

Program on Technology Innovation: Scoping Study for an Owner-Operator Requirements Document (ORD) for Advanced Reactors

2016 TECHNICAL REPORT

Program on Technology Innovation: Scoping Study for an Owner- Operator Requirements Document (ORD) for Advanced Reactors

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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 sources. 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 the potential technology customer (electric utilities and other owner-operators) with developers and vendors for alignment of requirements. This results in a product that can be designed, financed, built, licensed, operated, and maintained on a commercially sound basis.

In keeping with its previous leadership role in the commercialization of advanced light water reactors and experience with development of the *Advanced Light Water Reactor Utility Requirements Document, Revision 13* (URD) (report 3002003129), EPRI brought together advisors representing nuclear utilities and the advanced reactor development community. Their goal was to review the need for and appropriate scope of a new advanced reactor Owner-Operator Requirements Document (ORD). The key conclusions from this scoping study include the following:

- Development of an advanced reactor ORD is feasible, timely, and necessary and should focus on providing a high-level, flexible, technology-inclusive framework, especially at the policy and mission levels.
- Development and maintenance of more detailed design-specific requirements should remain in the hands of the developer/vendor and owner-operator.
- Given the potential breadth of technologies and missions, ORD development should proceed incrementally beginning with a well-understood mission—electricity generation.

This report provides a foundation for planning and executing a multiyear EPRI project to develop an initial ORD and pilot its application through collaboration with one or more advanced reactor developers/vendors.

Keywords

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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, regulators, policymakers, investors, and the 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 from advanced reactor technologies in order to consider adoption of new nuclear technology as part of a future electricity and energy generation infrastructure?”

RESEARCH OVERVIEW

In keeping with its previous leadership role in the commercialization of advanced light water reactors (ALWRs), EPRI evaluated the need for a common set of requirements that would reflect the expectations and needs of prospective owner-operators for advanced nuclear reactor designs, particularly advanced fission reactor designs that offer significant improvements with respect to currently available nuclear technologies. Objectives for EPRI’s advanced reactor Owner-Operator Requirements Document (ORD) include the following:

- Promoting alignment of technology attributes with customer needs
- Standardizing terms, attributes, and requirements (vs. prescribing them)
- Facilitating communication with key stakeholders, including regulators
- Providing a flexible framework for multiple missions and technologies

The experience and information associated with the EPRI *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Revision 13* (URD) (report 3002003129) provided a starting point for evaluating development of an ORD for advanced reactors. This approach recognizes that the scope, audience, and role for the ORD will likely be broader and different.

EPRI assembled representatives from electric utilities and reactor developers/vendors to evaluate the need for a new requirements document for advanced reactors as well as its proposed high-level structure,

content, and application. Results include identification of roles for key stakeholders; establishment of important features and goals; comparison and mapping to the existing ALWR URD; and a proposed philosophy and approach for maintenance, revision, and delivery of a sustainable, fit-for-purpose product.

KEY FINDINGS

- Development of an advanced reactor ORD by EPRI is feasible, timely, and necessary.
- Development of the ORD should focus on providing a high-level, flexible, technology-inclusive framework, especially at the policy and mission levels.
- Given the potential breadth of advanced reactor missions, ORD development should proceed incrementally beginning with a well understood reactor mission—electricity generation. Additional missions can be addressed in subsequent revisions.
- Given the potential breadth of advanced reactor technologies, initial ORD development should emphasize technology-independent requirements. Additional emphasis on requirements specific to classes of reactors and reactor design can be addressed in subsequent revisions.
- Development and maintenance of more detailed design-specific requirements can and should remain in the hands of the developer/vendor and owner-operator.
- The ORD should be a prospective, forward-looking document that anticipates future owner-operator needs, including aspirational goals that represent highly desirable but not necessarily currently available attributes and capabilities.
- The ORD is intended to be technology-inclusive and innovation-friendly. Therefore, construction of requirements should generally involve permissive “should” statements rather than prescriptive and limiting “shall” statements.
- Incorporation of lessons learned based on industry experience should be emphasized for ORD development and maintenance. This includes mining of the EPRI ALWR URD and other relevant information sources and operating experience.

WHY THIS MATTERS

As with the commercialization of ALWRs, early and meaningful engagement of prospective owner-operators in the design and development of advanced reactors through ORD development provides many potential, far-reaching benefits, including:

- Early buy-in from utilities and other potential technology customers
- Communication of owner-operator expectations and needs to developers and vendors
- A common approach to information gathering and communication
- Identification of unaddressed gaps and risks
- Informing development of a stable, predictable regulatory and licensing basis
- Informing 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 timeframes needed to meet future societal energy needs in an environmentally and economically sound manner.

HOW TO APPLY RESULTS

This report provides a foundation for planning and executing a multiyear EPRI project to develop an initial ORD and pilot its application through collaboration with one or more advanced reactor developers/vendors. A phased project plan is proposed to allow for rapid development and trial application of the ORD by vendors and potential buyers alike.

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 reports include *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Revision 13* (URD) (report 3002003129).
- 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 the first version of the advanced reactor ORD.

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INTRODUCTION

1.1 Background and Context

Over the past 30 years, EPRI has developed and refined the *Advanced Light Water Reactor Utility Requirements Document* (URD) [1]. This document provides a set of requirements to align advanced light water reactor (ALWR) plant designs with utility needs. The latest URD version (Revision 13) published in 2014 has been expanded to address small modular light water reactors (smLWRs). The URD comprises three tiers: Tier 0: Executive Summary, Tier 1: Policy and Top Tier Design Requirements, and Tier 2: Requirements for ALWR plants.

EPRI initially pursued URD development in support of U.S. electric utilities reeling from poor nuclear plant performance, flat electric demand, and the 1979 accident at Three Mile Island Unit 2. In 1983, EPRI asked nuclear utility executives what it would take for them to consider pursuing new nuclear construction.¹ The consensus pointed to 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 collaborative effort has expanded to include more than 30 U.S. and international utilities.

EPRI launched a new strategic program in 2016 focused on advanced reactor technologies for a global marketplace. Many of these designs fall under the Generation IV designation and most incorporate primary coolants other than light water. Many advanced non-light water designs are also amendable to modular manufacture, transportation, and construction methods and are deployable at scales that range from 10's to 1000's MWe; accordingly, the term small modular reactor (SMR) is applicable to both light water and advanced non-light water designs.

¹ *Reopening the Nuclear Option*. EPRI Journal. December 1994.

1.2 Study Purpose

In keeping with its previous leadership role in the commercialization of ALWRs, EPRI evaluated the need for a common set of requirements that would reflect the expectations and needs of prospective owner-operators for advanced nuclear reactor designs (advanced fission reactor designs that offer significant improvements with respect to current nuclear technologies), similar in function to the URD but adapted to the task of addressing a range of technologies, additional missions beyond electricity generation and owner-operators that may extend beyond the traditional electric power utility sector. In short, such an Advanced Reactor Owner-Operator Requirements Document (ORD) would:

- promote alignment of technology attributes with customer needs;
- standardize terms, attributes and requirements (vs. prescribing them);
- facilitate communication with key stakeholders, including regulators; and
- provide a flexible framework for multiple missions and technologies.

This scoping study intended to lay the foundation for launching the involved and resource intensive effort to develop a technology inclusive ORD applicable to an international audience. Outputs include identification of and roles for key stakeholders, proposal of a strawman high-level structure, identification of critical features and goals, comparison and mapping to the established EPRI URD, and outlining of a philosophy and approach for maintenance, revision and delivery of a sustainable, fit for purpose product.

The term “*advanced reactor*” is defined in this study as a reactor that is beyond Generation III technology² and provides compelling advantages over currently available designs in terms of safety, performance, and/or economics. Advanced reactors encompass a broad range of potential reactor designs and capabilities; accordingly, future owners and operators of nuclear energy systems may extend beyond the traditional electric utility. SMRs that employ light water reactor (LWR) technology offer many compelling attributes relevant to the ORD; however, they are not explicitly addressed in the ORD as they fall within the current scope of the URD.

While advanced reactors technologies differ from the currently operating designs of light water reactors, potential owner-operators will likely have similar expectations and requirements, including affordable, reliable designs with predictable construction timelines and licensing processes. At the same time, these new designs will need to offer compelling, demonstrable advantages over current, proven technologies in one or more aspects (for example, safety, performance, and economics) to justify the risk associated with adopting a new technology.

1.3 Leveraging the EPRI ALWR URD

An obvious starting point for developing an ORD for advanced reactors is the experience and information associated with the URD [1],³ while recognizing that the scope, audience and role for the ORD will likely be broader and, in many cases different.

² Other commercially operating and/or available non-LWR technologies would include Generation II/III pressurized heavy-water reactors (PHWRs) and Generation II advanced gas-cooled reactors (AGRs).

³ The more contemporary versions of the EPRI URD are licensed materials. However, Revision 8 (1999) of the URD is now publicly available in its entirety. While not fully up to date, it provides a useful example of the URD’s

1.4 Review of Prior Guidance on Advanced Reactor Design

In addition to the URD, a number of other efforts defining requirements for advanced reactors are available for reference and perspective [2]. However, taken together, this body of work is not adequate or fully applicable for the intended purposes of an advanced reactor ORD. few prominent examples of these historical efforts are highlighted below.

1.4.1 IAEA-1993

The first comprehensive effort to develop technology-inclusive requirements relating to both safety and performance of advanced nuclear reactors was completed by the IAEA in 1993 [3]. This document outlines technology-inclusive objectives for the design of advanced nuclear power plants. Objectives are qualitatively defined relative to the state of the art of LWRs operating at the time of writing, meaning requirements are phrased as methods for improvement rather than new baseline requirements. These objectives fall into five categories: enhancing safety, improving reliability, gaining better economics, assuring the fuel cycle, and expanding the market for nuclear power.

This document is now outdated, and therefore does not incorporate subsequent experience and information desired from the ORD to assist an owner-operator in making technology related decisions. The document does, however, provide a solid foundation for the types of attributes nuclear reactors in general should have, including application to new markets and new missions.

1.4.2 Generation IV International Forum

More recently, the Generation IV International Forum (GIF) Risk and Safety Working Group (RSWG) has developed guidance for safety-specific objectives, which consists of a safety philosophy and broad goals [4]. The three main goals presented for Generation IV nuclear power plants are to:

- Excel in operational safety and reliability.
- Have a very low likelihood and degree of reactor core damage.
- Eliminate the need for offsite emergency response.

The RSWG developed a list of findings and recommendations to help in achieving these safety goals. These findings focus on the safety philosophy for Generation IV, and on the design and assessment of innovative systems that will be required. Attention is given both to keeping the current safety practices in place which remain appropriate to Generation IV, and to adding new practices where appropriate.

The RSWG's safety approach is a step forward in defining safety requirements for advanced Generation IV reactor designs. The ORD however will not be limited to safety considerations, but will focus on assisting owner-operators in making advanced reactors more economically

useful example of the URD's content and structure: Advanced Light Water Reactor Utility Requirements Document, Volume 1, Revision 2: ALWR Policy and Summary of Top-Tier Requirements [TR-016780-V1R2]; Volume 2, Revision 8: ALWR Evolutionary Plant [TR-016780-V1R2]; Volume 3, Revision 8: ALWR Passive Plant [TR-016780-V3R8].

favorable and competitive than their traditional counterparts while maintaining the same standards for safety.

1.4.3 United States Government Efforts

The United States Department of Energy (DOE) has performed several studies of how to define regulatory requirements for advanced reactors. In July 2013, the U.S. Nuclear Regulatory Commission (NRC) and DOE established a joint effort to determine how to assess the *General Design Criteria* (GDC) to determine whether they apply to non-LWR designs and, if not, to propose modifications to address the non-LWR design features. A DOE team reviewed six non-LWR concepts (slightly different than the six specified by the GIF). In each case, the underlying safety objective of the GDC still applies. These non-LWR design criteria are intended as regulatory guidance to assist the staff and future applicants.

Submitted to the NRC in December 2014, the DOE report proposed a set of *Advanced Reactor Design Criteria* (ARDC), which could serve the same purpose for non-LWRs as the GDCs serve for light water reactors [5]. The ARDCs are intended to be technology-neutral and, therefore, could potentially apply to any type of advanced non-LWR design. Based on review of the DOE ARDC report and other previous assessments, the NRC released a summary of its proposed policies and requirements for advanced reactors in early April 2016 for public comment [6].

The DOE and NRC's work is critical to including advanced reactors in the regulatory framework and culture that exists for traditional reactors, but owner-operators need more than federal regulations. The ORD will be created to serve and assist the owner-operator in procuring an advanced reactor that not only meets the minimum standards of regulation, but meets the performance, and economic needs of the owner-operator.

1.4.4 Technology Specific Generation IV Requirements Development

Other efforts have also been made to define objectives for specific types of reactors that have since been designated as Generation IV designs. The *SFR Specific Design Criteria* document (SDC) from the GIF represents such an effort [7]. Information from these technology-specific documents may be used to inform certain sections of the ORD, but the ORD will take an approach to providing advanced reactor guidance that is not limited to one reactor type

1.5 Study Approach

EPRI solicited feedback on the potential content and structure of the ORD from advisors representing electric utilities and reactor vendors during two workshops. The first workshop was held on May 9-10, 2016, on EPRI's campus in Charlotte, NC; the second workshop was held on June 9 in Alexandria, VA, at the offices of MPR Associates. Generally, the workshop discussions resulted in clear consensus on many elements captured in this report; however, there was some variation in opinion on most of the topics discussed. Accordingly, this scoping study represents the conclusions reached by EPRI based on a synthesis of all input received.

2

KEY ORD WORKSHOP FINDINGS

2.1 ORD Workshop 1: May 9-10, 2016 (Charlotte NC)

In the first meeting, EPRI facilitated a group discussion regarding the high-level structure of the ORD: Tiered format, policy statements, relationship of technology to mission, etc. The group also addressed the viability of creating the ORD, the value of the ORD, and how an owner-operator might use the ORD to make decisions during technology selection and design maturation. Major conclusions and outcomes of the first meeting are listed below:

- The group reached agreement that the ORD has potential value, and is worth pursuing.
- The ORD should be at a much higher level than the URD, and it should provide a clear general framework, that a utility can adopt without too many modifications
- The overall structure of the ORD should be expanded beyond that of the URD (which is closely tied to a specific light water based technology), given the applicability to an expanded set of missions beyond electricity generation and the diversity of reactor technologies. The result is a notional framework consisting of three primary tiers: Tier I covering high-level policies, Tier II covering mission-level requirements, and Tier III covering technology-level requirements. The URD tiers were also mapped to the proposed ORD tiers for comparison. These tiers are discussed further in Section 4 of this study.
- Guidance should be categorized under five main attributes: safety, performance, economics, implementation, and security/non-proliferation. These attributes are discussed further in Section 5 of this study.
- The ORD needs to consist mostly of "should" statements rather than "shall" statements, in order to avoid constraining an Owner/Operator's decision process and preventing design changes that would be perfectly allowable by the current regulation.
- The initial version of the ORD should focus on electricity generation as the best understood mission and business case represented by actual nuclear utility owner-operators. Additional missions should be added in subsequent revisions.
- The ORD should have Policy Statements similar in purpose to those from the URD. The specific statements from the URD were evaluated for applicability to the ORD, and a preliminary list of policy statements for the ORD was drafted. This list included the statements listed in Section 5 of this study.

2.2 ORD Workshop 2: June 9, 2016 (Alexandria VA)

In the second meeting, EPRI facilitated a group discussion regarding more specific details of the ORD content. Discussion regarding the specific content and goals of this scoping study also took place. Major conclusions and outcomes of the second meeting are listed below:

- During the writing of the ORD, the URD should be thoroughly mined for requirements that may be applicable to the ORD.
- The ORD should incorporate lessons learned from the current nuclear fleet as much as possible. This is discussed in more detail in Section 3 of this study.
- The group added “Flexibility” and “Investment Protection” to the list of policy statements generated in the previous meeting. These statements are included in Section 5 of this study.
- An “Aspirational Goals” section should be included in the ORD to discuss possibilities for advanced reactors that are not necessarily requirements, but are positive developments that are already considered to be desirable. This section, along with a list of proposed aspirations, is discussed in more detail in Section 5 of this study.
- A preliminary list of missions that the ORD should eventually evaluate was drafted and is discussed in Section 5 of this study.
- Specific URD requirements were discussed and evaluated for applicability to the ORD. Appendix B of this study includes some of the results of this discussion.
- The group discussed the specific content of Tiers II and III of the ORD (mission and technology, respectively), and reached consensus regarding the most efficient and useful organization of these requirements, as presented in Section 4 of this study.

This input provides the basis for the scoping study recommendations and results presented below.

3

PROPOSED ORD CHARACTERISTICS

The advanced reactor ORD is intended to provide a framework relevant to a diverse set of international stakeholders having vested interests in the effective design, licensing, construction, and operation of advanced reactors. As advanced reactor technologies mature, some stakeholders may not have sufficient familiarity with the various technologies to efficiently identify key issues and gaps. Compounding the challenge is the lack of an applicable regulatory framework, which increases the uncertainty of advanced reactor commercialization. The proposed ORD seeks to remedy these issues by clearly communicating owner-operator expectations for advanced reactors at a high-level and by providing the framework for development of more detailed requirements and designs.

The following sections provide insight into the guidance the ORD is to provide to owner-operators. The ORD is intended to be broadly applicable to international energy sectors and markets and flexible enough to accommodate all advanced reactor technologies. The ORD requirements will not be as detailed as the URD, and will remain high-level. Additionally, the ORD will incorporate significant lessons learned from the current commercial nuclear fleet. The method by which the ORD will be written is also discussed, as are possibilities for presenting the ORD content in an alternative, interactive format.

3.1 Audience

The ORD is intended to be applicable to an international audience. Within this audience, the primary ORD user comprises advanced reactors technology customers or buyers (electric utilities and other potential nuclear reactors owner-operators) and nuclear technology developers and vendors. Throughout this report, the terms owner-operator, customer, and buyer are used interchangeably and, for the purpose of this study, refer to the same stakeholder. Likewise, the use of the term vendor generally includes reactor designers and developers that are developing advanced reactor concepts for the purpose of selling those designs to a buyer.

The ORD should facilitate an improved understanding of expectations between those desiring to acquire, license or operate advanced reactor technology and the vendors who are developing advanced reactor designs. Advanced reactor vendors need access to information that will provide confidence and assistance in identifying customer expectations so that resources can be applied most efficiently and effectively. Owner-operators need to ensure that their most basic needs are understood and incorporated early in advanced reactor designs. Therefore, the primary purpose of the ORD is to integrate stakeholder needs and desires to achieve a balance between owner-operator needs and reactor developer/vendor design capabilities, enabling the deployment of advanced reactors to meet commercial and societal needs. A secondary but importance audience for the ORD includes investors, regulators, policymakers and the public.

3.2 Applicability beyond Electricity Generation

Compelling drivers for pursuing commercialization of advanced reactor designs includes greater access to new markets and economic opportunities. Accordingly, the ORD should be applicable to reactors serving alternative markets and customers with missions ranging from commercial to national in character, including:

- electricity;
- district heating;
- process heat;
- natural resource amplification via fuel breeding and recycling;
- actinide waste management; and
- nonproliferation.

However even as attractive new missions and markets appear, the initial version of the ORD should start with a focus on electricity generation. Electricity generation currently represents the dominant market for nuclear and will likely remain a core mission for nuclear technology going forward. Also, from a practical standpoint, electricity utilities represent the primary owner-operators of nuclear plants and nuclear electricity is the best understood commercial application. An initial focus on electricity generation also allows for maximum use of the URD as a model for early ORD development. In spite of this electricity focus, initial drafting of the ORD can and should include at least a skeleton structure for the other missions to ensure adequate flexibility is maintained for further expansion.

3.3 Technology Inclusiveness

The ORD document as a whole will remain technology-inclusive, but will be developed in a phased manner to document appropriate guidance for specific advanced reactor technologies that are currently under development. The technology-specific guidance provided in the ORD will be limited to “advanced reactors” as defined by this scoping study. The guidance provided in the ORD will allow the application to any of these technologies so as to be as technology-inclusive as possible and promote ingenuity and creative solutions.

Many key attributes, capabilities, and limitations of reactor designs are derived from the fundamental physical properties of the primary system coolants. Figure 3-1 shows a breakdown of reactor technologies by the primary coolant used. Also indicated are available neutron energy spectra (thermal and fast) associated with the different coolant classes. Aside from supercritical water reactor designs, light-water and pressurized heavy water reactor designs do not fall under the ORD scope.

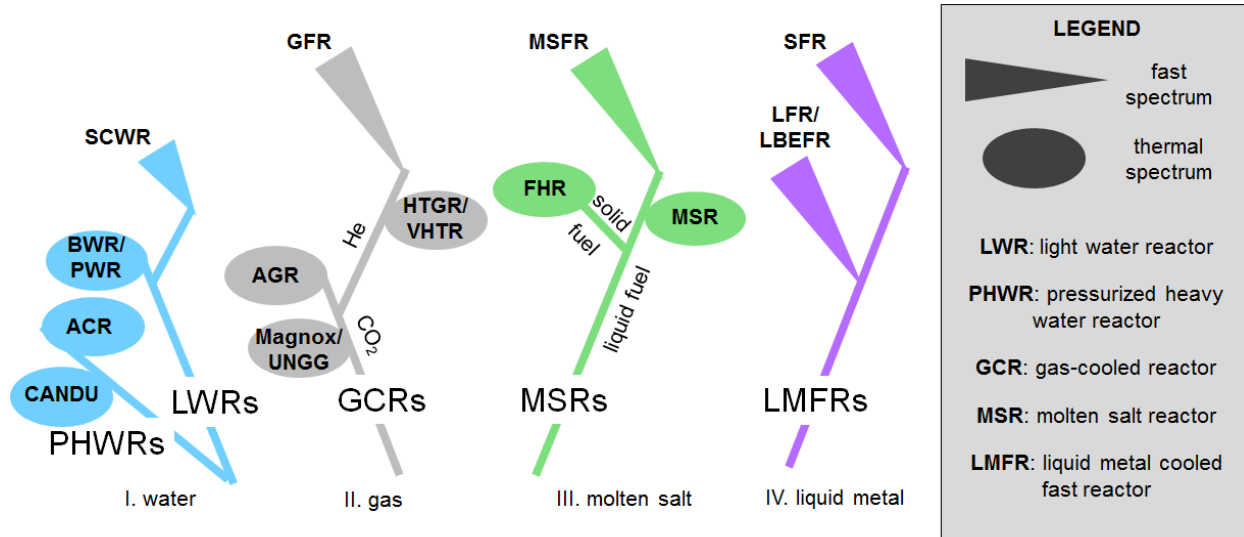


Figure 3-1
Diversity of reactor technologies for ORD, organized by coolant.⁴

3.4 Reactor Size

Reactor size should be considered as one of many key attributes to be determined by the owner-operator. Therefore, in keeping with a desire to encourage (and not constrain) flexibility and innovation, the ORD should avoid prescribing a specific size range or scale for reactor deployment. However, a desire for scalability may represent an important technology attribute that will provide owner-operators a valued degree of flexibility in terms of how, when, and where new units are constructed and operated.

3.5 Level of Detail Provided

Once fully developed, the ORD should give owner-operators guidance related to specific systems and components of each particular plant type as it is applied to each of the missions. However, given the current lack of advanced reactor operating experience, it is not possible for the initial version of the ORD to meet this intended level of depth. Instead, the initial focus will be providing general guidance in the form of policy statements and attributes that transcend technology and mission, with some more in depth discussion as a few examples. The policy statements will establish the philosophies behind building and operating an advanced reactor, and will encourage practices that make advanced nuclear reactors competitive against traditional reactors and other energy sources. The attributes will establish characteristics a technology must satisfy in order to be a viable design.

The goal is for the ORD to provide guidance at a depth that is useful to the owner-operator without being unduly constricting or limiting, and is appropriate for the maturity of target markets and technologies. This concept is illustrated in Figure 3-2.

⁴ Terms, acronyms and initialisms are defined in Appendix A.

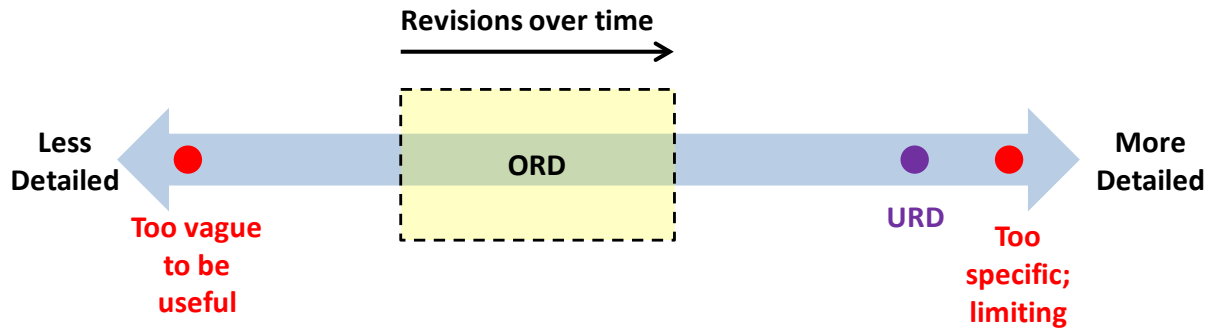


Figure 3-2
Evolution of ORD content and detail.

An illustration of phased ORD evolution toward broader and deeper coverage is provided in Appendix C.

3.6 Incorporating Lessons Learned and Operating Experience

While the ORD is a prospective attempt to anticipate future owner-operator needs, incorporation of learnings from previous experience remains an important element of the ORD development and maintenance philosophy. This is apparent in how the ORD itself is adapted from the existing URD. More importantly, the ORD should draw upon the decades of experience in designing, licensing, constructing, and operating LWRs to assist owner-operators with the commercial deployment of advanced reactors. When future advanced reactors 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, they will have a much better chance of reaching commercialization and providing long term economic benefits. The ORD should incorporate these lessons from LWR experience as a basis for each requirement, so that the user is presented with requirements that are thoughtful extensions of existing experience. The following learned lessons, in particular, should be included in the development of the ORD, as they apply regardless of technology or mission.

- Cooling water demands
- Passive safety
- Seismic isolation
- Planning for obsolescence
- Designing for reduced radiation exposure
- Designing for inspection, maintenance, repair, and replacement
- Designing for decommissioning
- Optimization of emergency planning zones and “good neighbor” status

3.7 Applicability of URD as a Model

The ORD is expected to share many of the same fundamental purpose as the URD in providing clear and agreed upon expectations for new reactor concepts. However, the broader applicability in terms of technologies, missions and audience necessitates departures from the URD model, which is based on specific light water technologies. The URD's structure (and in some cases content) will be utilized to the maximum extent practical in the writing of the ORD.

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

For these reasons, it will be neither possible nor desirable for the ORD to go to the same level of detail as the URD in terms of defining specific requirements. Instead, what is needed is a more general, technology-inclusive document. The ORD will provide guidance to inform decision-making rather than impose technical requirements and design limitations. Another motive behind making the ORD a higher level document than the URD is that the detailed and technology-specific URD requirements can become obsolete as technology progresses. The ORD's high-level requirements will strive to remain applicable regardless of technological progress, and the ORD structure and format will facilitate revision as technology developments and other changes warrant.

One key difference between the URD and the ORD is the intent of requirements. The URD requirements primarily involve "shall" statements intended to provide a comprehensive set of design requirements for the benefit of utilities considering the purchase of an advanced LWR based upon proven technology. The level of detail, represented in over 40,000 individual requirements, provides a potential buyer with:

- content sufficient for developing requests for proposals;
- criteria for evaluating proposals once received; and
- technical detail suitable for referencing in contracts and evaluating design and project performance throughout a new nuclear plant project.

Accordingly, the URD requirements were intentionally developed in a more prescriptive manner. In contrast, the ORD requirements are envisioned to comprise mostly permissive "should" statements to provide guidance without unduly constraining, inhibiting, or penalizing the innovation needed to make advanced reactors compelling and competitive technologies.

3.8 Writing Method

The writing of the ORD should begin with the information gathered in the scoping efforts summarized in this study. The following guidelines should be considered in the writing of the ORD:

- Frequent input and feedback from nuclear industry stakeholders should be solicited throughout the effort to guide the process, so that the ORD continues to serve its primary purpose and audience.

- Both potential owner-operators and advanced reactor developers/vendors should be sufficiently represented in the writing process, so that the final ORD product remains compatible with more detailed buyer and vendor requirements and bid specifications that are being or will be developed.
- The ORD should establish guidelines for how a vendor's specification interfaces with the ORD to begin to establish the connection between the two. ORD value will be diminished if its structure and content conflicts with developer/vendor requirements.
- A "steering committee" should be made available to provide the necessary feedback during the writing of the ORD. It is recommended this committee consist of at least three potential customers (owner-operators) and at least two vendor representatives and include international representation. Representation from government nuclear energy agencies should also be encouraged.
- During the writing of the ORD, the URD should be sufficiently mined for requirements that may be applicable to the ORD. The URD focus on LWR technology and the electricity generation mission indicates that some higher level URD requirements will map to lower levels in the ORD. Special care should be taken to ensure that the ORD requirements are established at the appropriate tier, and the technology inclusive intent of the ORD is preserved.
- The initial version of the ORD is expected to be limited in scope and heavily focused on the electricity generation mission. Upon completion and release of this initial version, EPRI will continue to solicit feedback from stakeholders who have reviewed it on how to expand the content to include additional missions and technologies as desired. Appendix C provides an example of how the ORD may expand over time.
- The URD contains guidance for how to revise the document. It should be determined if this guidance applies to the ORD as well. In either case, the ORD should provide guidance for revising the document to answer the following questions:
 - Who is involved in revising the ORD?
 - Whose approval is required to revise the ORD?
 - How are the revisions vetted by stakeholders?
 - How are revisions to referenced documents accommodated to maintain version control?

3.9 ORD User Interface

There are some new possibilities for the user-interface of the ORD that may be feasible using contemporary electronic media platforms and delivery options. One such possibility is an electronic database which would allow users to search the document by mission, technology, or other parameters to quickly locate requirements of interest. This could greatly increase the utility of the document merely by presenting the same information in a more user-friendly form, but may not be feasible until the ORD has reached a certain level of maturation.

A web-based forum may also be utilized to assist in soliciting stakeholder feedback and consensus for revising the ORD. This would allow a potential owner-operator to make suggestions on modifying, removing, or adding certain requirements throughout the document, and would allow other owner-operators to endorse or disagree with suggestions. This will allow the authors of the revisions to efficiently and effectively incorporate evolving key ORD stakeholder perspectives and needs.

4

NOTIONAL ORD STRUCTURE

Where possible, the tier structure of the ORD is adapted from that used for the URD. Figure 4-1 illustrates the proposed ORD structure described in this section.

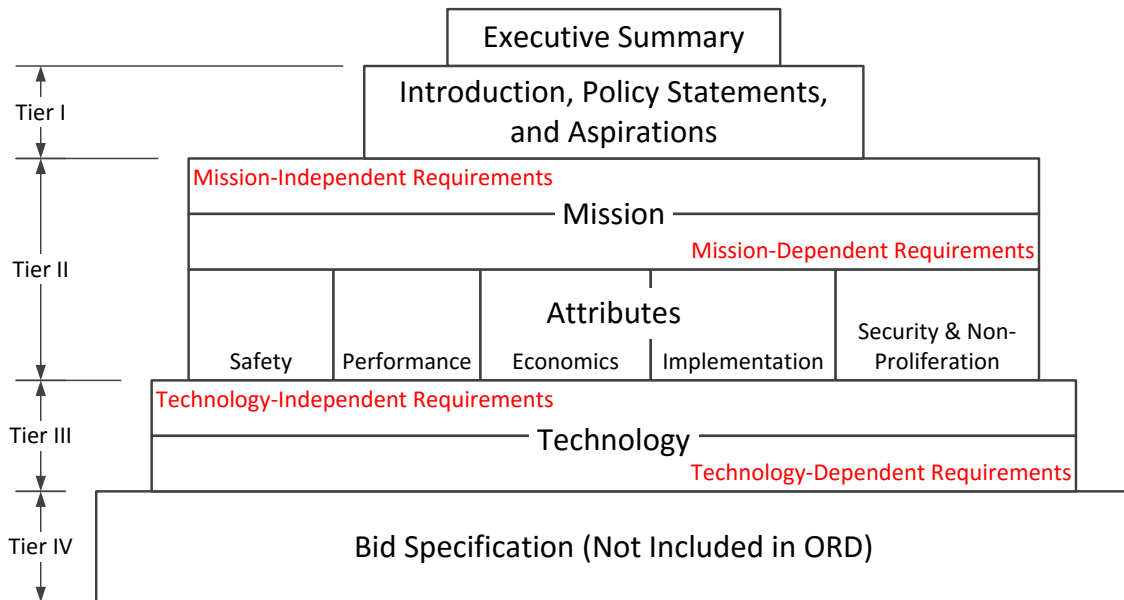


Figure 4-1
Notional ORD structure.

Similar to the URD, the ORD will be organized in tiers:

- Tier I will provide guidance generally applicable to advanced reactors as a whole. This tier represents high-level goals for advanced reactor technologies, and answers the question “*Why* build an advanced reactor?”
- Tier II will provide mission-level, technology-inclusive guidance for a selected set of missions. The principles used will be adaptable to new missions and new technologies that are not yet developed. This tier answers the question “*What* will an advanced reactor accomplish?”
- Tier III will provide technology-level guidance for a selected set of reactor technologies. These requirements will be detailed requirements taking advantage of experience applicable to specific reactor types, and will answer the question “*How* will an advanced reactor accomplish its goals?”

- Tier IV represents a design-specific bid specification that would expand on the requirements in Tier III, and cover all plant systems, structures and components in detail. ***It is currently not within the envisioned scope of the ORD to go to this level of detail; instead, this bid specification level of detail would remain the domain of developers/vendors and their prospective customers.*** Under this paradigm, the combination of the higher-level ORD (Tiers I – III) and the design specific Tier IV level requirements would comprise a complete requirements document for a prospective owner-operator.

4.1 Executive Summary

The ORD should begin with an Executive Summary that discusses the document’s purpose, flexibility, maturity, benefits, and limitations.

4.2 Tier I: Introduction and Policy Statements

Tier I should provide an introduction to the ORD, including background history, scope, purpose, intended audience, and important definitions. Tier I should provide the policy statements and aspirations for advanced reactors, and thereby should guide and shape the development of lower tiers—Tiers II and III. Each section in Tier I of the ORD is discussed below:

- The “Background” section of the ORD will discuss how future energy markets are expected to require more flexible generation sources that are generally capable of producing “energy on demand” with high reliability and without significant operating restrictions. This section will also include a reference to the Nuclear Promise initiative, and will explain, in easily accessible terms, the potential benefits of expanded nuclear power and, specifically, advanced reactors.
- The “Scope” section of the ORD will briefly introduce the breadth, depth, and limitations of the ORD’s applicability. The scope will be defined to broadly include advanced reactors, and to specifically include the missions and technology classes discussed in Tier II and Tier III, respectively.
- The “Purpose” section of the ORD will include guidance for how someone involved with advanced reactors can benefit from the ORD and how readers with different goals should navigate through the document. The purpose of the ORD will be modified from the corresponding section of the URD so that general tone, language, and context remain the same. This will make it easier for ORD users who are familiar with the current URD to understand the goals of the ORD. It will also make it clear how the two documents differ, and how they are alike.
- An “Intended Audience” section will briefly acknowledge that the focus is meeting the need of owners, operators, and reactor project decision-makers. The discussion will point out that others may benefit, such as regulators at all levels, investors, standard development organizations, etc.
- A “Definitions” section will be included so that important terms may be clearly defined for their use in the ORD. Appendix A includes a partial list of definitions suggested by this study. This list is not final, and may differ significantly from the definitions provided in the ORD.

- Next, a “Policy Statements” section will express what is desired from an advanced reactor without specifying a particular mission or reactor type. The idea of having overarching policy statements in Tier I of the ORD is inherited from the URD, as are many of the statements themselves, to maintain consistency and pedigree. The policy statements will communicate priorities to a vendor so that, even if specific requirements are not dictated, the vendor understands what the owner-operator is seeking.
- Tier I should also include an “Aspirational Goals” section that sets desired ambitious goals for advanced reactors to achieve. The policy statements are general characteristics or philosophies which advanced reactors should embody, whereas the aspirations are specific characteristics or features that should be an important consideration for any advanced reactor, also providing the reader with a better understanding of the types of advantages advanced reactors hope to achieve. 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, aspirations can and should be viewed as sources for new policies and requirements as technologies and business cases mature.

Tier I will be located immediately after the Executive Summary, as it contains general guidance that pertains to all missions and technologies discussed in the lower tiers. An individual using the document should be able to read Tier I and know what advanced reactors as a whole should be able to accomplish.

4.3 Tier II: Mission

After the guidance generally applicable to advanced reactors, the ORD will then provide guidance applicable to satisfying specific missions through which a reactor may meet a market need. Tier II will include the basic attributes that any reactor must satisfy in order to mitigate and retire the risks involved with developing and deploying an advanced nuclear technology. The attributes are: safety, performance, economics, implementation, and security & non-proliferation. Each mission-level requirement will be linked to one or more of these attributes. This means that each requirement will move the generic reactor closer to satisfying one or more of the attributes. Tier II will begin with an introduction to these attributes to provide clear definitions of each, and to give the user sufficient context on how the attributes drive the purpose and direction of the requirements. These attributes are discussed more in Section 5 of this study.

Tier II contains requirements that are mission-centric. There will be two levels of Tier II requirements: mission-independent requirements and mission-dependent requirements. Mission-independent requirements are those necessary to satisfying any mission. These requirements are differentiated from Tier I policy statements because they are not overarching themes, but actual specifications. Mission-dependent requirements are those necessary to satisfying a particular mission, but may not be applicable to all reactors satisfying a different mission. Tier II mission-dependent requirements will be separated by mission, so that all requirements for one mission are located in a single section of the ORD.

Figure 4-2 illustrates the notional organization of Tier II and gives two examples of how a Tier II requirement may be classified. “Example 1” shows a mission-dependent requirement that only applies to reactors serving the “Hydrogen Production” mission. “Safety” and “Security/Non-proliferation” are both tagged in the requirement, as the requirement helps satisfy both attributes.

“Example 2” shows a mission-independent requirement that helps satisfy the “Economics” attribute.

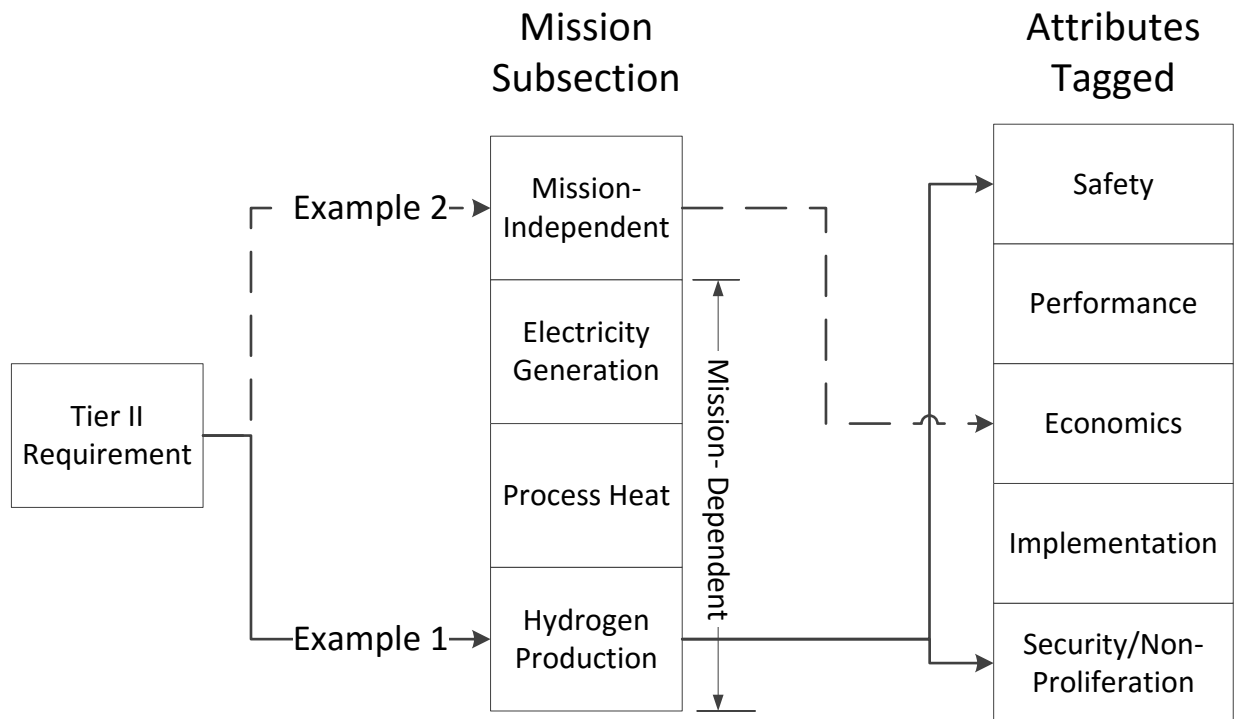


Figure 4-2
Notional organization of ORD Tier II.

4.4 Tier III: Technology

After providing mission-centric guidance, the ORD will then provide technology-centric guidance in Tier III. Because the ORD is meant to be technology-inclusive and non-restrictive in terms of design, Tier III is not intended to be a comprehensive set of requirements. The purpose of Tier III is to inform decision making, to exclude impractical and infeasible designs, and provide basic direction for how a specific technology should satisfy the requirements listed in Tiers I and II. It is assumed that the ORD user will have a basic knowledge of the technologies discussed in Tier III, as the fundamental operating principles behind each technology class will not be included.

Similar to Tier II, there will be two levels of Tier III requirements: technology-independent requirements and technology-dependent requirements. Technology-independent requirements are those that regard physical systems and components, but are applicable to all technologies. Technology-dependent requirements are specific to a particular technology class. Tier III technology-dependent requirements will be separated by technology class, so that all requirements for one technology are located in a single section of the ORD.

Tier III will also specify the missions that each technology may realistically serve. This information is likewise provided (grouped by mission) in Tier II; however, it is convenient for the user to have the same information regrouped by technology in Tier III.

An effective numbering system for the sections and requirements in the ORD should be identified based on existing models and examples such as the NRC’s *Standard Review Plan* (NUREG-0800) [8]. This numbering scheme would make it easy for owner-operators or vendors to locate a requirement or set of requirements in the document.

An individual using the document should be able to read Tier III for a specific technology class and know what a reactor of that type must be able to accomplish in order to serve the missions for which it is applicable.

4.5 ORD Hierarchy and Relationship among Tiers

Figure 4-3 illustrates the relationship among tiers and function of the associated hierarchy using a file-folder analogy for a specific example of where a prospective owner-operator is considering an advanced reactor solution to a combined heat and power application for two distinct technology classes, a sodium-cooled fast reactor (SFR) and a gas-cooled fast reactors (GFR). In principle, an interactive software-based ORD could self-assemble a tailored ORD for a user specified mission – technology combination.

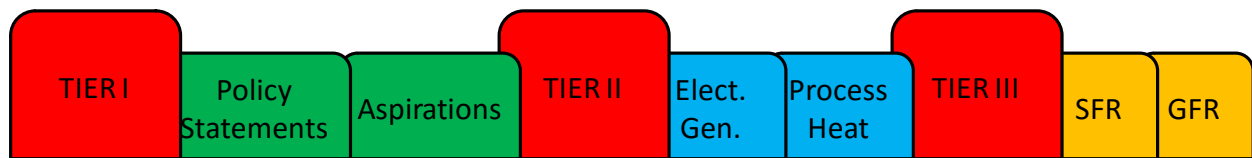


Figure 4-3
File-folder analogy for ORD hierarchy and relationship among tiers and content.

4.6 Comparison of the Notional ORD Structure to the EPRI URD Structure

The ORD tier structure discussed above is modified from the tiered structure of the URD. Because the URD is primarily focused on one reactor technology class, LWRs, and one mission, electricity generation, many of the high-level requirements contained in the URD will likely translate to lower-level requirements in the ORD, which will accommodate a broader set of reactor missions and technologies.


Table 4-1 presents a comparison between the tiers of the two documents, with load following requirements included in the right-most column to illustrate an example of the differences. Load following is a subset of certain missions, including electricity generation, as discussed in more detail in Section 5 of this study.

4.7 Use of the ORD

The purpose of this section of the scoping study is to provide examples of how different types of stakeholders may use the ORD to meet their individual needs. These examples are intended to provide conceptual examples of how the ORD could be used by owner-operators and developers/vendors. The ORD will have a number of different audiences, including utilities and other owner-operators, reactor technology developers and vendors, regulators, investors, policy-makers and the general public.

The following discussion illustrates conceptually how these stakeholders may interact with the ORD.

Table 4-1
Mapping of conceptual ORD structure to URD for a load following example.

Level of Detail	URD	ORD	Requirement
Generic  Highly detailed	Tier 0 – Executive Summary	Executive Summary	--
	--	Tier 1 – Intro. And Policy Statements	Economics, Innovative tech., Design Margin
	smlWR Guiding Principles	Tier 2 – Mission Attributes	Efficient, effective grid in all market conditions
	Tier 1 – Overall Requirements AND Tier 2 – Specific Requirements		Cyclic load conditions that must be supported
	Tier 2 – Specific Requirements	Tier 3 – Technology Specific Requirements	Transient temp limits, managing reactivity transients, etc.
Bid Specification (Not Included in ORD)		Ramp rates, load reject ride-through	

4.7.1 Owner-Operators

Figure 4-4 provides a conceptual example of a prospective owner-operator’s progression through the ORD. Since the ORD is primarily a document for owner-operators, the tiers are ordered to follow an owner-operator’s decision making process. Dashed boxes represent potential missions that may be identified and added to the ORD in the future.

Conceptually, the owner-operator begins with Tier I of the document, using the policy statements and aspirations to gain an overall appreciation for the objectives of advanced nuclear technologies, and the philosophies used to achieve those objectives. The owner-operator then moves to Tier II to obtain the requirements broadly applicable to all missions, and those applicable to the specific missions the owner-operator is interested in (electricity generation and actinide burning). The owner-operator then determines which technologies are viable to satisfying both missions under consideration, and moves to Tier III with these technologies in mind. Tier III provides the owner-operator with technology requirements broadly applicable to all technologies, and those applicable to the specific technologies of interest (for example, the sodium-cooled fast reactor and molten salt reactor technology classes). The owner-operator primarily uses the Tier III requirements to assist communication with the vendor.

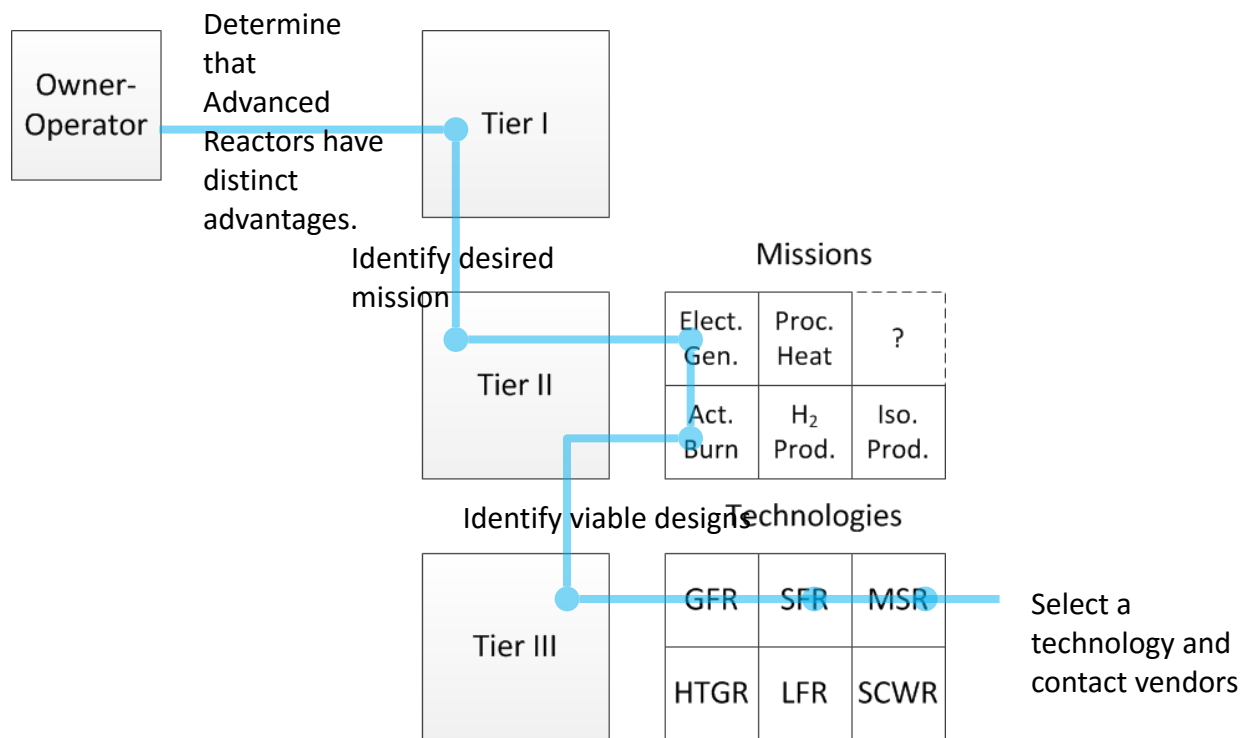


Figure 4-4
Illustration of owner-operator use of the ORD.

After using the document, the owner-operator should:

- gain a high-level perspective on the advantages to be gained with advanced reactor technology;
- be able to make an informed decision on what technology class can best serve the desired mission(s) under the owner-operator's unique circumstances;
- know the factors that must be taken into consideration during the entirety of the process; and
- understand the trade-offs associated with the selection of a specific technology.

4.7.2 Developers and Vendors

Because of their different objectives, developers and vendors will likely apply the ORD differently than an owner-operator. For a reactor vendor (or developer), the ORD can serve as a communication and interface tool to inform design and development with owner-operator expectations and needs. One desirable outcome from ORD use would be a more streamlined design process that provides alignment with customer expectations and needs earlier with reduced iteration and rework. After using the document, the vendor should:

- have an appreciation for the needs and desires of the potential customer,
- know the principles and philosophies that should be incorporated into the design of an advanced reactor,

- be aware of the limitations involved in designing a specific reactor type to serve one or more specific missions,
- have a framework upon which to efficiently respond to a bid solicitation,
- identify gaps where: practical limitations of design may prove challenging for satisfying owner-operator requirements; existing design concepts need to be revised to meet owner-operator needs; and communications between vendor and buyer may be needed for resolution.

Full implementation of the ORD by owner-operators and/or vendors would see integration of the higher level ORD and more detailed design-specific requirements developed by vendors or buyers, as depicted in Figure 4-5. Together, the combination of the ORD and design-specific requirements would comprise the functional equivalent of the URD.

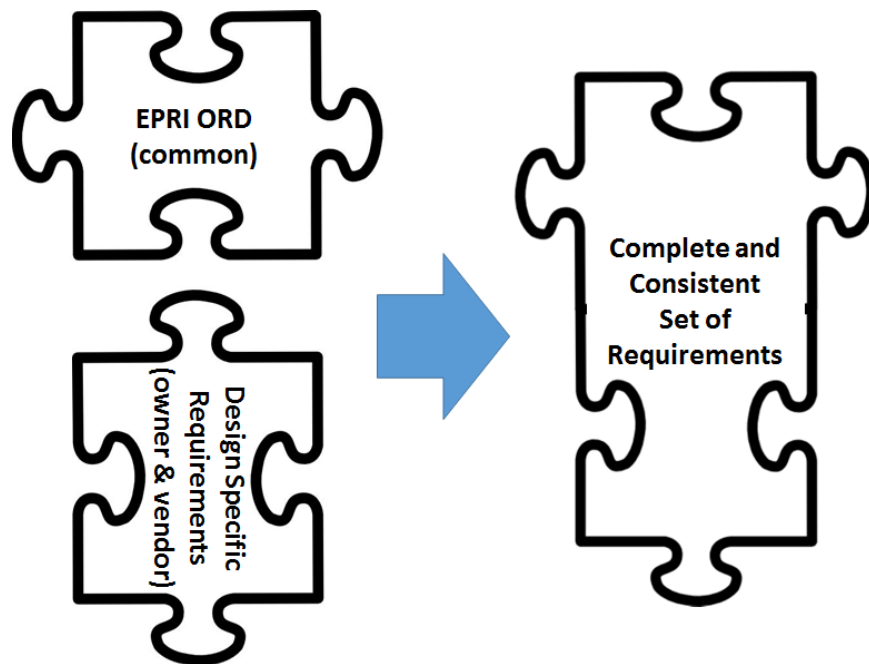


Figure 4-5
Vision for integration of high-level ORD with more detailed buyer (owner-operator) and vendor specifications and requirements to form a complete set of requirements.

4.7.3 Other Stakeholders

Policymakers, members of the public, regulators, and other interested parties will likely be most interested in Tiers I and II of the ORD. Since some of these users may not have an extensive knowledge of nuclear technologies and markets, these tiers should provide all users with necessary introductory information and a high-level overview of what advanced reactor technologies hope to accomplish. Accordingly, Tiers I and II should serve as a valuable communication tool to signal to a diverse set of stakeholders:

- the added capabilities provided by the adoption of advanced reactors;

- the methods by which developers, vendors, and owner-operators intend to address stakeholder issues and concerns; and
- commitments to safety, reliability, economics, environmental stewardship, and other local and national objectives.

5

PROPOSED ORD CONTENT

This section identifies some of the proposed content of the ORD, in terms of the policy statements, aspirations, attributes, missions, and technologies to be incorporated into the document. This section also discusses a proposed three-column structure for the Tier II and Tier III requirements of the ORD.

5.1 Tier I - Policy Statements

The ORD policy statements will be cross-cutting across missions and technologies. Kept high level, they will be useful for multiple audiences, especially those without detailed knowledge of nuclear technology. To help accomplish this, the ORD should clearly illustrate and explain attributes and features that are supported by the policy statements so that users can see the continuity between high-level policy statements and the ultimate advanced reactor design.

The policy statements should be carefully reviewed and vetted during the writing of the ORD. Each tier is meant to inform the lower tiers, so that the existence of a lower level requirement stemming from a higher tier requirement helps validate the appropriateness of the higher level requirement. If a policy statement in Tier I does not have any Tier II requirements that stem from it, the policy statement may need to be removed. This iterative validation process may result in final policy statements that are different from those presented in this scoping study.

The policy statements in the URD were reviewed for applicability to the ORD. Below is a list of proposed policy statements to be included in Tier I of the ORD. Many of these statements are adapted from the URD, and others are unique to the ORD. ORD writers may find it appropriate to modify this list.

1. Simplification – the design should employ passive means for plant stabilization and cooling during abnormal and accident transients and should minimize the number of components and systems to reduce complexity of operation and to reduce costs. *This policy statement is adapted from the URD.*
2. Flexibility – the design should be sufficiently robust to support a wide range of needs and desires with regards to fuel cycle, mission, and siting. *This policy statement is original to the ORD.*
3. Sustainability - a means of ensuring a long term (at least half of plant design life) price managed source of suitable fuel shall be offered. A means and cost for ensuring the availability of scarce materials with limited access shall be identified. *This policy statement is original to the ORD.*
4. Design Margin – designs should provide enhanced margins to failure of fission product barriers compared to current reactors. These enhancements should provide greater operational flexibility and allowance to address emergent problems found following completion of design. *This policy statement is adapted from the URD.*

5. Human Factors – human-machine interfaces for operation shall be simple and intuitive, be consistent across all system displays, and consider the flexibility to implement remote or multi-unit operation where permitted by regulations. *This policy statement is adapted from the URD.*
6. Regulatory Predictability – the design will address current applicable regulatory expectations and provide, at a minimum, equivalent safety provisions appropriate to the technology in order to reduce licensing risk. Some design aspects may fall outside current regulatory envelopes but are worth pursuing due to the benefits provided by advanced reactor properties and characteristics; these issues should be identified for their potential impact on regulatory risk. *This policy statement is modified from the URD “Regulatory Stabilization” policy. “Regulatory Stabilization” is not used due to its infeasibility in the foreseeable future.*
7. Plant Standardization – in order to leverage design effort, facilitate licensing, distribute support costs, and benefit from operating experience, successive plants should be standardized to the extent feasible. However, standardization should be balanced against the benefits on innovation. Standardized designs should not rely on specific components from specific suppliers, but should be flexible enough to support variety in sourcing materials and components, where possible. *This policy statement is adapted from the URD.*
8. Innovation and Proven Technology – innovative features will be used where justified to meet the mission but will be demonstrated where necessary prior to commercial deployment in order to reduce licensing and investment risk. Otherwise, technology should have been proven in similar applications, or qualified by a proven method. Appropriate measures should be taken commensurate with the accumulated operating experience of each new technology. The long time horizon for fuel and materials qualification is a particular concern. *This policy statement is modified from the URD “Use of Proven Technology” policy. “Innovation” is added to emphasize the philosophical departure of the ORD statement, applied to advanced reactors, from the URD statement, applied to LWRs. Advanced reactors are by nature unproven technologies, so the ORD statement applies “Proven Technologies” to low-level components (pumps, valves, materials, etc.) to maintain the pedigree of the design, while still allowing the innovation indicative of advanced technology at the higher levels of the design.*
9. Maintainability – plant arrangements should accommodate personnel access for maintenance and transfer routes for replacement of major components without removal of major structural components. Design of systems, structures, and components should consider inspectability, testability, and obsolescence. All health and safety hazards to personnel, including radiological exposure, should be considered. For instance, components and systems requiring frequent maintenance should be located in low-dose areas of the plant. *This policy statement is adapted from the URD.*
10. Waste and Spent Fuel Management – the volume of restricted waste streams (for example, greater than Class C waste) should be minimized and storage of them shall be consistent with regulatory requirements. Sufficient capacity for storage on-site of all spent fuel generated over the plant life should be provided, as necessary to support the

selected fuel cycle. The design should not assume reliance on any outside entity taking possession of spent fuel to allow for continued operation of the plant. *This policy statement is original to the ORD.*

11. Constructability and Decommissioning – the design should consider manufacturability, transportability, and efficiency and timeliness of construction and facilitate eventual dismantlement and site remediation. *This policy statement is modified from the URD “Constructability” policy. “Decommissioning” is added to emphasize that the design should consider the entire life-cycle of the plant.*
12. Quality Assurance – design, development, construction, and maintenance shall be performed in accordance with all applicable quality program requirements, including configuration management, training, etc. *This policy statement is adapted from the URD.*
13. Economics – the design should be competitive 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 practices for capital, operating, maintenance, and fuel cost estimating. Lifetime costs should be considered. Tradeoffs affecting competitiveness should be identified. Potential for major societal changes (for example, cyber security) should be addressed. *This policy statement is adapted from the URD.*
14. Threat Protection – protection against internal and external physical threats that could credibly challenge integrity of fission product barriers shall be provided in a manner that does not detract from safety and minimizes cost over plant life. Such considerations should 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. *This policy statement is modified from the URD “Sabotage Protection” policy. “Threat Protection” is used instead to broadly emphasize the possibilities of many different types of threats.*
15. Investment Protection – Plants should have features in place to assure that over the lifetime of the plant, investments in the plant receive a return that is worth making the initial investment. *This policy statement is original to the ORD.*
16. Good neighbor – the plant shall provide an overall benefit to the surrounding community through protection of the environment, while providing a dependable source of economic well-being. The design and siting of the plant should consider the needs and objectives (economic, social, etc.) specific to the community in which the plant is deployed. *This policy statement is adapted from the URD.*

5.2 Tier I – Aspirational Goals

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

Providing space within the ORD for declaration of bold aspirations is intended to motivate a raising of the bar for advanced reactor design without adversely constraining commercialization

efforts. It is hoped that including such a wish list can provide signals to developers, vendors, regulators, and other stakeholders that may not be otherwise documented and communicated. Below is a list of aspirational goals identified over the course of two workshops advisors that could be included in Tier I of the ORD:

- Low/No Emergency Planning Zone (EPZ) – The EPZ around the plant could be limited to a much smaller area than what is possible with current reactors. The ultimate goal is for the EPZ to be limited to the site boundary plant itself and to effectively disappear.
- Reduced Staffing – Plants could be designed to operate with staffing that is significantly reduced relative to current plants. Achieving this goal will require addressing a number of key issues including security and non-proliferation while also ensuring safety margins are maintained.
- Dry Cooling – Although generally too expensive in the past, dry cooling has become more attractive for use in water scarce locales and even where water is abundant but its use for cooling is restricted. Plants which efficiently utilize dry cooling as the normal heat sink as opposed to requiring service water flows would have inherent benefits to many potential customers.
- Closed Fuel Cycle – Plants could be designed to operate on a closed fuel cycle, or specialized plants could be built to use spent fuel from open-cycle plants as fuel, effectively closing the fuel cycle. However, this may make the design more vulnerable to political or economic decisions outside the control of owner-operators.
- 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 and significantly alter the economics. Regulatory and plant performance concerns including maintenance and inspection will need to be appropriately addressed.
- “Walk Away” Safety – Using passive safety features, plants could be designed so that the period of time in which the plant can remain safe after an accident without operator action or off-site electric power is indefinite. No operator action or off-site power is required for the plant to safely shut down and remain safe post-accident. Because “indefinite” cannot be objectively demonstrated, a time requirement should be specified.
- Reduced Inspection, Testing, Analysis, and Compliance Burden – Technology attributes, design features, and operations and maintenance approaches should be achievable to achieve meaningful reductions in burdens and increased regulatory efficiency.
- Product Flexibility – Plants will be capable of supplying high-grade heat for different processes, or some of the electrical energy output could be redirected for other processes (for example, hydrogen production or desalinization)
- Scalability – The advanced reactor designs will provide the owner-operator with another degree of flexibility in terms of how, when, and where new units are constructed and operated.

5.3 Tier II - Attributes

Tier II requirements in the ORD are categorized by attribute. The following five attributes should be satisfied for each mission discussed in Tier II in order for the plant to mitigate risk:

1. Safety – Requirements that satisfy this attribute mitigate any risk the plant may present to the health and safety of plant personnel, the local community, the environment, and society as a whole.
2. Performance – This attribute refers to 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 plant to perform its mission. For example, an electricity generating plant should reduce the risk of causing blackouts or brownouts in the areas it services by implementing requirements that support performance.
3. Economics – This attribute refers to the plant’s ability to provide a predictable return on investment for the investors by providing reliable operation within controllable budgets and/or state utility commissions to justify its existence. Requirements that satisfy this attribute mitigate the economic risks for all stakeholders, from the investors who receive profits, to the plant personnel who receive salaries. A sufficiently robust safety case, for example, could substantially reduce the economic uncertainty and impact associated with costly investments required to implement plant upgrades to structures, systems and components following events like the Three Mile Island and Fukushima Daiichi accidents.
4. Implementation – This attribute refers to the implementation of the plant’s entire life-cycle. Requirements that satisfy this attribute mitigate the economic and scheduling risks associated with the planning, design, construction, licensing, operation, maintenance, and decommissioning of the plant.
5. Security & Non-Proliferation – This attribute refers to the plant’s ability to prevent the loss of control of fissile and/or radiological material from plant, either through intentional or unintentional means. Requirements that satisfy this attribute mitigate the risk of releasing radiological material in a plant accident, and/or the risk of bad actors obtaining radiological material from the plant. *Because this attribute combines two related but distinct concepts of physical protection and support for non-proliferation objectives, there may be some segregation between the two for specific requirements. It was determined that there is enough overlap to justify the merger; however, specific requirements that apply to one or the other separately should acknowledge the division.*

5.4 Tier II - Missions

A future, more mature version of the ORD should contain a comprehensive set of missions for nuclear reactors. Below is a list of missions that merit inclusion in the first version of the ORD. Other missions may be added to this list, as it is not yet comprehensive, and the missions listed below may not initially be fully developed. As the technology develops, previously unconsidered markets and missions may emerge.

- Electricity Generation – This mission represents the most common commercial application of nuclear energy and will be primary focus for developing the initial draft of the ORD given decades of utility experience and well-defined markets.
- Process Heat – This mission refers to the use of reactor heat to accommodate processes of various types, such as chemical reactions, manufacturing, and stream production. Enhanced oil recovery is one market for stream production that may be of particular interest.
- Hydrogen Production – This mission refers to the use of reactor thermal energy to generate hydrogen using a number of processes and feedstocks. Hydrogen production can be achieved indirectly using electricity driven electrolysis or directly using high quality process heat.
- Desalination – This mission refers to the use of reactor thermal energy to remove dissolved minerals from saline surface and ground waters to yield fresh water suitable for drinking, irrigation and other uses. Desalination can be accomplished indirectly using electricity and reverse osmosis or directly using vacuum distillation and low temperature heat available from nuclear and other thermal plants.
- Actinide Burning – This mission refers to the irradiation of long-lived, heat generating actinide products for waste management and disposal benefits. Generally, this mission would be combined with other missions.
- Radioisotope Production – 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 industry use.

Load following is an operational mode that conceivably supports more than one mission such as electricity generation and process heat, where a particular plant output can be adjusted to meet demand. This type of reactor operation is opposed to baseload operation, where the plant output is constant. There are enough unique demands relating to ramp-rates and thermal inertia that justify load following as a unique sub-set of certain missions. There are also many ways of accomplishing load following. For electricity generation for example, the reactor heat output may be changed to match market demand, some of the electrical energy output could be redirected for other processes (for example, hydrogen production or desalinization) or the fraction of steam sent to the main turbine for conversion to electricity could be adjusted while maintaining the same reactor output. The latter option could use the excess steam to accomplish a secondary mission. The ORD should address matters concerning load following and incorporate such considerations into requirements for multiple missions.

5.5 Tier III - Technologies

As previously discussed, Tier I and Tier II requirements in the ORD will be completely independent of the chosen technology. However, since Tier III is at the technology level, it is necessary that it limit the specific technology classes discussed. The initial draft of the ORD will consider the reactor technologies in Table 5-1 as a starting point for its Tier III requirements. The list is organized by coolant type, as illustrated earlier in Figure 3-1.

Table 5-1
Four reactor design classes by coolant and seven prominent advanced reactor concepts based on the Generation IV International Forum's recognized technology categories.

Coolant Class	Coolant	Reactor Concept	Outlet Temperature (°C)	Pressure	Neutron Spectrum
Water	Water	Supercritical-water-cooled reactor (SCWR)	500 - 625	Very High	Fast or Thermal
Gas	Helium	Very-high-temperature reactor (VHTR)	700 - 1000	High	Thermal
	Helium	Gas-cooled fast reactor (GFR)	850	High	Fast
Molten salt	Chloride and fluoride salts	Molten salt reactor (MSR) <i>liquid-fueled variant</i>	700 - 1000	Low	Fast or Thermal
	Fluoride salts	Fluoride-cooled high temperature reactor (FHR) <i>solid-fueled variant</i>	700 - 1000	Low	Thermal
Liquid metal	Sodium (metal)	Sodium-cooled fast reactor (SFR)	500 - 550	Low	Fast
	Pb (metal) or Pb-Bi (eutectic)	Lead-cooled fast reactor (LFR)	500 - 800	Low	Fast

5.6 Structure of Requirements

The low-level requirements in the URD (Rev. 13) have a two-column structure: the first column contains the actual requirement, and the second column contains the basis/rationale for the requirement. In other words, the first column presents a rule or specification that shall be followed, and the second column explains *why*. Figure 5-1 below provides Requirement 2.3.1.1 from Tier II of the URD (Rev. 13) as an example [1].

2.3.1.1

<u>Requirement:</u>	<u>Rationale:</u>
<p>The Plant Designer shall define and analyze the design basis events discussed in Section 2.3.2 that are to be accommodated in the plant design. These ALWR design basis analyses shall be used to show that:</p> <ol style="list-style-type: none"><li data-bbox="393 407 805 453">1. Licensing design basis analyses meet NRC criteria;<li data-bbox="393 470 805 512">2. Design features are adequate to protect the Plant Owner's investment.	<p>This requirement helps establish a consistent approach to the process for identification of ALWR design basis events. These events in conjunction with the performance design basis of Section 3, and the structural design bases of Section 4, govern the design of the entire plant and, as such, are specifically applied in later chapters in order to verify:</p> <ul style="list-style-type: none"><li data-bbox="821 495 1229 583">• The functional adequacy of major plant systems and components, including the sizing and the number of cycles of operation;<li data-bbox="821 590 1229 657">• The structural adequacy of plant systems, components and structures, including reactor vessel internals;<li data-bbox="821 663 1229 709">• The operational adequacy of plant procedures.

Figure 5-1
Example URD requirement from the URD Rev. 13 [Copyright © 2014 EPRI]

The proposed structure for the Tier II and Tier III requirements in the ORD is to use the same two columns (but generally using “should” language), and add a third for “Alignment”. The “Alignment” column specifies how the requirement relates to important contexts such as regulations and industry standards, how regulations and standards may need to evolve to accommodate or address the requirement (and advanced reactors in general), and any significant existing operating experience related to the requirement.

Tier II and Tier III requirements in the ORD will utilize a system of “tagging” items from various locations of the document to sort requirements into finer categories. Each Tier II requirement will be tagged with one or more attributes, which the requirement helps satisfy. For example, the requirement “Design should [accomplish X, Y, and/or Z] (Performance)” is specifically concerned with the performance of the plant.

Also, if a Tier III requirement only applies to a technology serving particular missions, the missions will be tagged in the requirement. If there are no missions tagged in a Tier III requirement, then the requirement is generally applicable to the technology, regardless of mission. For example, the requirement “A sodium fast reactor should [accomplish X, Y, and/or Z]” would be generally applicable to sodium fast reactors, whereas the requirement “A sodium fast reactor should [accomplish X, Y, and/or Z] (electricity generation or process heat)” would be applicable only to sodium fast reactors satisfying either the electricity generation or process heat missions.

A numbering scheme for the requirements in the ORD derived from existing industry practice should be considered. One example is the structure employed in the NRC’s Standard Review Plan, NUREG-0800 [8]. In Appendix B, Tables B-1 and B-2 provide conceptual examples of ORD Tier II and Tier III requirements, respectively, to illustrate the proposed three-column format and structure.

6

CONCLUSIONS AND RECOMMENDATIONS

Based on input received during the two stakeholder meetings, the conclusion of this scoping study is that the creation of the ORD represents a feasible, timely and worthwhile endeavor. The effort should be led by EPRI on behalf of the advanced reactor enterprise, with frequent input and feedback from industry and other key stakeholders.

This scoping study provides the following suggested characteristics, structure, and content for the ORD:

- A high-level, technology-inclusive focus
- A wording for requirements, which generally favors permissive “should” statements over more prescriptive and limiting “shall” statements
- An inclusive, innovation-friendly scope encompassing a broad range of missions and technologies
- An emphasis on incorporating lessons learned from operating and decommissioned reactors
- Thorough mining of the URD document to use/adapt any applicable requirements, with a special emphasis on the applicable, broader ORD tiers
- An emphasis on incorporating feedback from developers, vendors, potential owner-operators and other key stakeholders
- Consideration of interactive formats using electronic media for enhancing the user interface and overall accessibility and value
- A three-tier structure for organizing requirements
- A list of Tier I policy statements and aspirations
- A list of Tier II attributes
- A list of missions to include in Tier II
- A list of technologies to include in Tier III
- A three-column structure for describing each requirement, the associated technical basis and the alignment within other contexts
- A system of tagging requirements with applicable items from other locations in the document
- A numbering scheme for the requirements

The initial version of the ORD should consist of the following:

- An executive summary
- Important definitions
- A complete list of Tier I policy statements and aspirations
- A comprehensive set of Tier II requirements for the “Electricity Generation” mission
- A partial set of Tier II requirements for other selected missions
- Identified missions for further development
- A partial set of Tier III requirements for more mature advanced reactor concepts (Tier III requirements that are specific to certain missions should be limited to electricity generation)
- A prescribed method for receiving and evaluating stakeholder-suggested revisions
- A clear approach and protocol for revision

The development of the ORD may consider the recommendations contained in this report but should not be constrained or limited by them. The ORD should be reviewed and updated as needed to include new missions and technologies as operating experience and industry knowledge grow. Appendix C provides a preliminary project plan that outlines a vision and potential path forward for developing and piloting the initial versions of the ORD.

7

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A

DEFINITIONS

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

- ACR: Advanced CANDU Reactor
- AGR: Advanced Gas-cooled Reactor
- BWR: Boiling Water Reactor
- CANDU: Canada Deuterium Uranium reactor
- FHR: Fluoride-cooled High Temperature Reactor
- GCR: Gas-Cooled Reactor
- GFR: Gas-cooled Fast Reactor
- HTGR: High Temperature Gas-cooled Reactor
- LBEFR: Lead-Bismuth-Eutectic-cooled Fast Reactor
- LFR: Lead-cooled Fast Reactor
- LMFR: Liquid Metal cooled Fast Reactor
- LWR: Light Water Reactor
- Magnox: *Magnesium Non-Oxidizing* (a Generation I gas-cooled reactor deployed in the United Kingdom named for the magnesium-aluminum alloy used for fuel cladding)
- MSFR: Molten Salt Fast Reactor
- MSR: Molten Salt Reactor
- PHWR: Pressurized Heavy Water Reactor
- PWR: Pressurized Water Reactor
- SCWR: Supercritical Water Reactor
- SFR: Sodium-cooled Fast Reactor
- UNGG: Uranium Naturel Graphite Gaz reactor (a Generation I gas-cooled reactor deployed primarily in France)
- VHTR: Very High Temperature gas-cooled Reactor

B

EXAMPLE ORD REQUIREMENTS

Tables B-1 and B-2 are included here as illustrations of how ORD requirements could be presented in tabular form with appropriate information, including the technical basis and the context for each. The content of these examples are strictly for illustration only and are not being proposed for the draft ORD.

Table B-1
Example ORD Tier II Requirements.

Requirement	Basis	Alignment
<i>Mission-Independent</i>		
<p>The waste management system and waste forms should allow for on-site storage capacity sufficient to avoid reactor operation impacts over the anticipated economic life of the plant.</p>	<p>History has shown that the assumption of used nuclear fuel removal from commercial nuclear plants have led to unforeseen complications of plant operations and refueling due to accumulation of inventories and the need to implement alternative onsite storage solutions. Loss of full and partial core reserves in spent fuel pools has threatened the ability to refuel and restart LWRs in the United States.</p>	<p>Commercial LWRs store spent 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.</p>
<i>Electricity Generation</i>		
<p>The design should limit off-site consequences in the event of design basis and severe accidents. Attributes: Safety</p>	<p>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.</p>	<p>Existing metrics for off-site consequences should be valid independent of reactor type. Some advanced reactors may achieve greater appeal by providing further enhanced safety performance (for example, reduced or eliminated EPZ).</p>
<p>The design should maintain cooling post-accident with no operator action or off-site power for 14 days. Attributes: Safety</p>	<p>A plant that can retain adequate decay heat removal without operator action will have a stronger safety basis.</p>	<p>The Fukushima-Daiichi accident demonstrated that supporting infrastructure and off-site power may not be available for an extended period of time after an accident.</p>

Example ORD Requirements

Requirement	Basis	Alignment
The first of a kind unit should be competitive with lowest price large scale generating method in the electricity market the owner-operator intends to operate. Attributes: Economics	The number of reactors of a specific type built may be low. Therefore, N th of a kind efficiencies cannot be depended on for economic competitiveness.	Consistent with utility desires and expectations.
Vendor should be able to define construction time and deployment time within ± X% accuracy. Attributes: Implementation	Capital costs typically define the economic case for nuclear reactors. Predictable timelines provide additional confidence that projected costs are accurate.	Consistent with utility desires and expectations.
The design should utilize modular construction to the maximum extent possible. Attributes: Implementation	Modular construction improves the predictability and timeliness of construction.	AP-1000 exemplifies the use of modular construction and is experiencing the benefits of it.

Table B-2
Example ORD Tier III Requirements for SFRs.

Requirement	Basis	Alignment
The design should have an intermediate coolant loop. Missions: All	An intermediate loop is established to ensure that radioactive sodium does not have the potential for exposure to steam or other secondary coolants.	NRC Draft ARDC Criterion 70 requires provision of an intermediate cooling system
The design should control the purity of sodium within specified limits to prevent: plugging of passages, adverse chemical reactions, and to control radionuclide concentrations. Missions: All	Sodium purity is important for preventing the accumulation of activation products, oxides, and other adverse effects.	NRC Draft ARDC Criterion 71 requires sodium purity control. Existing SFR experience has shown this to be an important operational consideration.
The design should keep sodium from freezing. Missions: All	Freezing of sodium has the potential to block coolant flow and induce undesirable stresses on materials and mechanical components.	NRC Draft ARDC Criterion 72 requires provision of sodium heating systems to prevent sodium freezing.

C

PRELIMINARY ORD PROJECT PLAN

A phased development plan is proposed for the Advanced Reactor ORD, through which content will be expanded and deepened based on user interest and needs and the availability of resources. Development of an initial ORD version, “Rev. 0” will build on the recommendations contained in this report (Phase Ia) and proceed according to detailed project plan prepared in Phase Ib (Figure C-1 and Table C-1).

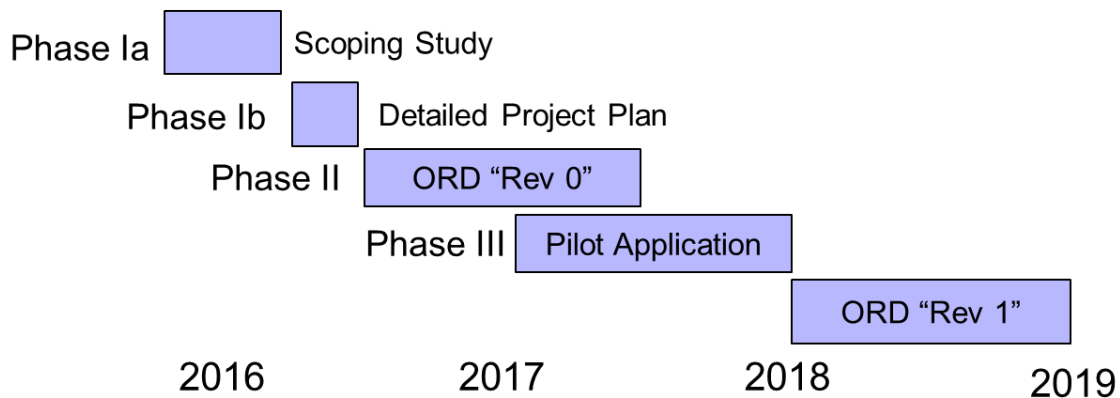


Figure C-1
Proposed ORD development timeline.

Preparation of a working ORD draft is targeted for the Phase II mid-point to allow for concurrent startup of a pilot application project (Phase III) in collaboration with one or more reactor developers/vendors and partner utilities. The project plan objective is to have a functional ORD ready for use in 2018.

Table C-1
Phasing of ORD development schedule.

Phase	Description	Schedule
Ia	Scoping Study	Complete (this report)
Ib	Development of a detailed project plan	October - November 2016 (2 months)
II	Drafting of ORD Rev 0	January 2017 – February 2018 (14 months)
III	Pilot application of ORD Rev 0 in collaboration of one or more advanced reactor developers	October 2017 – September 2018 (12 months; overlapping with Phase II)

The initial drafting effort for the ORD should be limited and realistic in scope to favor timely completion. Further ORD development (for example, Revision 1 and beyond) will be informed by early adoption and use by developers/vendors and utilities.

Figure C-2 depicts this process conceptually, with increasing ORD breadth reflected by the size/area of each box and increasing depth and detail reflected in darkening of color. The ORD is intended to be a proactive forward-looking resource, anticipating future missions, technologies and innovation. Accordingly, opportunities for further ORD expansion, indicated by dashed borders, can be identified and prioritized based on need and resources.

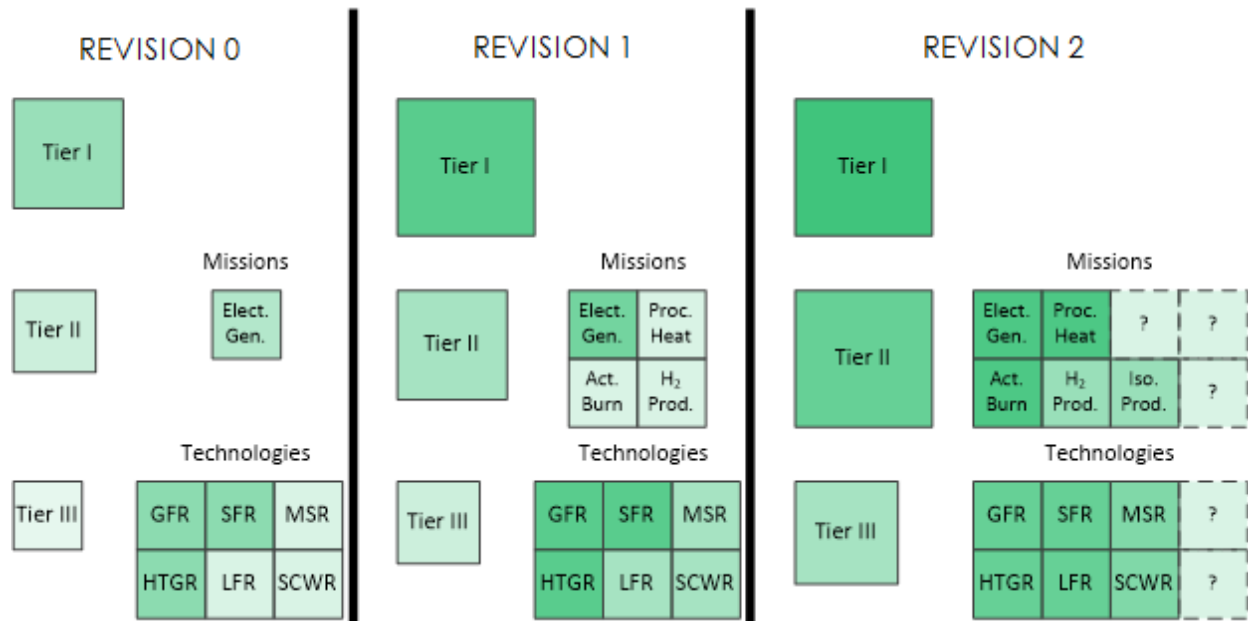


Figure C-2
Phased incremental development of the ORD for the inclusion of additional content corresponding to new missions and technologies as well increasing detail for existing content.

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