	MSR	ALL	SAFE PERF
3.05.0720.020	SFRs should demonstrate the ability to counteract the maximum core void reactivity with active reactivity control systems, assuming the most limiting single failure (i.e., rod insertion with one rod stuck out).	SFR core void reactivity coefficients are positive, so control systems need to be established to provide negative reactivity as voids are created. These control systems should be capable of functioning with an assumed single failure.	USNRC RG 1.232	Licensing and Safety Analysis	SFR	ALL	SAFE
3.05.0730.010	Reflector blocks exposed to high radiation doses should be designed to accommodate radiation-induced stresses and to have sufficient cooling.	Irradiation must be accommodated to prevent structural damage. Past HTGRs have designed reflectors with slits in their surface to allow better cooling and reduce the radiation-induced stresses in the components.	Wachholz, “The Present State of the HTR Concept Based on Experience Gained from AVR and THTR, Hochtemperatur-Reaktorbau, Mannheim Federal Republic of Germany” (Wachholz, 1988)	Licensing and Safety Analysis	HTGR	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0740.010	Analysis should confirm that the integrity of the reactor coolant boundary will be maintained against the release of mechanical energy due to a bounding re-criticality event unless analysis shows that re-criticality is not credible.	The configuration of a reactor core is not maintained in its most reactive state. Therefore, a loss of core geometry due to a severe event such as fuel melting and relocating could place the fuel in a more reactive state allowing it to achieve prompt criticality.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0740.020	The reactor helium pressure boundary should be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated event conditions (1) the boundary behaves in a non-brittle manner and (2) the probability of rapidly propagating fracture is minimized.	“Reactor coolant pressure boundary” has been relabeled as “reactor helium pressure boundary” to conform to standard terms used for HTGRs.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0740.030	The primary coolant boundary should be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated event conditions (1) the boundary behaves in a non-brittle manner and (2) the probability of rapidly propagating fracture is minimized.	The cover gas boundary is included as part of the reactor primary coolant boundary (referred to as RCPB by PRISM) per NUREG-1368 (page 3-38).	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0740.040	Materials, design, and fabrication methods of the components of reactor systems should be selected so that the material will not behave in a brittle manner, be subject to rapidly propagating failure, or otherwise fail considering the environmental conditions that will be present during all normal operations.	Components of reactor systems are critical components.	URD Rev 13 Tier II Chapter 4 Section 2 EUR Volume 2 Chapter 6	Licensing and Safety Analysis	ALL	ALL	SAFE PERF
3.05.0740.050	The design should consider and define the maximum acceptable helium embrittlement and hydrogen embrittlement for the core and primary loop structural materials.	Helium and hydrogen embrittlement will be a constant degradation mechanism for the structural materials and is likely the limiting factor is determining the replacement frequency for components.	“Minimizing the Fissile Inventory of the Molten Salt Fast Reactor”, E. Merle-Lucotte et. al.	Licensing and Safety Analysis	MSR	ALL	SAFE IMPL
3.05.0750.010	The design should include a method to collect any fuel-salt leaks and divert them to an emergency drain tank.	Fuel salt leaks may occur as a result of manufacturing flaws, excessive wall temperatures and stresses, corrosion, thermal stress cycling, etc.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE PERF
3.05.0750.020	A gas service system should be provided to maintain the primary gas circuit inventory, store gas during depressurizations, and provide a backup supply of gas.	Maintaining gas inventory in the primary gas circuit helps to maintain coolability of the core during normal and postulated event conditions.	"Key Design Requirements for the High Temperature Gas-Cooled Reactor Nuclear Heat Supply System," INL/EXT-10-19887	Licensing and Safety Analysis	HTGR	ALL	PERF
3.05.0750.030	A system to maintain primary coolant inventory for protection against small breaks in the primary coolant boundary should be provided as necessary to assure that specified acceptable fuel design limits are not exceeded as a result of primary coolant inventory loss due to leakage from the reactor primary coolant boundary and rupture of small piping or other small components.	“Reactor coolant pressure boundary” has been relabeled as “primary coolant boundary” to reflect that the SFR primary system operates at low-pressure and to conform to standard terms used in the LMR industry.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0760.010	The design of the reactor vessel, reactor system, and reactor building should be such that their integrity is maintained during postulated events to ensure the geometry for passive removal of residual heat from the reactor core to the ultimate heat sink and to permit sufficient insertion of the neutron absorbers to provide for reactor shutdown.	The reactor vessel and reactor system for HTGR is relied upon for effective heat removal and reactivity control during all conditions (including postulated events).	USNRC RG 1.232 “A Safety Re-evaluation of the AVR Pebble Bed Reactor Operation and its Consequences for Future HTR Concepts”	Licensing and Safety Analysis	HTGR	ALL	SAFE
3.05.0760.020	The passive residual heat removal system should be designed to permit appropriate periodic functional testing to assure (1) the structural integrity of its components, (2) the operability and performance of the system components, and (3) the operability of the system as a whole.	Some modular HTGR Reactor Cavity Cooling System (RCCS) designs should provide continuous passive operation without need for a requirement to test the operation sequence that brings the system into operation. This requirement reflects the passive nature of the HTGR RCCS and the need to verify ability to transition the RCCS from active mode (if present) to passive mode during postulated events.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0760.030	Residual heat removal systems should be based on passive systems rejecting heat to effectively infinite heat sinks (e.g., natural-circulation air-cooled condensers).	An effectively infinite ultimate heat sink reduces the need for outside action in the event of an accident.	USNRC RG 1.232 EUR Volume 2 Chapter 1	Licensing and Safety Analysis	ALL	ALL	SAFE PERF
3.05.0780.010	Penetrations in the reactor vessel should be designed to prevent the release of radioactive material.	Successful means of achieving this have been based upon: • Two pressure-tight covers; • An outer pressure-tight cover, and an inner flow limiting cover which, in the case of the outer cover being damaged, restricts the escaping coolant flow to a precise value.	Schoening, “Design, Features and Engineering Status of the THTR 300 Mew Prototype Power Station” (Schoening, 1970)	Licensing and Safety Analysis	HTGR	ALL	SAFE
3.05.0800.010	In addition to the heat rejection capability of the passive residual heat removal system, systems to transfer heat from SSCs important to safety, to an ultimate heat sink should be provided, as necessary to transfer the combined heat load of these SSCs under normal operating and postulated event conditions.	Removing decay heat is required to support the safety basis.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0800.020	All flow branching from the main steam lines should be directed to the condenser.	This requirement conserves BOP water inventory.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Licensing and Safety Analysis	ALL	GR OG PH	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0810.010	The design should allow piping carrying radioactive or potentially radioactive liquids to be placed above or below ground.	Experience at numerous operating and decommissioning commercial nuclear power stations has positively identified unintentional releases of small quantities of radionuclides from plant structures, ponds and pools. Any one or a combination of component, system, and structural integrity failures has ultimately led to unmonitored activity being released to both the site and local environment. Designing these piping systems to allow installation above or below ground gives the owner-operator the opportunity to weigh risks and benefits of the two options.	URD Rev 13 Tier II Chapter 1 Section 12 NEI 09-14 "Guideline for the Management of Underground Piping and Tank Integrity" (NEI, 2009) EPRI report 1021175, "*Recommendations for an Effective Program to Control the Degradation of Buried and Underground Piping and Tanks*" (EPRI, 2010) NUREG-1801, Generic Aging Lessons Learned (GALL report) (USNRC, 2010b)	Licensing and Safety Analysis	ALL	ALL	PERF
3.05.0810.020	The design of the reactor should include appropriate margin to assure that specified acceptable core radionuclide release design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.	Metals diffuse in fuel kernels, coatings, and graphite and they may break through during long term reactor operation. Therefore, the typical "specified acceptable fuel design limits" do not apply.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR	ALL	SAFE
3.05.0810.030	Liquid-salt fueled reactors should be designed with provisions for managing fission product off-gassing during operations to minimize the impact of fission product poisons and to manage radioactive contamination of plant equipment, radiation exposure to plant personnel, and fission product release to the environment.	Liquid fuels will naturally off-gas all gaseous fission products. These require management to control reactivity effects of these gases and to control radiation exposure due to fission product decay.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0810.040	Holdup tanks for radioactive effluents should include the means for controlling release following an interfacing system break (e.g., "backflow" preventers or other automatic isolation valves acting upon sensed depressurization).	Industry experience has found that some analyses show significant radiological consequences for releases from holdup tanks. By preventing outflow from holdup tanks in the event of a system break, these consequences can be avoided.	USNRC RG 1.232	Licensing and Safety Analysis	SFR LFR MSR	ALL	SAFE
3.05.0810.050	Sufficient holdup capacity should be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0820.010	The MSR design should minimize excess reactivity as much as possible by applying continuous fuel processing.	The ability to externally add fissile material when needed reduces the need for excess reactivity inventory, minimizing the likelihood and severity of a criticality accident.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0820.020	SFR fuel should be handled submerged in sodium where possible to provide cooling and shielding (for irradiated fuel).	SFR fuel is designed for the sodium environment.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	SAFE PERF
3.05.0820.030	For pebble bed HTGR designs, the reactor designer should include a licensed fresh fuel storage system for the continuous feed of fuel pebbles.	Because pebble bed reactors are refueled continuously by replacing individual pebbles, a supply of fresh pebbles will need to be available on-site, and the storage method will need to be licensed.	Industry Feedback	Licensing and Safety Analysis	HTGR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0840.010	Criticality in the fuel storage and handling system should be prevented by physical systems or processes, preferably by use of geometrically safe configurations.	It is preferred to use physical limitations to reach configurations that have been demonstrated to be subcritical through analysis, rather than relying on procedural steps to ensure subcriticality.	USNRC RG 1.232	Licensing and Safety Analysis	ALL	ALL	SAFE
3.05.0840.020	The flow geometry of fuel salt should limit the areas where fuel salt may become critical, accounting for localized salt concentrations.	Inadvertent criticality of the fuel loop should be avoided.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0840.030	Emergency drain tanks used to achieve subcritical geometries for liquid-fueled reactors should be designed to consider conservative assumptions for post-accident conditions, including surrounding moderator and reflector materials, fuel temperature, fuel enrichment, and chemical composition.	Postulated events resulting in emergency draining could subject the fuel to other effects. For example, emergency drain tanks at low elevations could be subjected to water flooding in surrounding areas, which would result in increased reflection of neutrons and should be considered in the criticality analysis of the drain tanks. Additionally, the chemical and isotopic concentration of drained fuel should span the range of possible compositions.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE
3.05.0840.040	When SFR fuel is handled outside of sodium, physical controls (i.e., physical limitations of cranes, storage racks, etc.) should be used to prevent criticality in preference to administrative controls.	Most SFRs have positive void coefficients. Generally SFR fuel is more reactive when void of sodium. Physical limitations are more reliable in preventing improper positioning of fuel during handling.	Industry Feedback	Licensing and Safety Analysis	SFR	ALL	SAFE IMPL
3.05.0860.010	External building openings and temporary openings should be designed in concert with leak detection systems so that leaks can be identified.	Providing positive, long-term controls and containment design features that minimize the unplanned, unmonitored release of radioactivity to the environment supports regulatory compliance and the ORG's good neighbor policy intent.	URD Rev 13 Tier II Chapter 1 Section 7 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 13	Licensing and Safety Analysis	ALL	ALL	SAFE IMPL
3.05.0860.020	Means should be provided for monitoring the reactor building atmosphere, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated events.	The underlying concept of monitoring radioactivity releases from the HTGR particle fuel to the reactor building, effluent discharge paths, and the plant environs applies. High radioactivity in the reactor building provides input to the plant protection system. In addition, the reactor building atmosphere is monitored for personnel protection.	USNRC RG 1.232	Licensing and Safety Analysis	HTGR GFR	ALL	SAFE
3.05.0860.030	The design should include a method to detect the leakage of fuel salt and immediately alert the operator to the condition.	In a liquid fueled reactor, a leak of the primary boundary is an immediate concern because such a leak constitutes a relocation of fuel material.	Industry Feedback	Licensing and Safety Analysis	MSR	ALL	SAFE PERF
3.05.0860.040	Means should be provided for monitoring the reactor containment atmosphere, spaces containing components for primary system sodium and cover gas cleanup and processing, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated events.	SFR designs include unique requirements for monitoring atmospheres.	USNRC RG 1.232 NUREG-1368	Licensing and Safety Analysis	SFR LFR	ALL	SAFE
3.05.0860.050	Radiation detectors installed for the detection of fission product releases should be designed and positioned such that operators are able to distinguish the breach of fission product barriers from other sources of radiation, such as neutron/gamma flux from normal operations.	Distinguishing radiation sources allows for the correct diagnosis of system failures.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.05.0860.060	Radiation detectors installed for the detection of fission product releases should be designed and positioned such that (coupled with their data systems) they are able to distinguish the breach of fission product barriers from the failure of installed shielding systems.	Distinguishing radiation sources allows for the correct diagnosis of system failures.	Industry Feedback	Licensing and Safety Analysis	ALL	ALL	PERF
3.06.0010.010	Vents, drains and suitable isolation valves should be provided for draining, filling, and venting piping systems at all locations that are capable of trapping fluid.	This requirement allows for drainage of lines for maintenance and prevents buildup of radioactive materials.	URD Rev 13 Tier II Chapter 3 Section 2 URD Rev 13 Tier II Chapter 8 Section 3 EUR Volume 2 Chapter 7	Maintenance and Operability	ALL	ALL	PERF
3.06.0010.020	A drain should be located at each low point in the main steam piping system where water may collect during startup, shutdown, or normal operation of a unit.	The consideration of hot and cold conditions of the piping is necessary due to the possible difference in pipe position between the cold and hot conditions.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 2 Chapter 11	Maintenance and Operability	ALL	GR OG	PERF
3.06.0010.030	In long runs of piping with no special low point, a low point drain should be installed at the turbine end of the section.	To prevent condensation from accumulating and entering the turbine, possibly causing damage.	URD Rev 13 Tier II Chapter 2 Section 3	Maintenance and Operability	ALL	GR OG	PERF
3.06.0010.040	If the main steam line is split into more than one lead going into the turbine, then each of these leads and the main header should be reviewed for low points.	To prevent condensation from accumulating and entering the turbine, possibly causing damage.	URD Rev 13 Tier II Chapter 2 Section 3	Maintenance and Operability	ALL	GR OG	PERF
3.06.0010.050	The routing of drain piping should trend downward, and horizontal pipes should slope to allow for proper removal of liquid.	To ensure proper flow in drain lines and to prevent condensation from accumulating and entering the turbine, possibly causing damage.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Maintenance and Operability	ALL	GR OG	PERF
3.06.0020.010	Instruments for identifying fuel failures should be positioned such that they can effectively distinguish true fuel failures.	If not carefully planned, instruments that identify fuel failures may be located in an area that would inhibit their ability to distinguish fuel failures from the other sources of ionizing radiation.	EUR Volume 2 Chapter 8	Maintenance and Operability	ALL	ALL	PERF
3.06.0020.020	Engineered barriers with leak detection and monitoring capabilities should be used for piping that is required to carry radioactive/potentially radioactive liquids.	Experience at numerous operating and decommissioning commercial nuclear power stations has positively identified unintentional releases of small quantities of radionuclides from plant structures, ponds and pools. Any one or a combination of component, system, and structural integrity failures has ultimately led to unmonitored activity being released to both the site and local environment.	URD Rev 13 Tier II Chapter 1 Section 12 NEI 09-14 "Guideline for the Management of Underground Piping and Tank Integrity" EPRI report 1021175, "*Recommendations for an Effective Program to Control the Degradation of Buried and Underground Piping and Tanks* NUREG-1801, "Generic Aging Lessons Learned (GALL report)"	Maintenance and Operability	ALL	ALL	PERF
3.06.0020.030	For HTGR designs, means should be provided for detecting and, to the extent practical, identifying the location of the source of the reactor helium leakage.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Maintenance and Operability	HTGR GFR	ALL	SAFE
3.06.0020.040	For liquid metal and MSR designs, means should be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.	Limiting potential reactivity insertions limits the severity of postulated events.	USNRC RG 1.232	Maintenance and Operability	SFR LFR MSR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0030.010	For tasks which require access to areas with high radiation fields, the design should consider the use of robotic devices incorporating radiation hardened components.	The use of robotic devices can greatly reduce the burden of operating a maintaining the plant. This requirement helps decrease personnel dose.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF
3.06.0030.020	Multi-pass pebble bed HTGRs should include the means to monitor the burnup of individual fuel pebbles, or estimate a statistical distribution of pebble burnup.	The absence of a means of ascertaining fuel burnup would require reactor operation with much greater margins and would therefore limit the reactor's capability.	Industry Feedback	Maintenance and Operability	HTGR	ALL	PERF
3.06.0060.010	Additional sensor taps as noted in EPRI NP- 3915, “Guidelines for Nuclear Plant Performance Data Acquisition,” should be installed to facilitate performance monitoring and analysis of heat cycle components.	The taps would allow for the installation of temporary instrumentation which can be used to monitor and analyze off-design performance.	EPRI NP- 3915, “*Guidelines for Nuclear Plant Performance Data Acquisition*” (EPRI, 1985) URD Rev 13 Tier II Chapter 2 Section 3	Maintenance and Operability	ALL	ALL	PERF
3.06.0060.020	The heat balance instrumentation should include as a minimum the recommended sensors shown in ANSI/ASME PTC 6 (or equivalent) for an alternative procedure for testing steam turbines.	The power industry has recognized the need for development of a cost-reduced, less complex method of accurately obtaining heat cycle information. Sufficient instrumentation should be provided to allow accurate testing of BOP components and for the calibration of nuclear instruments based on heat balance measurement.	ANSI/ASME PTC 6 URD Rev 13 Tier II Chapter 2 Section 3	Maintenance and Operability	ALL	GR OG	PERF
3.06.0060.030	HTGR designs should include instrumentation that allows for confidence in fuel temperatures throughout the core.	To ensure that specified acceptable core radionuclide release design limits are not exceeded throughout the core under all conditions.	USNRC RG 1.232	Maintenance and Operability	HTGR GFR	ALL	SAFE PERF
3.06.0060.040	The steam system design should provide connections for steam sampling for chemical analysis.	Necessary for testing of steam chemistry.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Maintenance and Operability	ALL	ALL	PERF
3.06.0100.010	Containment leakage should be restricted to be less than that needed to meet the acceptable on-site and off-site dose consequence limits.	USNRC used language in their Advanced Reactor Design Criteria (ARDCs) to restrict the leakage of the containment to be less than that needed to meet the acceptable on-site and off-site dose consequence limits (Ref. SRM, SECY-93-092). Therefore, the Commission agreed that the containment leakage for advanced reactors, similar to and including PRISM, should not be required to meet the "essentially leak tight" statement in GDC 16. (Ref: NUREG-1368).	USNRC RG 1.232	Maintenance and Operability	SFR	ALL	SAFE
3.06.0100.020	Methods should be developed to control the concentrations of radionuclides in high temperature fluids used by the plant such that radionuclide levels that could be transported from the primary circuit or activated by proximity to the primary circuit do not exceed design specifications.	Limiting the radionuclide content of the secondary/tertiary loop will reduce the dose received by workers in the plant and reduce the burden of additional radiation shielding and protection measures in the plant.	"Key Design Requirements for the High Temperature Gas-Cooled Reactor Nuclear Heat Supply System," INL/EXT-10-19887	Maintenance and Operability	ALL	ALL	SAFE ECON
3.06.0100.030	The shielding design should be based upon radiation sources validated through analyses and applicable experience.	The deposition of activated material and the expected radiation produced during fission will impact the type, arrangement, and thickness of shielding installed in the plant.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 1 and Appendix A	Maintenance and Operability	ALL	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0110.010	If access to the reactor vessel interior or internals is required, the means provided to achieve such access should minimize or eliminate the need to construct or provide temporary access tools such as platforms and rigging.	Access to vessel internals and interior requires minimal operator time for exposure to be As Low as Reasonable Achievable (ALARA).	URD Rev 13 Tier II Chapter 1 Section 12	Maintenance and Operability	ALL	ALL	PERF
3.06.0110.020	Mechanical equipment should be modular in design to the extent practical.	This reduces the level of effort and exposure associated with repair, removal, and replacement.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Maintenance and Operability	ALL	ALL	PERF
3.06.0110.030	Pump internals should be designed so that they may be readily removed for maintenance; however, if this is impractical, the pump should be designed to facilitate removal and replacement, e.g., flanged connections and intelligently oriented electrical connections.	Pumps are a significant portion of the maintenance burden on the plant staff. Minimizing and simplifying pump maintenance will help achieve the availability goals for the reactor. For pumps in radioactive service, these requirements are important to meeting reactor goals.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter D49	Maintenance and Operability	ALL	ALL	PERF
3.06.0120.010	If complex or dissimilar metal welds are required, the reactor designer and owner-operator should consider using state-of-the-art three-dimensional finite element analysis capabilities to include and model weld residual stresses in the design phase to optimize the design and possibly the fabrication of specific components.	There is a significant ongoing effort in the nuclear industry to characterize and predict weld induced residual stresses in order to mitigate material degradation and optimize performance. Of particular importance is the confidence and accuracy of Weld Residual Stress (WRS) numerical modeling and experimental measurement techniques. Although finite element analysis may not precisely predict the weld residual stress values, when utilized appropriately it can be a useful tool to evaluate locations of tension and compression.	EPRI TR 3002010464 (EPRI, 2017a)	Maintenance and Operability	ALL	ALL	PERF ECON
3.06.0180.010	Condenser tubing should be of commercially available lengths and pipe sizes.	Consistent with the ORG standardization policy statement.	URD Rev 13 Tier II Chapter 2 Section 4	Maintenance and Operability	ALL	GR OG	PERF
3.06.0180.020	The condenser tubes, tube sheets, and tube gauge materials should be based on operating experience, published literature, and standard practice for both fossil and nuclear plants.	While 316L is acceptable for low chloride environments, a higher alloyed stainless steel such as 904L or 6X is recommended. A higher grade of stainless steel (such as 904L, 6X or 6XN) should be used for chloride levels between 500 and 800 ppm. For brackish or salt water applications containing high concentrations of dissolved solids (1000 ppm) or chlorides (greater than 800 ppm) or water contaminated by sewage discharges, titanium tubing should be used. Titanium tubing may be used for any water condition if the reactor designer's studies show this is optimum as a standard design.	URD Rev 13 Tier II Chapter 2 Section 4	Maintenance and Operability	ALL	GR OG	PERF
3.06.0200.010	Critical or frequently operated/accessed components that are not directly accessible from the floor (elevated) should use locator labels with directional indication at the floor level to direct personnel to the appropriate area.	This allows access while minimizing the time spent in radiological areas searching for the component(s).	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 11	Maintenance and Operability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0210.010	Work plans and facilities for cleanup, inspections and maintenance of condenser internals should be pre-engineered. Special equipment required for normal outage work should be minimized.	Pre-engineered work plans and facilities have been shown by experience to be necessary to permit efficient and reliable upkeep of the condenser internals, particularly the extraction piping and neck heater protection lagging. Special equipment requirements are minimized to reduce costs.	URD Rev 13 Tier II Chapter 2 Section 4	Maintenance and Operability	ALL	GR OG	IMPL
3.06.0260.010	Permanent type labels should be installed in time for start-up testing. Labels should be sized and located to facilitate reading from the floor elevation using visual enhancement devices, including binoculars and scopes.	Confusion in identifying equipment has caused operation and maintenance errors and has contributed to plant events when a component mistakenly taken out of service for maintenance has been called upon to operate.	URD Rev 13 Tier II Chapter 1 Section 8 EUR Volume 2 Chapter 11 EUR Volume 2 Chapter 12 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
3.06.0260.020	Component labels should be machine readable.	In addition to being readable by a human, labels also need to be readable by machines to enable increased use of automation in maintenance and operations. This can be done using bar codes, Quick Response (QR) codes, or other methods.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
3.06.0260.030	Component labels should be provided for robotic devices, and should be readable at all times.	Labels for robotic devices merit unique considerations due to the potential mobility of the devices. For example, the orientation of the robot could affect the readability of the label.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
3.06.0261.010	The CMIS should facilitate collaboration such that multiple personnel can work on requirements or deliverables simultaneously while minimizing duplication, lost work, and errors.	If only one personnel could modify the configuration management database at one time, a bottleneck would be created, limiting productivity. An integrated collaborative database would allow multiple personnel to edit items simultaneously while merging edits and managing version control, similar to how Git is used in programming.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF IMPL
3.06.0290.010	For tasks which require access to areas with high radiation fields, the design should consider the use of robotic devices incorporating radiation hardened components. Note: Same as 3.06.0030.010.	The use of robotic devices can greatly reduce the burden of operating a maintaining the plant. This requirement helps decrease personnel dose.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF
3.06.0290.020	The use of Complementary Metal Oxide Semiconductor (CMOS) components should be avoided in robotic devices.	CMOS components are susceptible to random radiation induced errors.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF
3.06.0290.030	If the design uses robotic devices for inspections, generic access ports (designed to accommodate robots that are likely to be available in the future) should be provided for equipment to allow robotic devices access to component interiors.	The use of robotic devices can greatly reduce the burden of operating and maintaining the plant. This requirement facilitates the use of robotic devices.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
3.06.0290.040	If the design uses robotic devices, means should be provided to retrieve robots from areas that are unreachable or potentially uninhabitable by humans.	The use of robotic devices can greatly reduce the burden of operating and maintaining the plant. This requirement facilitates the use of robotic devices and limits the financial loss if a robot experiences a malfunction while operating in an inaccessible space.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0290.050	If the design uses robotic devices, robot-battery charging stations with a standardized docking geometry and protocol should be located throughout the plant with clear access for ingress and egress of robotic devices.	The use of robotic devices can greatly reduce the burden of operating and maintaining the plant. This requirement facilitates the use of robotic devices. One possibility to satisfy the intent of this requirement is to have robots tethered to AC power supplies.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
3.06.0290.060	The design should consider using robotic devices to replace lighting. If incorporated into the design, lights should be designed for replacement by robots.	The use of robotic devices can greatly reduce the burden of operating a maintaining the plant. This requirement helps decrease maintenance burden.	URD Rev 13 Tier II Chapter 6 Section 2 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
3.06.0290.070	The plant arrangement should provide secure areas for the storage of robotic equipment with provisions for decontamination.	To prevent possible damage to the robotic equipment. Robotic equipment used for maintenance will likely constitute a significant investment. The equipment should be protected through the provision of dedicated storage areas.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	ECON IMPL
3.06.0310.010	If access to the reactor vessel interior or internals is required, the means provided to achieve such access should minimize or eliminate the need to construct or provide temporary access tools such as platforms and rigging.	Access to vessel internals and interior requires minimal operator time for exposure to be ALARA.	URD Rev 13 Tier II Chapter 1 Section 12	Maintenance and Operability	ALL	ALL	PERF
3.06.0320.010	Systems that could become contaminated should be designed to accommodate a decontamination process to reduce shutdown radiation levels in piping and components.	Consistent with ALARA principles for maintenance activities. This should include both a low concentration decontamination process to be used during normal shutdowns and provisions and planning for adding high concentration decontamination techniques, if needed, to reduce radiation levels for major inspection, backfit, repair or replacement. Consider use of temporary system connected to hook-in points.	URD Rev 13 Tier II Chapter 3 Section 2 EUR Volume 2 Chapter 1	Maintenance and Operability	ALL	ALL	PERF
3.06.0320.020	Equipment that cannot be moved using manual labor (lifting) should be situated with direct access to appropriate lifting devices including pad eyes, rails and cranes.	Ease of maintenance.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	PERF
3.06.0320.030	Provisions should be made for mechanical component removal and replacement including pad eyes, rails, elimination of berms/curbs, and access to the component or rigging equipment termination point (carts, pallet jacks, forklift) commensurate with the component's size, weight, and importance to plant operation.	This reduces the level of effort and exposure associated with repair, removal and replacement. This also reduces the potential for industrial safety accidents and adjacent plant equipment damage.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Maintenance and Operability	ALL	ALL	PERF IMPL
3.06.0331.010	Any crane handling high risk loads (e.g., spent fuel) should have a sufficiently slow movement speed to allow reasonable time (e.g., greater than 30 seconds) for personnel to respond to violating a load or position limit.	Large loads can get stuck or enter odd geometries during handling, making the maintenance activity more difficult for personnel.	Recent Lessons Learned	Maintenance and Operability	ALL	ALL	IMPL

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0340.010	The residual heat removal system should be designed to permit appropriate periodic inspection of important components to ensure the integrity and capability of the system.	In many advanced reactor designs, the systems or components relied upon for residual heat removal are passive, fixed components. Some will be inspected as a matter of course due to other requirements.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	SAFE
3.06.0340.020	The passive residual heat removal system should be designed to permit appropriate periodic functional testing to assure (1) the structural integrity of its components, (2) the operability and performance of the system components, and (3) the operability of the system as a whole.	Some modular HTGR RCCS designs should provide continuous passive operation without need for a requirement to test the operation sequence that brings the system into operation. This requirement reflects the passive nature of the HTGR RCCS and the need to verify ability to transition the RCCS from active mode (if present) to passive mode during postulated events.	USNRC RG 1.232	Maintenance and Operability	HTGR GFR	ALL	SAFE
3.06.0340.030	The reactor building should be designed to permit (1) appropriate periodic inspection of all important structural areas and the depressurization pathway, and (2) an appropriate surveillance program.	The reactor building of a gas-cooled reactor has specific safety functions of protecting and maintaining the configuration needed for passive cooling and providing a discharge pathway for helium depressurization events.	USNRC RG 1.232	Maintenance and Operability	HTGR GFR	ALL	SAFE
3.06.0340.040	System design should allow for periodic testing of valves.	This ensures that sufficient instrumentation and test connections are provided to monitor performance and trend degradation and ensures valve accessibility.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	PERF IMPL
3.06.0340.050	The system design should include provisions for periodic testing of pumps.	This ensures that sufficient instrumentation and test connections are provided to monitor performance and trend degradation and ensures pump accessibility.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Maintenance and Operability	ALL	ALL	PERF IMPL
3.06.0340.060	Electric power systems important to safety should be designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components.	Such testing includes performance characteristics like (1) the operability and functional performance of the components of the systems, such as on-site power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among systems.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	PERF
3.06.0340.070	Components which are part of the reactor coolant boundary should be designed to permit (1) periodic inspection and testing of important areas and features to assess their structural and leak tight integrity, and (2) an appropriate material surveillance program for the reactor vessel.	This requirement was adapted from the USNRC's Advanced Reactor Design Criteria (ARDCs) but has been modified to a "should" statement since not all advanced reactors rely on the reactor coolant boundary to perform a safety function.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	IMPL
3.06.0340.080	The structural and equipment cooling systems should be designed to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to ensure the integrity and capability of the systems.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	IMPL

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0340.090	The structural and equipment cooling systems should be designed to permit appropriate periodic functional testing to ensure (1) the structural and leak tight integrity of their components, (2) the operability and performance of the system components, and (3) the operability of the systems as a whole and, under conditions as close to design as practical, the performance of the full operational sequences that bring the systems into operation for reactor shutdown and postulated events, including the operation of associated systems.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	IMPL
3.06.0340.100	In designs with dedicated containment structures, the structure and other equipment which may be subjected to containment test conditions should be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactor designs rely upon a containment structure.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	SAFE
3.06.0340.110	The reactor containment structure should be designed to permit (1) appropriate periodic inspection of all important areas, such as penetrations, (2) an appropriate surveillance program, and (3) periodic testing at containment design pressure of the leak-tightness of penetrations which have resilient seals and expansion bellows.	This requirement is based upon the USNRC's Advanced Reactor Design Criteria (ARDCs) but was modified to be a "should" statement since not all advanced reactor designs rely upon a containment structure.	USNRC RG 1.232	Maintenance and Operability	ALL	ALL	SAFE
3.06.0340.120	When testing reactor systems (either during plant startup testing or after initial operation) a "steam dump" should be provided to receive the steam generated by the reactor.	During testing, there may not be a suitable destination for the plant's product. For example, when testing the reactor of an electricity generation plant, the plant may not want to output power, so the steam from the reactor would not be sent through the turbine, but would need to be sent somewhere else for condensing and, if required, recirculating back to the reactor or steam generator. Temporary systems should be considered.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
3.06.0350.010	Safety-related valves that cannot be tested while the plant is operating should be evaluated for a means to test/verify operability between shutdowns.	Valves that are important to safety should have some means to verify operability when not able to be tested due to lengthy periods between shutdowns.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
3.06.0350.020	The risk of frequent testing while operating should be compared to that of undetected failures during extended test intervals when determining test periodicity.	Testing during operation can present new failure modes. However, more frequent testing can also identify degraded component conditions. These consequences should be balanced.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
3.06.0350.030	Potential failure modes of features included solely to permit testing during operation should be assessed to determine if the feature presents a greater risk than testing only while shutdown.	Testing during operation can present new failure modes. However, more frequent testing can also identify degraded component conditions. These consequences should be balanced.	Industry Feedback	Maintenance and Operability	ALL	ALL	PERF
3.06.0360.010	Provisions should be made for conveniently (e.g., by pinning hangers) supporting the deadweight loads imposed during hydrostatic tests of piping systems.	The ability to pin hangers during a hydro test is desirable to prevent hangers from being knocked out of alignment and to prevent possible nozzle fatigue after several hydro tests.	URD Rev 13 Tier II Chapter 2 Section 3	Maintenance and Operability	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0410.010	Insulation for components which can be contacted by personnel during hot conditions should limit the outside wall temperature to 140°F.	Insulation is required for personnel protection as well as thermal performance. Hot conditions are those conditions during normal plant operation or expected system operation that can result in elevated temperatures to components that are readily accessible to plant personnel.	URD Rev 13 Tier II Chapter 3 Section 2	Maintenance and Operability	ALL	ALL	SAFE
3.06.0410.020	HTGR designs should include sufficient monitoring to identify chemical hazards, including the leakage of heat transfer fluids that may be hazardous to plant personnel or equipment.	Though most HTGRs use heat transfer fluids that do not result in strong chemical reactions, these fluids are usually a hazard to personnel if leaked in large quantities. Other chemical hazards should be identified and monitored if applicable.	Industry Feedback	Maintenance and Operability	HTGR	ALL	SAFE PERF
3.06.0430.010	The design should be such that a single operator can adequately control the plant (or multiple plants) during normal operating conditions.	This is consistent with utility desires and expectations. Though actual manning may never rely on only one single operator, this metric is a good standard for evaluating the simplicity of reactor operation.	URD Rev 13 Tier I Chapter 3 Section 2 Operation by a single operator is not currently allowed for in NUREG-0800. This requirement is not intended to contradict regulation, but is intended to reduce operational complexity and burden, and to anticipate future operational possibilities that may arise due to change in regulation.	Maintenance and Operability	ALL	ALL	ECON IMPL
3.06.0440.010	Maintenance tooling and test equipment needed to demonstrate the effectiveness of maintenance performed, which are not normally available in the plant's tool room inventory, should be provided.	This tooling and equipment should include, but is not limited to: valve seat honing and lapping devices, pump seal cartridge replacement devices, and bolt tensioning devices. The preferred implementation of this requirement is to provide at least one such tool or device per application. The availability and use of qualified maintenance tooling and test equipment has been shown to reduce the number of man-hours required to successfully complete required maintenance.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
3.06.0450.010	If access to vessel internals and interior is required, the vessel should be designed for ease of disassembly and assembly and ready access for removal, maintenance, and replacement of internals.	Access to vessel internals and interior requires minimal operator time for exposure to be ALARA.	URD Rev 13 Tier II Chapter 1 Section 12	Maintenance and Operability	ALL	ALL	PERF
3.06.0450.020	SFR designs should include means by which major component material condition can be evaluated or inspected without removal from the sodium pool.	These means may include permanently installed monitoring equipment or periodically performed measurements. Measurement and/or monitoring may not be required for all components. The opacity of the coolant prevents any visual inspection or inspection relying on optical means unless the vessel is drained of sodium.	N. Kasahara, "Fast Reactor System Design," (Kasahara, 2017)	Maintenance and Operability	SFR	ALL	PERF
3.06.0450.030	The steam system design should provide connections for steam sampling for chemical analysis.	Necessary for testing of steam chemistry.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Maintenance and Operability	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.06.0461.010	Critical interfaces between systems or buildings that could constrain operational flexibility should be identified, and suitable margin (or mitigating features) should be considered.	Allows for operational flexibility. The containment penetrations are an example of such an interface. The number of penetrations provided upon plant construction constrains what plant configurations are obtainable throughout the life of the plant (since in most cases, adding penetrations after commissioning would be impractical). If the minimum number of penetrations is provided, operational flexibility could be severely limited. Therefore, additional penetrations should be provided.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
3.06.0461.020	When adding margin to a critical interface, a cost-benefit analysis should be performed to provide justification for the added capital cost that may be associated with the additional margin.	A balance must be found between operational flexibility and capital costs in determining the appropriate level of margin to be added to an interface (e.g., 100% additional containment penetrations likely would not provide benefit proportional to the associated costs).	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
3.06.0461.030	When adding margin to a critical interface, an evaluation should be performed to ensure that there are no adverse consequences (e.g., reduced structural integrity, poor human factors) to adding the margin, or that such consequences are adequately mitigated.	Adding margin to an interface to gain operational flexibility could introduce unforeseen problems. For example, if several containment penetrations are added in close proximity, the leakage is potentially increased and structural integrity of containment is weakened in that area, and a structural evaluation is required to ensure that it is still adequate.	Industry Feedback	Maintenance and Operability	ALL	ALL	IMPL
3.06.0491.010	Complete maintenance and operating procedures, including detailed drawings and diagrams, materials of construction, etc., should be provided with each purchased component (e.g., instructions for proper lubrication of components, replacement of components, inspections for condition, and control settings). The information should be compatible with the CMIS utilized by the project as described in 2.04.0310.	Repair and condition monitoring of plant equipment is often complicated by a lack of detailed information on equipment. For example, field repair may be impossible because of a lack of detailed dimensions.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 14	Maintenance and Operability	ALL	ALL	IMPL
3.06.0500.010	Shop and warehouse facilities for contaminated and non-contaminated equipment should be sufficiently separated.	To prevent further contamination of equipment.	URD Rev 13 Tier II Chapter 6 Section 2	Maintenance and Operability	ALL	ALL	IMPL
3.06.0520.010	Feedwater/condensate system water chemistry should be maintained suitable for long-term plant operations, including power operation, startup, shutdowns, and extended outages.	Maintaining water chemistry is important for preventing corrosion and/or cracking.	URD Rev 13 Tier II Chapter 2 Section 4	Maintenance and Operability	ALL	GR OG	PERF
3.06.0520.020	For most cooling applications, raw service water should not be used. Water from a clean closed-loop source should be used.	This concentrates the problem of dealing with the fouling and corrosion caused by raw service water to one location rather than throughout the plant.	URD Rev 13 Tier II Chapter 8 Section 2 EUR Volume 2 Chapter 8	Maintenance and Operability	ALL	ALL	PERF
3.06.0520.030	The fire protection water should be chemically treated to reduce biological fouling and filtered to reduce silt and debris.	Older plants are experiencing continuing difficulty using a raw water system from fresh water bodies. A properly treated water source will mitigate many of these problems.	URD Rev 13 Tier II Chapter 9 Section 3 EPRI TR 109633 “Guideline for the Evaluation and Treatment of Corrosion and Fouling in Fire Protection Systems”.	Maintenance and Operability	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.07.0030.010	The reactor designer should select corrosion resistant materials compatible with the environment, to account for design conditions over the life of the plant (i.e., shutdown and startup cycles, etc.).	The general corrosion resistance of an alloy needs to be adequate to minimize the release of impurities to the reactor coolant.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Materials	ALL	ALL	SAFE
3.07.0030.020	MSR materials should be demonstrated to perform adequately at the temperatures and chemistry conditions expected during operation and transient conditions for the life of the plant.	Temperature and chemistry conditions in MSRs are unique and require that materials are appropriately qualified. Operating experience from MSRs or similar salt applications should be used to the extent practical.	Industry Feedback	Materials	MSR	ALL	PERF
3.07.0030.030	The design of MSR fuels should consider conservative vessel/piping corrosion assumptions within the structural qualification of the vessel/piping.	The chemistry of fuel salts is unique and the corrosive aspect of the heat transfer fluid should not impact the structural capacity of the piping/vessel over the life of the reactor.	Industry Feedback	Materials	MSR	ALL	SAFE IMPL
3.07.0030.040	The reactor designer should consider the use of large passive anodes (located very close to any dissimilar metal interface) for cathodic protection in heat exchangers exposed to corrosive environments.	Although passive anodes require periodic inspection and replacement, the design has historically proven to be robust and effective.	URD Rev 13 Tier II Chapter 1 Section 12 EPRI Report # 1011905, “Cathodic protection system application and maintenance guide” (EPRI, 2005a)	Materials	ALL	ALL	PERF
3.07.0030.050	Helium should be used as the heat transfer fluid for HTGR designs.	Helium will does not affect reactor core susceptibility to coolant induced power oscillations.	USNRC RG 1.232	Materials	HTGR	ALL	PERF
3.07.0050.010	TRISO type fuels should be demonstrated to withstand event conditions such that they can be relied upon as an effective fission product barrier, reducing the need for other barriers to demonstrate a defense in depth strategy.	A major benefit of the TRISO fuel type is the relaxation of design requirements for other fission product barriers.	Industry Feedback	Materials	HTGR GFR	ALL	SAFE PERF
3.07.0050.020	The MSR fuel qualification should demonstrate that expected changes in fuel salt solubility during operation are well characterized and factored into the design.	Fuel solubility may change during plant transients and some fuel may precipitate out of solution. The effects of this precipitation will change the concentration and gradient of fuel distribution in the reactor, possibly leading to adverse reactor conditions (i.e., localized hot spot).	Industry Feedback	Materials	MSR	ALL	SAFE IMPL
3.07.0050.030	MSR fuel qualification should demonstrate that unacceptable gradients in fuel concentration, poison concentration, or concentrations of other solutes will not develop (e.g., as a result of differing molecular weights).	The fuel salt chemistry should be sufficiently homogenous to mitigate the creation of localized "hot spots" in the reactor, which would act as an increased source of radiation and heat.	Industry Feedback	Materials	MSR	ALL	SAFE IMPL
3.07.0050.040	The design of MSR fuels should consider conservative vessel/piping corrosion assumptions within the structural qualification of the vessel/piping.	The chemistry of fuel salts is unique and the corrosive aspect of the heat transfer fluid should not impact the structural capacity of the piping/vessel over the life of the reactor.	Industry Feedback	Materials	MSR	ALL	SAFE IMPL
3.07.0050.050	MSR fuel qualification should demonstrate the acceptability of chemical properties and the stability of chemical compounds over the range of temperatures and pressures (and under the influence of a neutron and gamma flux) that could be experienced during normal operation and event conditions.	The fuel salt chemistry should be sufficiently homogenous to mitigate the creation of localized "hot spots" in the reactor, which would act as an increased source of radiation and heat.	Industry Feedback	Materials	MSR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.07.0070.010	The reactor design should control the purity of the heat transfer fluid within specified limits for particulate and dissolved impurities.	High temperatures in the HTGR or Gas-cooled Fast Reactor (GFR) will aggravate chemical attack from any impurities in the helium and negate the benefit of using an inert coolant. The owner-operator needs to understand the operational and financial impact of maintaining purity. Maintenance requirements include how frequently purification must run, makeup gas purity requirements (i.e., prior to polishing).	USNRC RG 1.232 MPR-4218, "The Very High Temperature Reactor: A Technical Summary" (Chapin, 2004)	Materials	HTGR GFR	ALL	PERF
3.07.0070.020	MSR designs should include reliable chemical monitoring and polishing systems to ensure that fuel/coolant salt chemistry problems can be identified and addressed in time to prevent adverse effects.	Corrosion, fuel performance, and safety all depend on maintaining salt chemistry within specified bounds.	Industry Feedback	Materials	MSR	ALL	PERF
3.07.0070.030	Cover gas purity should be monitored, maintained, and provided with the means to remove coolant aerosols.	Cover gas purity is important for maintaining the performance of reactor systems. Aerosols can deposit on components within the reactor vessel and result in mechanical clearance and other problems.	Operating Experience from the BN 600 Sodium Fast Reactor, O.A. Potapov	Materials	SFR LFR MSR	ALL	PERF
3.07.0070.040	Reactor design should include means to restore cover gas purity from out-of-specification conditions.	Cover gas purity is important for maintaining the performance of reactor systems. Aerosols can deposit on components within the reactor vessel and result in mechanical clearance problems, and other complications.	Operating Experience from the BN 600 Sodium Fast Reactor, O.A. Potapov	Materials	SFR LFR MSR	ALL	PERF
3.07.0070.050	The design should control the purity of sodium and the cover gas within specified limits to prevent: plugging of passages, adverse chemical reactions, and to control radionuclide concentrations.	Sodium and cover gas purity is important for preventing the accumulation of activation products, oxides and other adverse effects.	USNRC RG 1.232, Appendix B, SFR-DC Draft ARDC Criterion 71 requires sodium and cover gas purity control. Existing SFR experience has shown this to be an important operational consideration.	Materials	SFR	ALL	PERF
3.07.0080.010	Non-metallic materials in reactor coolant applications should meet appropriate impurity limits.	Experience has shown that under the influence of heat and radiation, organic compounds containing chlorine and fluorine will break down to chlorides and fluorides, which may negatively impact the reactor coolant. Other chemical impurities, and particulates, should be evaluated to determine the acceptability of selected materials.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Materials	ALL	ALL	SAFE
3.07.0080.020	Non-metallic materials in BOP applications should meet appropriate impurity limits.	Impurity limits should be used to limit the impact of impurities in the process fluid.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Materials	ALL	ALL	SAFE
3.07.0090.010	Any mixing of the MSR fuel salt and coolant salts in the collected leaks should be evaluated.	Fuel salt leaks may occur as a result of manufacturing flaws, excessive wall temperatures and stresses, corrosion, thermal stress cycling, etc.	Industry Feedback	Materials	MSR	ALL	SAFE PERF
3.07.0090.020	When the primary coolant system interfaces with a structure, system, or component containing fluid that is chemically incompatible with the primary coolant, the interface location should be designed to ensure that the primary coolant is separated from the chemically incompatible fluid by two redundant, passive barriers.	Barriers ensure that radioactive sodium does not have the potential for exposure to steam or other incompatible substances. For most SFR designs, this is accomplished with an intermediate loop. Barriers could include inert gas layers and/or mechanical boundaries. The rates and exothermic energies of chemical reactions must be evaluated by the designer to determine what constitutes "chemically incompatible."	USNRC RG 1.232	Materials	SFR	ALL	SAFE

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.07.0090.030	The reactor design should include means to detect sodium leakage and control the extent of sodium-air, sodium-concrete, and sodium-water reactions.	Sodium reactions may be violent and require special consideration when used as the primary coolant.	USNRC RG 1.232	Materials	SFR	ALL	SAFE PERF
3.07.0090.040	The sodium-steam generator system should be designed to detect and contain sodium-water reactions and limit the effects of the energy and reaction products released by such reactions, as well as to extinguish a fire as a result of such reactions.	Previous experience has suggested the need for a separate criterion for protection against sodium reactions.	USNRC RG 1.232 NUREG-1368	Materials	SFR	ALL	SAFE
3.07.0090.050	Reactions between the primary heat transfer fluid and water or air should be considered when choosing the chemical composition of the primary heat transfer fluid.	Some salts react violently with water or burn in air. Therefore, the primary salt should be chemically inert with respect to water and air (or the potential reactions minimized or controlled).	Industry Feedback	Materials	MSR	ALL	SAFE PERF
3.07.0100.010	The HTGR design should reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated event conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.	“Reactor coolant pressure boundary” has been relabeled as “reactor helium pressure boundary” to conform to standard terms used for HTGRs.	USNRC RG 1.232	Materials	HTGR GFR	ALL	SAFE
3.07.0100.020	The reactor design should reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated event conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.	The cover gas boundary is included as part of the reactor primary coolant boundary (referred to as RCPB by PRISM) per NUREG-1368 (page 3-38).	USNRC RG 1.232	Materials	SFR LFR MSR	ALL	SAFE
3.08.0050.010	Portable engineering workstations and M&TE equipment that interfaces digitally with safety-related equipment should be maintained, controlled, and accessed in a physically secure location.	Providing physical access to CDAs could give bad actors an access point to infiltrate cyber systems. Portable devices could be used as a medium for such attacks.	IEEE 7-4.3.2-2016 Section 5.9.1	Physical Protection and Proliferation Resistance	All	ALL	SEC/NP
3.08.0050.020	All safety-related digital components and network cabling should be installed in plant locations that provide physical security for the equipment.	Providing physical access to CDAs could give bad actors an access point to infiltrate digital systems.	IEEE 7-4.3.2-2016 Section 5.9.1	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP
3.08.0050.030	Permanently connected engineering workstations and connections for M&TE should be installed in a plant area that provides physical security.	Providing physical access to CDAs could give bad actors an access point to infiltrate cyber systems.	IEEE 7-4.3.2-2016 Section 5.9.1	Physical Protection and Proliferation Resistance	ALL	ALL	SEC/NP

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.08.0060.010	MSR designs should include means by which fissile isotope inventory can be adequately tracked.	Most molten salt designs include dissolution of the fuel in the coolant. This results in the potential for fuel isotopes to deposit in the piping or otherwise be diverted. Appropriate inventory control processes should be established to account for the greater uncertainty in fuel inventory. These methods should account for distribution of fissile material in plant piping and components and should account for uncertainty associated with measurements of weight or activity. The maximum potential uncertainty in fissile isotope inventory should be clearly determined and inventory procedures should be established at periodicities appropriate for the calculated uncertainty.	Industry Feedback	Physical Protection and Proliferation Resistance	MSR	ALL	SEC/NP
3.08.0060.020	MSR designs should include means by which the diversion of fissile material is prevented or they should include chemistries which make diversion of fissile materials less appealing than direct procurement through mining and enrichment.	Some salts make extraction of fissile isotopes relatively easy. MSRs should be designed to prevent their direct implementation as a means of proliferating weapons.	"Proliferation Resistance and Physical Protection of the Six Generation IV Nuclear Energy Systems," Generation IV International Forum, GIF/PRPPWG/2011/002	Physical Protection and Proliferation Resistance	MSR	ALL	SEC/NP
3.09.0010.010	The HTGR design should reflect consideration of service temperatures and other conditions of the reactor helium pressure boundary material under operating, maintenance, testing, and postulated event conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.	“Reactor coolant pressure boundary” has been relabeled as “reactor helium pressure boundary” to conform to standard terms used for HTGRs.	USNRC RG 1.232	Quality Assurance	HTGR GFR	ALL	SAFE
3.09.0010.020	The reactor design should reflect consideration of service temperatures and other conditions of the reactor coolant boundary material under operating, maintenance, testing, and postulated event conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.	"Reactor coolant pressure boundary" has been relabeled as "reactor coolant boundary" to avoid the assumption that the boundary is pressurized.	USNRC RG 1.232	Quality Assurance	SFR LFR MSR	ALL	SAFE
3.09.0010.030	Materials should be selected to accommodate erosion commensurate with the expected particulate concentrations and fluid flows experienced in the reactor.	In some advanced reactor designs, erosion may be a greater concern than corrosion.	Industry Feedback	Quality Assurance	ALL	ALL	IMPL
3.09.0010.040	Materials of construction for reactor components should have low susceptibility to neutron damage.	Exposure of reactor components to high neutron flux should not limit their ability to perform their functions.	URD Rev 13 Tier II Chapter 4 Section 2 EUR Volume 2 Chapter 6	Quality Assurance	ALL	ALL	PERF
3.09.0010.050	SFR components should be compatible with the fast neutron flux environment as applicable, including such phenomena as radiation-induced creep, swelling, and embrittlement.	Prevent component damage from fast neutrons.	USNRC RG 1.232	Quality Assurance	SFR	ALL	SAFE PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.09.0010.060	Valves in which the valve disc is not positively restrained or can otherwise move in response to flow-induced forces should not be used in applications where the valve internals will be subjected to high velocity flow, variable flow velocity or pressure, or fluid flashing conditions.	Looseness of the disc can result in significant valve damage when flow-induced forces batter the disc onto valve internal surfaces.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.070	Flow concerns (e.g., cavitation, erosion, flashing) should be considered in the selection process for valve designs.	Many advanced reactor applications will involve fluids and flow conditions outside the bounds of typical industrial applications. The ability to accommodate or prevent such phenomena will need to be specially considered in selecting valve designs.	Industry Feedback	Quality Assurance	ALL	ALL	PERF
3.09.0010.080	Gate valves should not be used in flow regulation or throttling service.	Gate valves have experienced service disc erosion when used in throttling services.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.090	Solid wedge gate valves should be limited to applications where service temperatures will not result in unacceptable thermal distortion.	Solid wedge gate valves are subject to sticking because of thermal distortion.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.100	The reactor designer should assure that check valves are used only where necessary.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Quality Assurance	ALL	ALL	PERF
3.09.0010.110	The reactor designer should assure that the system requirements, e.g., closure time, leakage and flow rates, for each check valve are completely defined.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Quality Assurance	ALL	ALL	PERF
3.09.0010.120	The reactor designer should assure that the type and size of each check valve selected is proven in service and compatible with plant (environment) and system requirements.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Quality Assurance	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.09.0010.130	The reactor designer should ensure special precautions are taken to assure that each check valve is located and oriented properly in the piping system.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, *"Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Quality Assurance	ALL	ALL	PERF
3.09.0010.140	The reactor designer should assure that for each check valve part clearances, disc stability, and wear relative to the actual operational flow conditions should be are considered.	Check valve failures in nuclear power plants have caused such problems as water hammer, system over pressurization, and steam binding of pumps. They have also been responsible for generating loose parts and, in general, have been a significant source of operational and maintenance problems. The application of the guidelines should result in a substantial reduction in check valve-related problems and thereby increase plant availability, reduce maintenance effort, and reduce personnel radiation dose.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7 EPRI Report NP-5479-R1, "*Application Guidelines for Check Valves in Nuclear Power Plants Revision 1*."	Quality Assurance	ALL	ALL	PERF
3.09.0010.150	High performance butterfly valves should be considered when butterfly valves are utilized for throttling flow.	Flow is not linear as a function of valve position. Large globe valves are cost prohibitive. Experience shows that high performance butterfly valves can work effectively.	URD Rev 13 Tier II Chapter 1 Section 12	Quality Assurance	ALL	ALL	PERF
3.09.0010.160	"Y" pattern globe valves should not be used in raw water applications.	These valves tend to foul with silt and corrosion products. The actuators do not have adequate margin to overcome the additional loads imposed by fouling.	URD Rev 13 Tier II Chapter 1 Section 12	Quality Assurance	ALL	ALL	PERF
3.09.0010.170	Valves should be designed and fabricated of materials proven in service to have a high resistance to internal and external corrosion and erosion. Special attention should be taken in the selection of materials of valves subject to cavitation.	Adequate corrosion allowance must be provided to assure life expectancy of the valve. Cavitation and erosion of control valves has been a major maintenance problem in older plants.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.171	A means to cope with leaking safety valves and safety relief valves should be provided.	All valves should be assumed to leak. However, the leakage of safety valves and safety relief valves needs to be mitigated.	Industry Feedback	Quality Assurance	ALL	ALL	PERF
3.09.0010.180	Pumps which handle highly radioactive liquids or which are located in a radiation environment should be provided with drain and flush connections for decontamination, if applicable.	Pumps are a significant portion of the maintenance burden on the plant staff. Minimizing and simplifying pump maintenance will help achieve the availability goals for the reactor. For pumps in radioactive service, these requirements are important to meeting reactor goals.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter D49	Quality Assurance	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.09.0010.190	Heat exchanger fouling factors should be established by the reactor designer considering conservative predictions of material buildup based on actual system and equipment designs and expected plant operating conditions.	The assumed fouling factor has a significant effect on heat exchanger sizing. A conservative value is desirable from the point of view of not limiting operation or requiring excessively frequent cleaning; however, too large a value could result in unnecessarily high capital cost and in some cases can result in operational problems because of excessive heat transfer capability. Failure to provide a fouling factor may result in inappropriate assumptions on the part of component designers and manufacturers.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.200	Margin for heat exchanger tube plugging should be provided consistent with experience in similar heat exchangers.	Providing a tube plugging margin maintains the design heat exchanger performance, even with some degraded tubes plugged. This can substantially extend the time before a tube bundle must be replaced.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.210	A minimum tube plugging margin of 10% should be considered in the heat exchanger design where other requirements do not take precedence.	In the absence of other data, some tube plugging margin is appropriate. Providing a tube plugging margin maintains the design heat exchanger performance, even with some degraded tubes plugged. This can substantially extend the time before a tube bundle must be replaced. More margin may be needed if heat exchanger includes FOAK design or chemistry.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.220	Heat exchangers should be designed to withstand the maximum system pressure, and relief valves should be provided only if necessary (e.g., the heat exchanger can be isolated). However, relief valves should not be used to justify the use of a heat exchanger that is designed for less than system pressure.	This requirement is good engineering practice and avoids heat exchanger damage due to off normal pressure conditions which are within the capability of the system.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.230	Threaded and flanged connections should not be used in the main steam system except where required to permit component removal for maintenance.	These connections have been sources of reliability problems in operating LWR plants.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 2 Chapter 7	Quality Assurance	ALL	ALL	PERF
3.09.0010.240	The flow area of the steam piping should be selected to provide an acceptable steam velocity based on successful operating experience, considering expected fluid conditions (pressure, temperature, and moisture levels) and considering the material requirements necessary to limit corrosion.	Operating velocity should be selected to provide the most economical pipe size as calculated by optimization studies. Although carbon steel has been successfully employed for steam piping for up to 25 years without significant operating problems and is much less expensive than either chrome moly or stainless steel, selection of the latter materials should be considered to reduce corrosion product transport and the risks of flow assisted corrosion.	URD Rev 13 Tier II Chapter 2 Section 3	Quality Assurance	ALL	ALL	PERF
3.09.0010.250	Piping should be arranged so as to minimize the occurrence of water hammer. When water hammer effects cannot be completely eliminated, provisions to accommodate the loads in appropriate analyses must be made.	Loads due to water hammer events have resulted in substantial damage in the past. The loads resulting from water hammer may be the most severe loads imposed on the system and, improperly addressed, may result in degradation of safety function, damage to plant equipment, or loss of plant availability.	URD Rev 13 Tier II Chapter 6 Section 4	Quality Assurance	ALL	ALL	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.09.0010.260	Insulation on piping systems should be selected to account for the specific service conditions of the piping.	For example, the presence of heat tracing, temperature and humidity conditions, whether the insulation is to be painted or not, whether the piping is in a space accessed by personnel, whether the insulation needs to be periodically removed for inspections, etc., should all be considered.	Industry Feedback	Quality Assurance	ALL	ALL	IMPL
3.09.0010.270	Plants that have three-phase AC electrical distribution systems should design for the possibility of an open phase condition (fault of one or two phases).	The unbalanced power source created by an open-phase condition can damage electrical equipment.	EUR Volume 4 Chapter 4	Quality Assurance	ALL	ALL	PERF
3.09.0010.280	The pressure drop at the maximum guaranteed rated operation should not cause the inlet moisture level to the turbine to exceed its rated moisture level.	The actual level of pressure drop is the result of design and operating limitations imposed by the steam quality on the material and output economics of the plant.	URD Rev 13 Tier II Chapter 2 Section 3	Quality Assurance	ALL	GR OG	PERF
3.09.0010.290	The equipment specification for each pump important to safety should require shop performance tests to demonstrate that head/flow characteristics, Net Positive Suction Head (NPSH) and horsepower requirements meet design, and that cavitation or excessive vibration are not encountered over the entire operating range of flows and pump speeds.	Shop testing of pumps is standard practice. These requirements incorporate recommendations included in “Evaluation of Basic Causes of Repetitive Failures of Nuclear and Fossil Feedwater Pumps,” EPRI Report NP-1571.	URD Rev 13 Tier II Chapter 2 Section 4 “Evaluation of Basic Causes of Repetitive Failures of Nuclear and Fossil Feedwater Pumps,” EPRI Report NP-1571 (EPRI, 1980)	Quality Assurance	ALL	GR OG	SAFE IMPL
3.09.0190.010	SSCs should be tested during and following fabrication for compliance with service requirements.	Examinations and tests help assure the critical process steps are controlled.	URD Rev 13 Tier II Chapter 1 Section 5 EUR Volume 2 Chapter 6	Quality Assurance	ALL	ALL	IMPL
3.10.0010.010	Liquid-fueled reactors using emergency drain tanks should be designed so that the fuel can be recovered after draining. Note: Same as 3.04.0020.010.	Emergency drain tanks are designed to achieve subcritical geometries. After draining and subsequent cooling, the fuel should be recoverable, even if this requires electric heating to melt the fuel prior to pumping back to the primary system.	Industry Feedback	Reliability and Availability	MSR	ALL	ECON
3.10.0020.010	The instrumentation and control system should be designed to allow the required periodic testing without placing the plant in an unacceptable one-out-of-two or one-out-of-three trip logic.	Designing the instrumentation and control schemes to support the required periodic testing without placing the plant in an easy-to-trip condition will enhance availability, operability, reliability and maintainability.	mPower DSRS Chapter 7 URD Rev 13 Tier II Chapter 1 Section 8	Reliability and Availability	ALL	ALL	PERF IMPL
3.10.0020.020	Significant power operation should be possible with a single major feedwater/condensate component out of service.	The plant should maintain relatively high availability with a single component unavailable.	URD Rev 13 Tier II Chapter 2 Section 4 EUR Volume 4 Chapter 6	Reliability and Availability	ALL	ALL	PERF
3.10.0020.030	The condenser should have flexibly arranged circulating water so that a single pump or intake can be isolated without significant impact to turbine operation.	Parallel flow paths allow on-line repairs. More than two paths are preferred to minimize power reduction. Condenser arrangement should consider turbine back end condition limitations when one or more paths are isolated.	URD Rev 13 Tier II Chapter 2 Section 4	Reliability and Availability	ALL	GR OG	PERF
3.10.0030.010	Auxiliary system design should maximize operational flexibility by ensuring that the auxiliary systems' availability does not unduly depend on the operation of another system.	Industry experience with auxiliary steam systems has shown that operational flexibility is hampered in designs which preclude the use of the auxiliary steam system when main steam is not available.	URD Rev 13 Tier II Chapter 2 Section 7	Reliability and Availability	ALL	GR OG	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.10.0040.010	Conditions causing the automatic initiation of emergency cooling systems (including passive safety systems that are not normally in operation) or the automatic actuation of primary safety valves or relief valves should be selected such that these systems are only automatically initiated when appropriate.	Unnecessary initiation of emergency systems and safety/relief valves will result in excessive wear, consumption of allowable thermal cycles, reduced lifetime, and additional maintenance on these systems. Initiation of emergency systems also has a negative impact on the public perception of the plant due to media exposure.	URD Rev 13 Tier II Chapter 1 Section 3 EUR Volume 2 Chapter 1 EUR Volume 2 Chapter 10	Reliability and Availability	ALL	ALL	ECON
3.10.0050.010	Fluid systems should be designed to minimize the number of valves consistent with safety, functional, reliability and availability requirements.	The reactor designer should evaluate the need for each valve based on: • System safety functions; • System operational functions; • Expected flow rate range; • Design pressure drop range; • Reliability requirements; • Redundancy requirements; • Code requirements; • Regulatory requirements; • Isolation or maintenance requirements. Simplicity is an ORG policy statement. The number of valves affects the cost of the plant, construction difficulty, and the operation and maintenance effort over the plant lifetime.	URD Rev 13 Tier II Chapter 1 Section 12 EUR Volume 2 Chapter 4 EUR Volume 2 Chapter 7	Reliability and Availability	ALL	ALL	PERF
3.10.0170.010	The design should consider and minimize the potential effects of Flow Accelerated Corrosion (FAC) and Flow Induced Vibration (FIV).	FAC is a known degradation mechanism in operating plants that should be limited in newer designs.	EUR Volume 2 Chapter 4 EUR Volume 2 Chapter 6	Reliability and Availability	ALL	ALL	PERF
3.10.0170.020	Threaded and flanged connections should not be used in the main steam system except where required to permit component removal for maintenance. Note: Same as 3.09.0010.230.	These connections have been sources of reliability problems in operating LWR plants.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 2 Chapter 7	Reliability and Availability	ALL	ALL	PERF
3.10.0170.030	The feedwater system layout, valve characteristics, etc. should be designed so that water hammer loads are below steam generator design limits.	Water hammer pressure pulses can be generated as a result of feedwater isolation or control valve closure/opening, check valve closure or pump start and stop and resultant system/component damage must be prevented.	mPower DSRS 10.3 URD Rev 13 Tier II Chapter 2 Section 4	Reliability and Availability	ALL	GR OG	PERF
3.10.0170.040	Horizontal centrifugal pumps should be centerline-mounted, rather than foot-mounted.	Centerline mounting allows symmetric thermal expansion growth of the casing from the shaft centerline outwards. This prevents coupling misalignment regardless of temperature variations.	URD Rev 13 Tier II Chapter 2 Section 4	Reliability and Availability	ALL	GR OG	PERF
3.10.0170.050	A static excitation system is recommended for the main generator, as opposed to a rotating excitation system.	Static excitation systems have improved inherent reliability due to the absence of a rotating component.	URD Rev 13 Tier II Chapter 13 Section 4 EUR Volume 4 Chapter 5	Reliability and Availability	ALL	GR OG	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.10.0180.010	The reactor designer should inform failure analyses and probabilistic risk assessment with applicable data from relevant non-nuclear experience.	Many lessons learned may be provided from non-nuclear operating experience.	Industry Feedback	Reliability and Availability	ALL	ALL	PERF
3.10.0180.020	For SFRs, components submerged in the sodium pool should be designed and constructed so that they promote the passive removal of entrained gas bubbles during normal operation and during evolutions that require removal or repositioning of the component.	Entrained gas is deleterious to heat transfer and reactivity stability. Design for passive removal of entrained gas reduces plant complexity and reliability by limiting active components.	Industry Feedback	Reliability and Availability	SFR	ALL	PERF
3.10.0180.030	The drainage system for main steam piping should be designed to remove water prior to and during initial rolling of the turbine and during shutdown.	This requirement is based on standard practices in LWR designs. Such draining prevents operational and maintenance problems.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Reliability and Availability	ALL	GR OG	PERF
3.10.0180.040	Means should be provided to protect the tubes from pitting during periods of condenser shutdown.	Experience has shown that condenser tube materials are very susceptible to pitting in stagnant water. A circulating water recirculation loop or provisions to completely drain the condenser waterbox and tubes are examples of achieving this requirement.	URD Rev 13 Tier II Chapter 2 Section 4 EUR Volume 4 Chapter 6	Reliability and Availability	ALL	GR OG	PERF
3.10.0190.010	The postulated events specific for a HTGR should include (but not be limited to): • Water ingress to Reactor Pressure Vessel (RPV); • Fuel compaction due to seismic events; • Double pipe break.	The response to these events are unique for the reactor technology and should be considered.	Industry Feedback	Reliability and Availability	HTGR	ALL	SAFE
3.10.0190.020	The postulated events specific for a MSR should include (but are not limited to): • Freezing of salt in primary loop (over-cooling event); • Fuel precipitation (over-cooling event); • Primary loop failure representative of a fuel failure); • Loss of fuel/coolant confinement.	The response to these events are unique for the reactor technology and should be considered.	Industry Feedback	Reliability and Availability	MSR	ALL	SAFE
3.10.0190.030	The postulated events specific for a SFR should include (but not be limited to): • Water flooding of reactor cavity (chemical reactions/contamination); • Sloshing of coolant during a seismic event; • Overcooling event; • Reactor vessel leaks and intermediate system leaks; • Decay heat removal system leaks.	The response to these events are unique for the reactor technology and should be considered.	Industry Feedback	Reliability and Availability	SFR	ALL	SAFE
3.10.0190.040	The flow geometry of fuel salt should prevent the fuel salt from becoming critical except in the reactor volume, accounting for localized salt concentrations.	Inadvertent criticality of the fuel loop should be avoided.	Industry Feedback	Reliability and Availability	MSR	ALL	SAFE

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.10.0200.010	The feedwater system should be designed to allow feedwater heating to commence at the minimum feasible turbine power, preferably at initial load following synchronization.	Initiation of feedwater heating at low power will help to reduce thermal stress on components.	URD Rev 13 Tier II Chapter 2 Section 4	Reliability and Availability	ALL	GR OG	PERF
3.10.0210.010	The feedwater and condensate system should be designed with the capability of automatically providing the required flow to the steam generators during startup, power operation, and shutdown evolutions at power levels up to, and including, rated load and during plant design transients without interruption of operation or damage to equipment.	To reduce the complexity of operating the feedwater and condensate systems during startup and reduce the chances of a low steam generator level trip during startup.	URD Rev 13 Tier II Chapter 2 Section 4 EUR Volume 4 Chapter 6	Reliability and Availability	ALL	ALL	PERF
3.10.0210.020	The turbine bypass system should have sufficient capacity and transient response capability to permit generator synchronization with the power grid during startup without impacting the plant.	Difficulties with operating LWRs designed with inadequate turbine bypass systems have indicated that specification of this requirement is needed for stable plant operation.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Reliability and Availability	ALL	GR OG PH	PERF
3.10.0210.030	The turbine bypass system should have sufficient capacity and transient response capability to permit stable operation of the automatic control of the reactor and to permit manually controlled cooldown of the plant.	Difficulties with operating LWRs designed with inadequate turbine bypass systems have indicated that specification of this requirement is needed for stable plant operation.	URD Rev 13 Tier II Chapter 2 Section 3 EUR Volume 4 Chapter 6	Reliability and Availability	ALL	GR OG PH	PERF
3.10.0215.010	An HTGR should operate at a higher temperature than the traditional LWRs for efficient power generation and high temperature-based process heat applications.	HTGR technology is examined as a long term source of energy for the process industry in consideration of the high-temperature process heat that can be produced, and the highly efficient electric power generation capability. The robust nuclear safety characteristics of HTGR technology allow its use adjacent to major industrial facilities.	EPRI TR 1009687	Reliability and Availability	ALL	GR OG PH	PERF
3.10.0215.020	The reactor core outlet temperature in a HTGR used for hydrogen production should be optimized for the hydrogen production system used.	The leading hydrogen production processes are: • the membrane-based low temperature, high-pressure electrolysis process; • the membrane-based steam methane reforming process; • the sulfur-iodine thermo-chemical process; • the high-temperature steam electrolysis process. The processes have different reference design temperature operating regimes, and so the temperature of the reactor core outlet helium and the temperatures in the coupling heat transfer system (CHTS) are different.	EPRI TR 1009687	Reliability and Availability	HTGR	PH	PERF
3.10.0290.010	For a hydrogen producing plant, the process plant should be made up of a large number of multiple modules (e.g., electrolyzers) to assure that no significant fraction of the process plant is down at one time.	The large capital investment in the hydrogen production system implies a premium on high availability and short refueling down times for the nuclear heat source.	EPRI TR 1009687	Reliability and Availability	HTGR	PH	PERF
3.10.0290.020	A hydrogen producing HTGR plant should have fewer planned shutdowns (e.g., for refueling) than electricity generation plants.	The capacity factors for hydrogen HTGR plants must be high.	EPRI TR 1009687	Reliability and Availability	HTGR	PH	PERF

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Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.10.0290.030	Considering a modular reactor arrangement for a hydrogen producing HTGR plant, the hydrogen process plant and the CHTS should be designed to operate with a portion of the reactor modules out of service.	Economics and the intended high capacity factor design criteria indicate a very high probability that only one modular reactor will be out of service at any time. However, the requirement for periodic refueling and an unscheduled outage allocation implies that during some percentage of the time a forced outage in a second module will reduce the thermal output further. Therefore, the process plant should run at a reduce capacity as a normal mode of operation.	EPRI TR 1009687	Reliability and Availability	HTGR	PH	PERF
3.10.0300.010	For advanced reactors with experiment ports or other core penetrations (e.g., for radioisotope production), the neutronic effects of insertion and removal of the irradiation targets must be considered.	Localized neutronic effects may impact power distributions or assumptions for shutdown reactivity. Designs should consider flux discontinuities occurring during power operations, changes in shutdown reactivity margins, and other effects resulting from the presence of irradiation targets. Accounting for these concerns early in the design may allow some reactors to meet a radioisotope production mission, even if not intended as the primary mission of the reactor during the initial design.	Industry Feedback	Reliability and Availability	ALL	RP	SAFE
3.11.0040.010	For reactors designed to operate at high temperatures, the designer should perform the safety classification of the plant's SSCs in accordance with applicable codes and standards.	Division 5 of Section III of the ASME B&PV Code was created to address the unique concerns associated with the high operating temperatures of advanced reactors. The temperature threshold for "high" is variable, but existing codes and standards may require further development for a number of proposed reactor designs.	USNRC RG 1.232 URD Rev 13 Tier II Chapter 1 Section 4	Seismic and Structural	ALL	ALL	SAFE PERF
3.11.0040.020	The location and finish of applicable welds should be suitable and accessible for future automated In-Service Inspection (ISI) of 100% of the ASME Section XI (or equivalent) -required volume using Ultrasonic Testing (UT) or other exam techniques in accordance with ASME Section XI.	Automated ISI aligns with ALARA principles.	ASME Code Section XI (ASME, 2017) URD Rev 13 Tier II Chapter 4 Section 2 EUR Volume 2 Chapter 13	Seismic and Structural	ALL	ALL	PERF
3.11.0070.010	Thermal cycling of the heat transfer fluid (in the extreme, repeated freezing and melting) should not damage structures in the reactor.	As the salt expands/contracts from melting/freezing, cracks in structural materials may be subjected to additional stresses and could propagate.	Molten-Salt Reactor Program "Semiannual Progress Report for Period Ending July 31", 1964, Oak Ridge National Lab, ORNL-3708. pg. 381 (ORNL, 1964)	Seismic and Structural	SFR MSR	ALL	SAFE PERF
3.11.0070.020	The reactor structural design should be qualified to withstand the elevated temperatures, low pressures, and fluid conditions characteristic of SFRs for the design life of the plant.	The pressure-temperature combinations expected from SFRs present unique challenges to structural design. Changes in free surface level, high-temperature creep, and other effects are unique to SFRs.	Industry Feedback	Seismic and Structural	SFR	ALL	SAFE
3.11.0100.010	Steam-line supports should be designed for water-filled line loads under static loading conditions that may be encountered in plant operations.	Water-filled conditions are specified to ensure that they are included in the design of piping supports because they may be encountered in plant operation.	URD Rev 13 Tier II Chapter 2 Section 3	Seismic and Structural	ALL	ALL	PERF

Owner-Operator Requirements Guide Tier III Requirements							
Req. #	**Requirement**	**Basis**	**Alignment**	**Category**	**Technology**	**Mission**	**Attribute**
3.11.0130.010	If complex or dissimilar metal welds are required, the reactor designer and owner-operator should consider using state-of-the-art three-dimensional finite element analysis capabilities to include and model weld residual stresses in the design phase to optimize the design and possibly the fabrication of specific components.	There is a significant ongoing effort in the nuclear industry to characterize and predict weld induced residual stresses in order to mitigate material degradation and optimize performance. Of particular importance is the confidence and accuracy of WRS numerical modeling and experimental measurement techniques. Although finite element analysis may not precisely predict the weld residual stress values, when utilized appropriately it can be a useful tool to evaluate locations of tension and compression.	EPRI TR 3002010464	Seismic and Structural	ALL	ALL	PERF ECON

ORG Definitions

Definitions are provided to frame the discussion and establish clear terms for use in the ORG (both in this document, and in the Tier II and Tier III requirements). These definitions are usually the same as usage in the arena of LWRs, but they contain some important distinctions to make them useful in the broader technical domain of advanced reactors.

The following terms are defined as used in the ORG:

- **Active Component –** A component which is required to change state to perform a **safety function** (e.g., a valve shutting or a breaker opening) through the reliance on externally supplied energy (e.g., AC power) or operator action.
- **Advanced Reactor –** A reactor that is not a traditional **light water reactor** and provides a distinct advantage over a LWR in meeting a market need. *The term "Generation IV" is not used because the ORG is not necessarily limited to the technologies designated as such by the Generation IV International Forum (GIF), nor is the ORG connected to the GIF.*
- **Aspirational Goal –** An ambitious goal which, if achieved, provides the potential to take full advantage of the capabilities and advantages offered by **advanced reactor** technologies. Aspirational goals, while not **requirements** at present, could be promoted to policies and requirements at a later date as technologies mature.
- **Attribute –** A broad reactor characteristic embodied by many specifications. Attributes retire **risks**. Five attributes are included in the ORG. Each **requirement** is linked to one or more of these attributes.
- **Availability –** The percentage of time a reactor is capable of meeting its **mission**, if demanded[4].
- **Balance-of-Plant (BOP) –** The portion of the nuclear plant that produces the desired output. Considered separate from the **Reactor** and reactor support systems.
- **Beyond Design Basis Event –** This term is used as a technical way to discuss accident sequences that are possible but were not fully considered in the design process because they were judged to be too unlikely. In that sense, they are considered beyond the scope of **design-basis events** that a nuclear facility must be designed and built to withstand. As the regulatory process strives to be as thorough as possible, "beyond design-basis" accident sequences are analyzed to fully understand the capability of a design. Generally, the ORG used "**severe event**" to avoid wording that may be specific to a particular country or regulator.

[4] Traditionally, the availability of a nuclear power plant is very close to its capacity factor (i.e., the ratio of a plant's average output to potential full capacity output). Capacity factor is equal to the plant's availability multiplied by a load factor, which represents the percentage of the plant's full capacity that is demanded. Most nuclear power plants have supplied baseload power (i.e., they operate at 100 percent power continuously), which is represented by a load factor of 100 percent. This gives a capacity factor that is equal to availability. However, this mode of operation may not be the norm for all advanced reactors and missions, making the distinction between availability and capacity factor more important. For some missions and/or owner-operators, availability may be a more important metric than capacity factor.

- **Boiling Water Reactor (BWR) –** A type of traditional **LWR** in which primary coolant water is heated by the reactor to create steam, which is sent directly to the turbine to generate power. Contrasted with a **pressurized water reactor**.
- **Breeding –** Breeding refers to the production of fissile fuel during the normal operation of a nuclear reactor. All nuclear reactors generate **fissile material** if a **fertile material** (e.g., Uranium-238) is present. In the context of the ORG, breeding refers only to reactors whose rate of production of fissile material exceeds the rate of consumption of fissile material.
- **Commercial Off-the-Shelf (COTS) –** Refers to a standard item (hardware or software) that is available for purchase and does not need to be specially designed for an application.
- **Constructor –** The organization responsible for the construction of the reactor plant at the **owner-operator's** chosen site. The constructor is typically an EPC (Engineering, Procurement, and Construction) firm.
- **Coolant –** A fluid that is used to remove heat from a nuclear reactor and is relied upon to do so for safety needs. Light water is the coolant predominantly used in existing reactors. Most **missions** use the heat absorbed by the coolant to some productive end (e.g., generate steam to spin a turbine). For most designs, the **heat transfer fluid** enabling the productive use of the reactor is also the coolant relied upon for safety. For these designs the term coolant can be used interchangeably with heat transfer fluid. The term coolant is used in technology-independent ORG content to refer to both coolant and heat transfer fluid.
- **Could –** Used to indicate a specification or aspirational goal that is intended to introduce possibilities, not mandates. "Could" statements are not intended to constrain design in any way, but encourage the consideration of features or capabilities that have the potential to provide significant advantages. As technology and markets progress, "could" statements may be promoted to "should" or "shall" statements.
- **Design Basis Event –** A postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to ensure public health and safety. Generally, the ORG used "**postulated event**" to avoid wording that may be specific to a particular country or regulator.
- **Engineering, Procurement, and Construction (EPC) –** Refers to the contractor hired by the **Owner-Operator** to manage the construction of the plant. The owner-operator and the EPC can be the same organization.
- **Fast Reactor –** A nuclear reactor in which the fission chain reaction is sustained by "fast neutrons," or neutrons with high kinetic energy. Such reactors do not need a **neutron moderator**, which intentionally slows neutrons.
- **Fertile Material –** A material (such as Uranium-238) that can be transmuted to become fissile material (e.g., Pu-239 and Pu-241) by neutron absorption. Fertile materials are the basic material for **breeding**. In the thorium fuel cycle, Th-232 is the fertile isotope.
- **Fissile Material –** A material (such as Uranium-235) that can sustain a nuclear fission reaction with neutrons of any speed, including very slow neutrons. More highly enriched nuclear fuel contains a higher percentage of fissile material.

- **Fissionable Material –** A material that can sustain a nuclear fission chain reaction. **Fissile materials** are a subset of fissionable materials. Some materials may be fissionable but not fissile (e.g., a material that can only sustain nuclear fission with fast neutrons, like U-238).
- **Fluoride salt-cooled High Temperature Reactor (FHR) –** A fluoride salt-cooled, solid-fueled reactor. These reactors are distinguished from typical **MSR** concepts in that the fuel in an MSR is dissolved in the salt. For the purposes of the ORG, the term MSR refers to the liquid-fueled reactor, but many MSR requirements could be easily adapted to FHR designs.
- **Gas-cooled Fast Reactor (GFR)**[5] – GFRs are **fast spectrum reactors** with gas **heat transfer fluid**. They are designed to operate at high temperatures up to the same ranges as **HTGRs** but are distinguished by their fast neutron spectrum.
- **Heat Transfer Fluid –**A fluid that enables the productive use of the reactor by absorbing heat and using it to some productive end (e.g., generate steam to spin a turbine). See **coolant** for the distinction between the two terms. Coolant is used in the ORG to refer to both terms in general discussion, and when both terms apply (e.g., most reactor types). Heat transfer fluid is used in technology specific discussion when the term coolant does not apply (e.g., for gas reactors).
- **High Temperature Gas-Cooled Reactor (HTGR)**[6] **–** HTGRs are cooled by a flowing gas (generally helium or CO_2). They can use **pebble-type fuel** or **prismatic fuel** and can be used in electricity generation and other missions. Some reactor vendors use the term **Very High Temperature Gas-Cooled Reactor (VHTR)** to distinguish HTGRs that operate at an even higher temperature than most HGTRs.
- **Human-Machine Interface (HMI) –** An instrumentation and controls (I&C) system that facilitates the interaction between human operators and plant equipment.
- **Light Water Reactor (LWR)** – LWRs are **thermal spectrum reactors** with light water as **coolant**. Most commercially operated reactors in the history of nuclear power are LWRs. **PWRs** and **BWRs** are different types of LWRs. The ORG is intended to support the development of reactor technologies that offer distinct advantages when compared to the traditional LWR.
- **Liquid Metal-Cooled Fast Reactors (LMFR) –** Reactors that use liquid metal as **coolant** and operate on a **fast spectrum**. They are capable of being built as **breeder reactors** and they typically operate at high temperatures and very low reactor coolant pressures. LMFRs can be large or small and pool-type or loop-type in design. LMFRs include Sodium-Cooled Fast Reactors (SFRs)[7] and Lead-Cooled Fast Reactors (LFRs)[8].
- **Mission –** An application of reactor technology for a particular societal purpose. Missions are related to the products of reactor operation – heat, neutron flux, and radioactive isotopes.

[5] No GFRs have ever been built and operated.

[6] Commercial gas-cooled reactors have operated successfully around the world.

[7] Many SFRs have been built and operated both experimentally and commercially.

[8] LFRs were built and operated as part of the Soviet submarine propulsion program, with mixed success.

Missions are dependent on the owner-operator (government, utility, industrial activity) and some reactors may serve multiple missions, potentially for multiple customers.

- **Molten Salt Reactor (MSR)**[9] – MSRs are reactors that use a molten salt mixture as **coolant** with fuel dissolved in it. The fuel and coolant are therefore one and the same. Nuclear fuel may either be solid fuel (as is used in other reactor designs), or a liquid fuel that is dissolved in the coolant and circulates through the reactor. For the purposes of the ORG, the term MSR refers to the liquid-fueled reactor, but many MSR requirements could be easily adapted to solid-fueled designs (such as the **FHR**). When referring to the liquid fuel in a MSR, the reader should recognize that these discussions refer to aspects of reactor design and operation that would apply to both fuel and heat transfer fluid in other designs. MSRs can operate on a **fast** or **thermal spectrum**.
- **Modular –** Refers to construction techniques in which major portions of a design are constructed off-site, typically in an enclosed/covered fabrication facility, allowing for better production quality than in traditional construction techniques. Modular construction can present additional challenges, including transporting prefabricated modules to the site, and integrating modules with each other, and with the plant structures and layout.
- **Neutron Moderator –** A medium that reduces the speed of fast (high kinetic energy) neutrons, turning them into thermal (low kinetic energy) neutrons, which are capable of sustaining a nuclear chain reaction with fuel used in **thermal reactors**. LWRs use light water as a moderator, which is also the **heat transfer fluid**. However, not all thermal reactors use the heat transfer fluid as a moderator.
- **Owner-Operator –** The organization that owns and is responsible for the day-to-day operation of the reactor. The owner-operator is invested in the ability of the reactor to perform its intended **mission(s)** to generate profit throughout its design life. In some cases, the Owner and Operator may be separate entities; however, the ORG avoids this distinction for simplicity, and treats the Owner-Operator as one entity.
- **Passive System –** Systems which employ primarily passive means (e.g., natural circulation, gravity, stored energy) for essential safety functions. Contrasted with active systems (i.e. systems with primarily **active components**). In passive systems, some components may re-position, but they do so without reliance on an outside power source. In passive systems, such re-positioning components are usually limited to valves, relays, blow-down discs, or other simple components.
- **Passively Safe –** Passively safe reactors are those which can be demonstrated to avoid unacceptable consequences for a minimum of 72 hours after design basis events (and much longer for some designs), without any need for operator action and without reliance on any active components.

[9] Only experimental MSRs have been built and operated; all without power conversion.

- **Pebble Bed Fuel –** Fuel used in **HTGRs** that consists of fuel embedded in a spherical matrix of graphite ("pebble"), which acts as a **neutron moderator**. The reactor consists of many pebbles moving downward through a funnel, while gas flows through the funnel to cool the fuel. These pebbles are formed with thousands of small fuel particles commonly referred to as "TRISO" particles (for tri-structural isotopic). The fuel contains built-in barriers to fission product release.
- **Plant –** The term applied to the nuclear facility established and operated to take advantage of the nuclear heat source. The plant includes all the auxiliary and support systems required to operate and complete the designated mission(s). It is generally synonymous with the physical boundary of the property under the Owner-Operator's control.
- **Plant Designer –** The organization responsible for the design of the reactor plant (i.e., the Original Equipment Manufacturer). In most cases, the plant designer develops a reactor design and searches for potential **owner-operators** to purchase the design.
- **Postulated Event –** An abnormal plant occurrence that must be considered in the plant design. Generally used in favor of **design basis accident** in the ORG to avoid wording that may be specific to a particular country or regulator.
- **Pressurized Water Reactor (PWR) –** A type of **LWR** in which primary coolant water is maintained at a relatively high pressure so that it remains liquid when heated by the reactor. The hot pressurized water then transfers heat to lower pressure secondary water via a steam generator. The secondary water is sent to the turbine to generate power. Contrasted with a **boiling water reactor (BWR)**.
- **Prismatic Fuel –** Fuel used in **HTGRs** that consists of more traditional style vertical elements that are molded into compacts or rods and then inserted into graphite blocks (the reactor's moderator material). Molten-salt cooled reactors with the fuel in solid form can use prismatic fuels as well.
- **Probabilistic Risk Assessment (PRA) –** A method of quantifying risks. PRA is used extensively in the existing **LWR** fleets to determine the likelihood of certain events occurring in a plant.
- **Programmable Digital Device (PDD) –** A digital component that must meet certain software and cyber security requirements.
- **Proliferation –** The spread of **fissionable material** to persons, organizations, or nations that intend to produce nuclear weapons.
- **Reactor –** A nuclear device in which fission may be initiated and controlled in a self-sustaining chain reaction to generate heat or produce useful radiation.
- **Regulator –** The organization responsible for ensuring the operation of nuclear technology does not present a **risk** to the health of the public or the environment in the country of operation. The **owner-operator** must be licensed to operate their plant by the regulator. The regulator establishes safety requirements that must be followed.

- **Requirement –** In the ORG, requirements are those items which represent best-practice, compliance with international standards, and adherence to existing regulatory standards. These are expectations which should be met for all designs. Deviations from ORG requirements should be made only with strong technical justification.
- **Risk –** A negative consequence to plant personnel, stakeholders and investors, the local population, the environment, or society that has a probability (no matter how remote) to occur due to the continued operation of a nuclear reactor during its lifecycle.
- **Safeguards –** The use of material control and accounting programs to verify that all special nuclear material is properly controlled and accounted for, as well as the physical protection (or physical security) equipment and security forces. As used by the International Atomic Energy Agency, this term also means verifying that the peaceful use commitments made in binding nonproliferation agreements, both bilateral and multilateral, are honored.
- **Safety Function –** A function that a component performs that is part of the designed reactor response to an event and helps prevent the release of radiological material.
- **Safety Related –** Systems, structures, components, procedures, and controls (of a facility or process) that are relied upon to remain functional during and following **design-basis events** (e.g., loss of power offsite power, loss of core cooling, earthquake). Their functionality ensures that key regulatory criteria, such as levels of radioactivity released, are met. Examples of safety-related functions include shutting down a nuclear reactor and maintaining it in a safe-shutdown condition.
- **Severe Event –** A type of event that may challenge safety systems at a level much higher than expected. Generally used in favor of **beyond design basis event** in the ORG to avoid wording that may be specific to a particular country or regulator.
- **Shall –** Used to indicate a specification that is mandated by the ORG. Deviation from such a specification is likely to require very strong, well-documented justification to the owner-operator and, in most cases, to the regulator as well.
- **Should –** Used to indicate a specification that is strongly encouraged, yet not mandated, by the ORG. Deviation from such a specification is likely to require justification to the owner-operator.
- **Site –** The property on which the **plant** resides. Used in favor of plant to refer to the land or the location, rather than the equipment and facilities.
- **Used fuel –** The term used fuel has traditionally meant fuel that has undergone irradiation during a normal cycle in a nuclear reactor. With changes in the intended fuel cycle for some advanced designs, used fuel in the context of the ORG refers only to fuel that has been removed from the reactor and will not be irradiated again without reprocessing.
- **Stakeholder –** A group or individual impacted or perceived to be impacted by any decision to construct, operate, maintain, or decommission a nuclear reactor.
- **Structures, Systems, and Components (SSC) –** A term used in the context of the ORG to refer broadly to the equipment and buildings of which the plant is comprised.

- **Supercritical Water Reactor (SCWR) –** SCWRs are similar to modern **BWR or PHWR (pressurized heavy water reactor)** designs, except the light water **coolant** becomes a supercritical fluid (i.e., operating at a pressure above the critical point). High pressures and temperatures are used to generate supercritical water. Requirements specific to SCWRs have not been included in the initial ORG since there were no major commercial efforts to deploy one at the time of writing.
- **Supplier –** An organization responsible for providing components, equipment, materials, software, or any other product that is used in the construction, operation, maintenance, or decommissioning of the reactor plant. Suppliers are subject to quality assurance requirements commensurate with the quality classification of the item provided.
- **Technology-inclusive –** A term used in the ORG to describe requirements structured to accommodate any reasonably feasible nuclear technological concept.
- **Thermal Reactor –** A nuclear reactor in which the fission chain reaction is sustained by "thermal neutrons", or neutrons with low kinetic energy (slow). Such reactors need a **neutron moderator**, which intentionally slows neutrons so that fission is more likely to occur. Most commercially operated reactors in the history of nuclear power have been thermal spectrum reactors. This principle of operation can be contrasted with **Fast Spectrum Reactors**.
- **Unit –** Each individual nuclear reactor core and the associated support systems unique to that core together form a single "unit." Some vendors use the term "module" rather than "unit" for plant designs predicated on an arrangement of several nuclear reactors. Though multiple units may be coupled to the plant's load, each unit's reactor is characterized by an independent, sustained fission reaction.
- **Verification and Validation (V&V) –** The process by which software is proven to perform its functions and meet necessary requirements.

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ORG Revision 1 Position Paper and Potential Listings for Future ORG Revisions

In Rev. 13 of the URD, EPRI and industry representatives agreed to produce topic position papers to inform the new portions of the URD as they relate to smLWRs. This method included assigning research topics and then putting together all the results in the final version of the URD. The same approach was used for the ORG Revision 0 and Revision 1 work. EPRI has identified topic/issue areas for further research and has asked for volunteers to write these (Issue) papers. Four potential outcomes of each Issue Paper are:

1. New requirement(s).
2. Summary of information still needed to adequately define a requirement.
3. Conclusion that no requirement is needed, or that defining a requirement is not feasible.
4. New Aspirational Goal(s).

As part of ORG Revision 1 work, "Automation and Human Factors" was identified as a crucial aspect in the future development, design and deployment of advanced reactors. The resulting position paper is documented in the next section.

Other potential position papers, of interest for future ORG revisions are provided in the table below.

Table 1
Potential ORG Position Papers

Title	Description
Material Control and Accounting for Molten Salt Reactors	This paper should address the unique effects a circulating fuel could have on material control and non-proliferation objectives for MSRs.
Flexibility for Operation and Load Following	This paper should discuss load following in the electric generation mission and identify metrics for an aspirational goal with respect to electric load following. The aspirational goal should state ramp rates to achieve breakthroughs in electricity generation.
Developing Metrics for Risk-Based Investor Protection	Owner-Operators are interested in seeing vendors develop reliability studies and failure analyses to determine the reliability risks that may endanger the capital investment and the assumptions for the availability of the plant. This paper will address what metrics are appropriate and what methodologies owner-operators want to see.
Special Definitions for Advanced Reactors	This paper should identify important terms to define, define them according to a technology-inclusive mindset, and develop requirements whose clarity was dependent on such definitions. The paper should especially address terms which are commonly used but whose definition may have significance in the licensing treatment, safety case, or operational patterns of advanced reactors. For instance, is "shutdown" defined as safe, stable, and controlled while not producing useful power? Or is it defined as lower than a certain maximum thermal power? There may be several terms which require tailored definitions in order to remain technology inclusive or to apply generically around the world.

Title	Description
Historical Experiences with Insufficient Margin	This paper should compile all the utility experiences in design aspects that had insufficient margin, causing major delays on outages or early shutdowns. The person or group charged with competing the paper could make determinations on which margins are likely worthwhile to build-in to requirements based on the cost of the margin increase. Examples include spare space or for expansion, spare connections, etc. The person or group completing the issue paper should ask: Can existing margin issues be captured and compared against the gain/loss of that margin to determine which margins are likely to be worth their inclusion? The comparison should be against the “next best” option. Margin is not just achieved by specifying the design with margin against the regulatory and owner-operator requirements. It also includes margin in manufacturing tolerances so that slight deviations in as-built configuration do not impact whether the system is acceptable. Good examples of margin issues in recent experience are: the AP-1000 basemat, reactor vessel head penetrations, extra space in battery rooms, spare fiber optic conduit. The paper should be forward-looking and should therefore consider the types of systems included in advanced reactor designs. One method of beginning to scope this out is to consider the portions of the URD which provide explicit requirements for margin.
Methods of Measuring Economic Competitiveness	Three possible methods of analyzing the economic competitiveness of a nuclear reactor have been identified: (1) Capital Cost per kW Installed (2) Levelized Cost of Electricity (LCOE) (3) Affordability (a measure of the consequences to the owner-operator if the project fails) This paper should consider the three options above (and other methods, if identified) and determine which should be the primary consideration of an owner-operator.
Cost Estimation for Advanced Reactors	Cost estimating for advanced reactors may warrant some industry standard practices. The issue paper should address such questions as: (1) What assumptions should be made on the cost estimate responsibility for each contributor, i.e., vendor/utility/EPC? (2) How are costs categorized? (3) At what stage can you determine each cost category and at what level of fidelity? There is a recent study by “Energy Options Network” that attempted to quantify cost advantages of advanced reactor technologies. This work may be a good starting point to categorize costs and to develop initial criteria for defining advantages/challenges of different technologies. The person or group completing this paper should be aware that nuclear construction is not wholly different from other industries in terms of cost uncertainty. Analogous cost estimating challenges abound in other industries, e.g., chemical process plants, commercial and military aircraft, shipbuilding, etc.

Title	Description
Electricity Generation Needs of the Future	There are numerous efforts underway across the electricity generation industry to answer questions on energy storage, costs, transmission infrastructure, etc., that will influence the needs of owner-operators in the future. This disparate information does not necessarily tailor itself to use by advanced reactor designers as they attempt to create technologies that meet these shifting needs. This paper would aggregate the applicable information from these various industry efforts to define electricity generation's needs of the future, in terms that would assist advanced reactor designers in meeting those needs. It would inform questions on needed ramp rates, sizing electrical output for grid stability, frequency response, and load profile with competing generation from other resources.
Current Licensing and Advanced Reactors	There are some licensing concepts or nearly universal licensing requirements that are not likely to apply for advanced reactors. One example is the set of firm requirements for staffing (numerically), the need to have control rods, pre-defined values for EPZs, electrical power supply requirements (GDC 17), prescriptive ISI/IST requirements, etc. This paper would attempt to catalogue a host of prescriptive regulatory requirements or regulatory concepts (e.g., "severe accident" being defined as one leading to fuel damage) and to make a determination as to whether there are meaningful differences for advanced reactor designs. The person or group completing this paper should start with industry comments to the USNRC ARDCs. The issue paper would look internationally as well, starting by evaluating which international regulatory constructs are based on USNRC. NEI's regulatory task force has begun a similar effort. This issue paper may simply incorporate findings from that task force, or may complement that effort.
Staffing and Advanced Reactors	This paper should be a historical investigation of how utility staffing got to be what it is today. This topic has been studied in depth to support many industry efforts to reduce staffing. However, these studies have not been performed through the lens of advanced reactors. Much of the previous utility work could be built upon to evaluate opportunities for staff optimization at advanced reactor plants. The assumptions of these studies and the outcomes could be used to inform advanced reactor design.
Design Life of Advanced Reactors	Many concept designs may take advantage of shorter design lives if the result is a much cheaper plant that achieves cost recovery sooner for the owner. This introduces the question of whether there is an optimum balance between a plant's design life and the risk profile (financing especially, and construction timeline). This paper would investigate the sensitivity of a plant's capital cost and LCOE as a function of the plant's design life, with appropriate assumptions for the cost of capital, construction timelines, etc.

Automation and Human Factors Position Paper for ORG Revision 1

Issue:

The original treatment of Human Factors in the first draft of the EPRI Owners-Operators Requirements Guide (ORG) did not adequately incorporate the concept of automation in the overall advanced nuclear plant design philosophy, particularly in the treatment of the instrumentation and control systems.

Background and Basis:

The policy statement on Human Factors in the first draft of the ORG was virtually the same as that provided in the ALWR Utility Requirements Document with an emphasis on human factors, human-machine interfaces and simplification. There was no treatment of automation for advanced nuclear plant operation and maintenance. Presently, automation of almost all engineered systems is inevitable. It is estimated that 40% of all manual tasks will be replaced by robots or automation by the time the advanced nuclear plants are deployed in the late 2020s. Consequently, the instrumentation and control systems of the advanced plants should be designed to support the eventual automation of all advanced nuclear plant functions.

Proposed Resolution:

Automation of engineered systems is most mature in the field of vehicular transportation. Many lessons and insights from the automated vehicle development can be applied to the automation of advanced nuclear plants. In many ways the automation of nuclear facilities is less complicated than the automation of automobiles. One of the principal tenants of the automated vehicle is the phased approach to automation. The six phases of automobile automation are articulated by the Society of Automotive Engineers in the *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Vehicles (SAE International, J3016TM, June 2018).*

The proposed solution is to modify the existing policy statement to facilitate automation in the advanced nuclear plants in a phased approach. The new policy statement with the additional language highlighted in italics follows:

The advanced reactors should be capable of full automation in all modes of operation, including accident conditions. This capability will reduce human error, staffing requirements and costs. Automation will be phased in stages beginning with full manual operation and use machine learning (artificial intelligence) methods to gain 'experience and knowledge' of reactor behavior as the design moves from full manual to full automatic operation. Fully automatic operation permits the plant(s) to be operated remotely and autonomously with no operators physically on-site. Offsite supervisory control is required under these circumstances. Throughout this evolution to full automation, it is critically important for the human machine interfaces be simple and intuitive, be consistent across all system displays, and consider remote or multi-unit operation.

Interactions between human and machine **create opportunities for human error**. These errors can be minimized by:

- Making the human-machine interface as simple and easy to use as possible.
- Making the human-machine interfaces consistent throughout the plant.
- Building human-machine interfaces to *support phased automation*.

RATIONALE FOR THE REVISION

Automation of most engineered systems is underway. It is estimated that 40% of all manual tasks will be replaced by robots or automation. The tasks range from simple floor sweeping to complex surgical procedures, including brain surgery. Human error in one form or another constitutes about 90% of the root causes of engineering failures and disasters. In the field of automobile safety, 94% of all crashes in the U.S. are attributable to human error and cost the economy more than $250B annually. It is in this field that automation is advancing most rapidly. Many lessons from the automated vehicle development can be applied to the automation of nuclear plants. In many ways the automation of nuclear facilities is less complicated than the automation of automobiles. One of the principal tenants of the automated vehicle is the phasing of degrees of automation. The Society of Automotive Engineers (SAE) defines six levels of automation, ranging from no automation (Level 0) up to full automation (Level 5).

Using the SAE approach to automation as a template and applying it to advanced nuclear plants, the following matrix of levels of automation for advanced nuclear plants was developed:

Summary of levels of advanced nuclear plant automation

Level	Name	Definition	Control System	Primary Operator	Support Operator	Operational Domain
0	No Automation (current state of the art)	Control by operator of the entire spectrum of operation with limited automation, i.e. alarms	Operator and conventional I&C system	Operator	Operator	Normal, Upset and Accidents
1	Operator Assistance	Limited control of power level change at steady state (frequency control or load follow) by automation system	Operator and Automated Control System	Operator	Operator	Normal (Limited)
2	Partial Automation	All Normal Plant Modes (Startup to Shutdown)	Automated Control System with Operator Supervision	Automated Control System	Operator	Normal
3	Conditional Automation	All Normal Plant Modes (Startup to Shutdown) plus upset conditions	Automated Control System	Automated Control System	Operator supervising	Normal and Upset

Level	Name	Definition	Control System	Primary Operator	Support Operator	Operational Domain
4	High Automation	All Normal Plant Modes (Startup to Shutdown) plus upset conditions	Automated Control System	Automated Control System	Automated Control System	Normal and Upset with Accident Conditions managed by Operator (may be remote)
5	Full Automation	All Normal Plant Modes (Startup to Shutdown) plus upset and accident conditions	Automated Control System	Automated Control System	Automated Control System	Normal, Upset and Accidents with no Operator onsite.

The control space for an advanced nuclear plant is actually much simpler than the control space for vehicles. With the advent of accurate reactor, multi-physics models which span the spectrum from micro- to macroscopic scale coupled with exascale computing, the experimental programs required to ‘qualify’ advanced reactor designs will be more resource effective than that required for the light water reactor development program. Fuel behavior under normal, upset and accident conditions will be better understood and predictable. Taken together, the advanced reactor models with the appropriate amount of qualification testing will provide the basis for the control and instrumentation systems required for the phased-in automation of the future plants. The experience gained from the lower automation levels of plant operation will provide the foundation and confidence to progress to the next level of automation. The cumulative experience of the operating fleet of LWR plants will be used to the maximum extent possible using machine learning techniques.

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