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Revision 0

Summary of the Advanced Reactor Design Criteria (ARDC) Phase 1 Activities, Including the Development of the Final Report and the Advanced Reactor Technology Training

Mark R. Holbrook

April 2015

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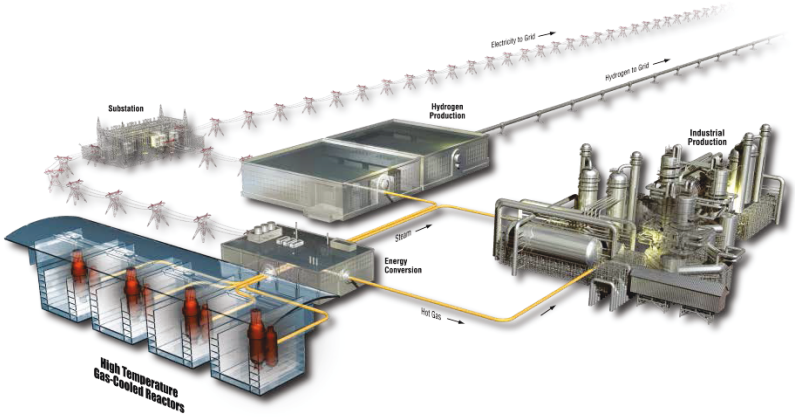

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SUMMARY

This report provides a mid-year summary reflecting the progress and status of development of proposed regulatory design criteria for advanced non-light water reactor designs. These criteria have been designated as Advanced Reactor Design Criteria (ARDC), and they provide guidance to future applicants for addressing the General Design Criteria (GDC) that are currently applied specifically to light water reactor (LWR) designs. The report provides a summary of activities related to the various tasks associated with ARDC development and the subsequent development of example adaptations of ARDC for Sodium Fast Reactor (SFR) and modular High Temperature Gas-cooled Reactor (modular HTGR) designs.

The report summarizes activities associated with Phase 1 of ARDC development tasks and the advanced reactor familiarization training that was provided to the Nuclear Regulatory Commission (NRC) staff. Phase 2 of this effort is currently in progress under the leadership of the NRC.

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FIGURES

ACRONYMS

ARDC	Advanced Reactor Design Criteria
ANL	Argonne National Laboratory
DOE	Department of Energy
GDC	General Design Criteria
HTGR	High Temperature Gas-cooled Reactor
INL	Idaho National Laboratory
LWR	light water reactor
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PDC	principal design criteria
SFR	Sodium Fast Reactor

Summary of the Advanced Reactor Design Criteria (ARDC) Phase 1 Activities, Including the Development of the Final Report and the Advanced Reactor Technology Training

1. Purpose 1

This report provides a mid-year summary reflecting the progress and status of proposed regulatory design criteria for advanced non-light water reactor (LWR) designs. These criteria have been designated as Advanced Reactor Design Criteria (ARDC), and they provide guidance to future applicants for addressing the General Design Criteria (GDC) that are currently applied specifically to LWR designs. The report provides a summary of activities related to the various tasks associated with ARDC development and the subsequent development of example adaptations of ARDC for Sodium Fast Reactor (SFR) and modular High Temperature Gas-cooled Reactor (modular HTGR) designs.

2. Background

Nuclear Regulatory Commission (NRC) requirements for reactor licensing and deployment include the requirement in 10 CFR 50.34 to establish principal design criteria (PDC) derived from the GDC of 10 CFR 50, Appendix A. Since the GDC in Appendix A were created primarily for LWRs, this requirement becomes challenging for future license applicants pursuing advanced (non-LWR) reactor technologies and designs.

During 2012, the Department of Energy (DOE) initiated a Technical Review Panel process to evaluate certain advanced reactor concepts for viable commercial deployment. Early in that process, Technical Review Panel members and advanced reactor designers voiced a need to develop a compatible regulatory framework for advanced non-LWRs to reduce risks and uncertainty to the advanced reactor industry.

The NRC provided "Report to Congress: Advanced Reactor Licensing," dated August 2012, that noted several prospective advanced reactor vendors who identified a need for refined regulatory guidance pertaining specifically to their advanced non-LWR designs. To support this need, DOE and NRC considered approaches for establishing a regulatory framework for advanced non-LWRs. From this, it was agreed that supporting a joint initiative for the development of ARDC for use by advanced reactor designers and license applicants would be an important first step in developing that framework.

3. Objective

The objective of the Advanced Reactor Regulatory Framework Development activity is to create a "technology-neutral" set of ARDC (derived from Appendix A of 10 CFR 50) for advanced non-LWR designs and a technology-specific set of design criteria for SFRs and modular HTGRs (as a supplement to the ARDC) that can be used as guidance by a future license applicant to develop PDC.

4. Scope

The Advanced Reactor Regulatory Framework Development work scope has been developed in two phases; Phase 1 was performed primarily by a DOE and national laboratory team, and involved development of the proposed set of ARDC, including additional development of design-specific criteria. Phase 2 is being performed primarily by NRC and will include the initiation of their regulatory development process, followed by the issuance of regulatory guidance to the industry.

The ARDC development activity considered design attributes and regulatory needs concerning the following advanced reactor technologies: SFRs, Lead Fast Reactors, Gas-cooled Fast Reactors, modular HTGRs, Fluoride High-Temperature Reactors, and Molten Salt Reactors.

5. Summary of Completed ARDC Phase 1 Development Tasks

The Advanced Reactor Regulatory Framework Development is a DOE multi-lab effort (led by the Idaho National Laboratory [INL]) to develop ARDC applicable to multiple advanced reactor technologies. The development team included subject matter experts from INL, Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and a small number of industry consultants that are well informed about the licensing considerations that accompany advanced reactors.

6. Categorize Existing GDC

Using a bottom-up approach to develop the advanced design criteria, the categorization task involved a detailed technology-specific review of the individual LWR-based GDC found in 10 CFR 50, Appendix A. The ARDC team developed a review strategy that categorized each existing criterion according to its applicability to well-understood advanced reactor design types (i.e., SFRs and modular HTGRs). The team established five criteria for classifying existing GDC and assessed the amount of potential modification needed to adapt the criteria to those two advanced designs. See the 2014 status report (CCN 232819, "Completion of Level 3 Milestone for FY-13 SMR Licensing R&D, "Development of Advanced Reactor Design Criteria - Status Report," March 31, 2014) for a summary of the categorization screening.

7. Develop Draft Design Criteria

The next task modified the existing GDC language in an effort to adapt the existing LWR-orientated GDC wording for use by SFR and modular HTGR designs. The team made a decision to develop design-specific wording for SFR and modular HTGR designs and then use the insights gained from this activity to develop more generic ARDC language that, in turn, could be applied to a range of advanced reactor designs. All team members collaborated on development of the draft ARDC language.

Redline/strikeout tables were developed to document the draft design-specific design criteria and ARDC language. Each table included the original GDC language for reference and emphasized suggested adaptation needed to (1) address the SFR or modular HTGR designs and (2) develop the generic ARDC language. Each design criterion adaption included a rationale (with necessary references to supporting documentation) that justified the wording changes, and indicated how the underlying safety basis for the associated GDC is addressed. In addition, insights associated with the other advanced reactor design types (i.e., Lead Fast Reactors, Gas-Cooled Fast Reactors, Fluoride-salt-cooled High-Temperature Reactors, and Molten Salt Reactors) were considered where sufficient design information existed to draw conclusions and further refine the proposed adaptations.

8. Stakeholder Workshops

Once development of the ARDC language and the adapted design-specific design criteria were complete, an industry workshop was held (April 15–16, 2014) in Rockville, MD, with interested external stakeholders (industry, Nuclear Energy Institute, American Nuclear Society Standards steering committee, etc.) to obtain feedback regarding the proposed approach for adapting the existing GDC for use by advanced reactor designs. NRC staff members also attended the workshop as observers. Workshop attendees provided detailed comments on the ARDC language and the design-specific design criteria after the workshop.

The team analyzed the stakeholder feedback obtained after the first stakeholder workshop and used it to revise the ARDC language and the design-specific design criteria as deemed appropriate by the ARDC team. The revised language and design-specific criteria were presented to interested stakeholders during a second industry workshop held July 16–17, 2014, also in Rockville, MD.

9. Completion Status of Phase 1 Tasks

The results of the ARDC team's Phase 1 analysis are contained in INL/EXT-14-31179, "Guidance for Developing Principal Design Criteria for Advanced (Non-Light Water) Reactors," dated December 2014. This report finalized the proposed ARDC language and documented the results of generic and technology-specific design criteria development reflecting the resolution of stakeholder comments and outstanding issues and was developed under PLN-2690, "Idaho National Laboratory Advanced Reactor Technologies Technology Development Office Quality Assurance Plan," Rev. 13, dated March 13, 2015.

The proposed ARDC are intended to provide specific inputs and recommendations to support the NRC staff's issuance of guidance reflecting how developers of the selected advanced reactor technology types could adapt the existing GDC contained in 10 CFR 50, Appendix A, to the development of their respective PDC while retaining the underlying safety principles of the GDC. The relationship among the 10 CFR 50 GDC, the ARDC, the two sets of technology-specific design criteria contained in the report, and the PDC that a future license applicant is required to submit is reflected in Figure 1.

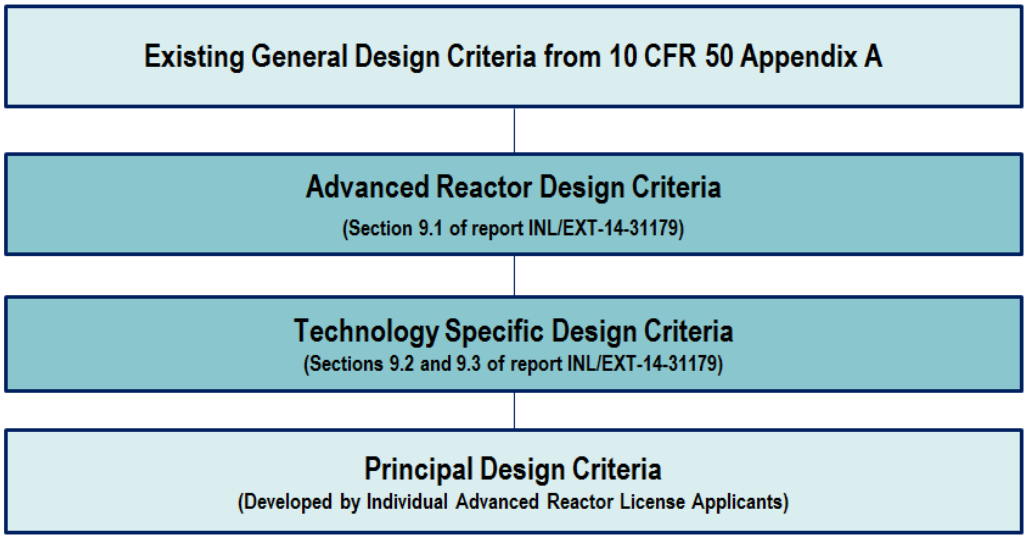

Figure 1. Design criteria relationship.

The structure of report INL/EXT-14-31179 is as follows:

1. Overview
2. Project Organization and Interface
3. Definitions and Assumptions
4. Approach
5. Advanced (Non-LWR) Reactor Design Criteria
6. SFR Design Criteria
7. Modular HTGR Design Criteria
8. References
9. Proposed Design Criteria.

Section 9 is the heart of the report. It includes the proposed ARDC, SFR-specific design criteria, modular HTGR-specific design criteria, and a special table (found in Section 9.4) that compares all of the modified versions of design criteria language to the original GDC.

The relationship among the 10 CFR 50 GDC, the ARDC (Section 9.1 of INL/EXT-14-31179), the two sets of technology-specific design criteria contained in the same report (Sections 9.2 and 9.3), and the PDC that a future license applicant is required to submit for a specific design is reflected in the figure on the next page.

An ARDC table entry (extracted from the table in Section 9.1) is provided below as an example to show how proposed ARDC language was documented by the report, including the associated basis for the proposed changes.

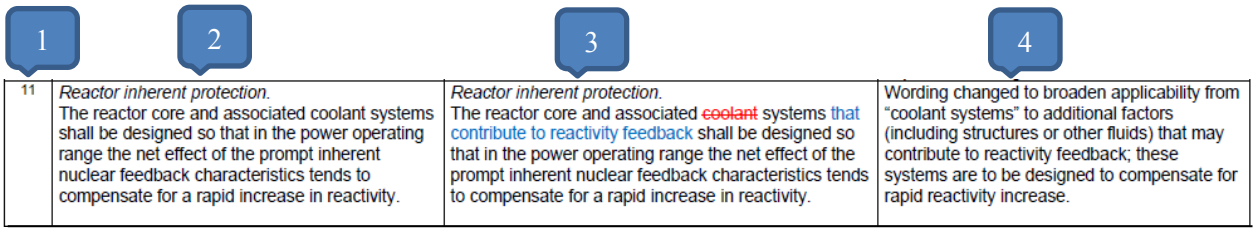

Figure 2. Example table entry (ARDC #11, "Reactor Inherent Protection").

The columns in the ARDC table contain the following types of information:

1. The criterion number.
2. The existing text for the general design criterion as is found in 10 CFR 50, Appendix A.
3. The proposed wording for the corresponding ARDC. If the existing general design criterion text was acceptable for advanced reactor designs, then this cell states "Same as GDC." However, if the existing general design criterion requires modification to adapt it to advanced reactor designs, these changes are indicated by using redline/strikeout to remove unneeded language and blue text to note wording that has been inserted into the original language (as shown by this example).
4. The justifications for any changes made to the proposed ARDC language as compared to the wording of the original general design criterion with a focus on retaining the underlying safety basis of the original criterion.

The design-specific tables found in Section 9.2 and 9.3 generally follow the same content guidelines with the following exceptions:

- Column 2 contains the proposed ARDC language as the reference instead of the existing text from the GDC.
- Column 3 contains the proposed design-specific criteria language. If the design can use the ARDC language unchanged, the cell will state "ARDC with no further SFR-specific (or modular HTGR-specific) clarification provided."

Section 9.4 consists of a table that allows for direct comparison of the ARDC and design-specific design criteria to each other and to the reference general design criterion. Therefore, the table construction differs from the tables found in Sections 9.1 through 9.3. An example from the comparison table in Section 9.4 is provided on the next page, again using ARDC #11.

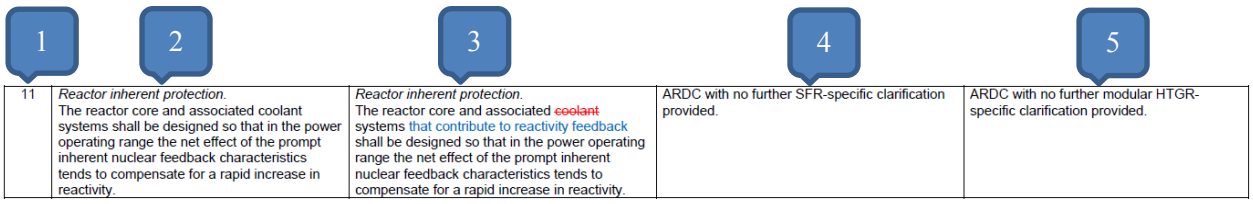

Figure 3. Example design criteria comparison (ARDC #11).

Each column in the ARDC table (and the design-specific Tables 9.2 and 9.3) contain the following types of information:

1. The criterion number.
2. The existing text for the general design criterion as is found in 10 CFR 50, Appendix A.
3. The proposed wording for the corresponding ARDC. The cell content rules are the same as described for item 3 in the previous example.
4. The proposed wording for the corresponding SFR design criteria. The cell content rules are similar to ARDC column 3 with the exception that design-specific wording changes are in reference to the ARDC language, not the GDC language. Therefore, if the SFR design-specific criterion can use the ARDC language unchanged, the cell will state "ARDC with no further SFR-specific clarification provided."
5. The proposed wording for the corresponding modular HTGR design criteria. The cell content rules are similar to ARDC column 3 with the exception that design-specific wording changes are in reference to the ARDC language, not the GDC language. Therefore, if the modular HTGR design-specific criterion can use the ARDC language unchanged, the cell will state "ARDC with no further modular HTGR-specific clarification provided."

The report also includes the identification of new design criteria that are necessary to address specific safety design approaches and attributes of the SFR and modular HTGR technology types. These new criteria are reflected in Sections 9.2 and 9.3 of the report, identified with a numbering scheme that commences at the end of the GDC adaptations proposed for those two technology types.

The report was reviewed by DOE and transmitted to the NRC on December 8, 2014, to begin the second phase of the initiative, which involves NRC's review of the content of the report, initiation of the regulatory review process, and the intended issuance of regulatory guidance.

10. Advanced Reactor Familiarization Training

During February 2015, the ARDC team provided advanced reactor design familiarization training to NRC personnel specifically related to SFR and modular HTGR technologies. The objective was to provide a basic understanding of the two technology types to facilitate development and review of language changes that accompany adaption of LWR-specific GDC to ARDC.

ANL and ORNL subject matter experts presented a 5-hour training course on SFR technologies at NRC headquarters on February 18, 2015. In attendance were approximately 30 NRC and DOE personnel with a small number of additional personnel participating via telephone connection. A focus of the presentation included SFR technology and testing/licensing experiences in the U.S. over the past 60 years and comparisons between a recent DOE-sponsored design (power reactor innovative small module) and a typical pressurized water reactor.

The course outline consisted of:

1. Introduction
2. SFR Technology Overview
3. Past and Present SFR Designs
4. SFR Safety
5. Past SFR Safety Testing Programs
6. U.S. SFR Licensing Experience
7. Factors that Impact Design Criteria for SFRs.

A number of questions were raised by the NRC staff related to potential release paths from the containment and the differences that would occur as compared to an LWR's containment configuration. These questions centered on potential conditions related to the cover gas and the impacts from sodium-water reactions that may occur in a variety of plant locations.

Similar modular HTGR technology training was provided February 25, 2015 by subject matter experts from INL. This training built upon prior HTGR technology training provided to the NRC staff as part of Next Generation Nuclear Plant prelicensing efforts. In attendance were approximately 30 NRC and DOE personnel with about 10 additional personnel participating via telephone connection. The modular HTGR technology training focused on safety characteristics that differ from a typical LWR. These topics included (1) functional containment, (2) particle fuel performance, (3) unique safety considerations related to use of helium, and (4) the very long accident response times associated with modular HTGRs. The course outline consisted of:

1. Modular HTGR Technology Overview
2. Modular HTGR Safety Design Approach
    a. Safety Design Approach
    b. Retention of Radionuclides at Their Source
    c. Control of Heat Generation
    d. Remove Core Heat
    e. Control of Chemical Attack
    f. Functional Containment Design and Performance.
3. Factors that Impact Design Criteria for Modular HTGRs
    a. Functional Containment vs. LWR Containment
    b. New Design Criteria
    c. Modular HTGR Fuel Design Limits
    d. Safety-Related Heat Removal
    e. Safety-Related Power Supply

Modular HTGR-related questions from the NRC staff related to potential release paths from the containment and the differences that would occur as compared to an LWR's containment configuration.

11. Future ARDC Phase 2 Tasks

Phase 2 of the initiative is being managed by the NRC and is expected to involve review of the Phase 1 work products and issuance of regulatory guidance resulting from the review. This process will include resolution of outstanding NRC staff technical questions and comments gathered through the public interaction process. The DOE national laboratory team and industry-licensing consultants will remain available to assist the NRC as requested during Phase 2. NRC has stated that they intend to develop and issue regulatory guidance commensurate with an official NRC staff position with a completion target of the end of calendar year 2016.