PRELIMINARY DRAFT

This draft document is being made publicly available to support a future public meeting on the topic of nuclear power reactor testing needs and prototype plants. This draft document has not been subject to all levels of NRC management review. Accordingly, it is incomplete and may be in error in one or more respects.

The subject matter in this document may be used in a future guidance document on this topic. Accordingly, the NRC will formally notice and request public comments during the guidance development process.

Nuclear Power Reactor Testing Needs and Prototype Plants for Advanced Reactor Designs

What Is the Purpose of This Document?

This document does the following:

- Describe the regulations governing the testing requirements for the licensing, approval, or certification of a proposed standard plant design for advanced reactors.
- Describe the process for determining testing needs to meet the U.S. Nuclear Regulatory Commission's (NRC's) regulatory requirements.
- Clarify when a prototype plant might be needed and how it might differ from the proposed standard plant design.
- Describe licensing strategies and options that include the use of a prototype plant to meet the NRC's testing requirements.

What Types of Facility Licenses Does the NRC Issue?

The NRC is authorized under the Atomic Energy Act of 1954, as amended (AEA), to grant licenses to two types of production and utilization facilities:

(1) a commercial or industrial facility licensed under AEA Section 103, "Commercial Licenses"

(2) a research and development (R&D) facility licensed under AEA Section 104, "Medical Therapy and Research and Development"

All future NRC-licensed commercial nuclear power reactors are to be licensed as utilization facilities under AEA Section 103. This document is directed specifically at nuclear power plants (including prototype plants) that would also be licensed as commercial utilization facilities under AEA Section 103. Pursuant to 10 CFR 50.22, a facility is deemed commercial if more than 50 percent of the annual cost of owning and operating it is devoted to the production of materials, products, or energy for sale or commercial distribution, or to the sale of services other than research and development or education or training.

All future NRC-licensed research and test reactors will be licensed under AEA Section 104(c). Some licensing project plans (which describe the activities needed to achieve permitting, licensing, and/or certification of the design, including design, R&D, testing, application, regulatory review, etc., as applicable) for advanced reactors may include obtaining data from a R&D facility that will be licensed under AEA Section 104(c) prior to proceeding with licensing a commercial plant under AEA Section 103. NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," issued February 1996, contains additional information and guidance on the licensing process for research and test reactors. Data obtained from the operation of a research or test reactor could be used to fulfill the testing requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.43(e) during a subsequent application for a license, approval, or certification for a prototype or commercial reactor under AEA Section 103. An applicant should also be aware that any data obtained using a research and test reactor for this purpose and subsequently used to support a commercial nuclear power plant design would be required to meet the quality assurance requirements set forth in Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50.

What Unique Terminology is Used in this Document?

The terms "prototype plant" and "demonstration reactor" have been used throughout the nuclear industry seemingly interchangeably and have thus confused stakeholders at times. Additionally, the terms "research reactor" and "testing facility" or "test reactor" are sometimes used interchangeably. Each of these terms has a different regulatory or practical meaning, and the definitions below are intended to clarify these terms. This section also describes several different categories of testing to be performed.

Advanced Reactor

The NRC's "Policy Statement on the Regulation of Advanced Reactors," published in the *Federal Register* in October 2008 (73 FR 60612; October 14, 2008), does not specifically define an "advanced" reactor. However, it does establish a set of expectations for advanced reactor designs, including providing at least the same degree of protection of the environment and public health and safety and the common defense and security that is required for current generation light-water reactors (those licensed before 1997); providing enhanced margins of safety; and/or using simplified, inherent, passive, or other innovative means to accomplish their safety and security functions. It also describes several attributes that could assist in establishing the acceptability of a proposed advanced reactor design, and therefore should be considered in advanced designs.

The NRC created its regulations for prototype plants specifically for the licensing of new or innovative design or safety features that are fundamental to advanced reactor designs.

<u>NRC Regulatory Terminology Related to Facility Type</u>

Prototype Plant

The NRC's regulations at 10 CFR 50.2, "Definitions," and 10 CFR 52.1, "Definitions," define a "prototype plant" as a nuclear reactor or power plant that is used to test design features or new safety features, such as the testing required under 10 CFR 50.43(e). The prototype plant is similar to, and can be, a first-of-a-kind (FOAK) or standard plant design in all features and size, but may include additional safety features to protect the public and the plant staff from the possible consequences of accidents during the testing period. The purpose of the prototype plant is to perform testing of new or innovative design or safety features and to validate integral system computer models.

The NRC addressed the need for prototype testing in its 2007 rulemaking amending its licensing processes under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (72 FR 49352; August 28, 2007). In responding to public comments on imposing prototype testing on combined license (COL) applicants (see 72 FR at 49370), the NRC stated the following:

> Although the Commission stated that it favors the use of prototypical demonstration facilities and that prototype testing is likely to be required for certification of advanced non-light-water designs (see Advanced Reactor Policy Statement at 51 FR 24646; July 8, 1986, and the statement of consideration for 10 CFR part 52, 54 FR 15372; April 18, 1989), this rule does not require the use of a prototype plant for qualification testing. Rather, this rule provides that if a prototype plant is used to qualify an advanced reactor design, then additional conditions may be required for the licensed prototype plant to compensate for any uncertainties with the unproven safety features. Also, the prototype plant could be used for commercial operation.

While the definition of a prototype plant (e.g., under 10 CFR 50.2) does not preclude a prototype plant from being licensed under a Class 104(c) license as a research or test reactor, a research or test reactor would not need to be licensed as a prototype. As discussed in the 2007 rulemaking amending 10 CFR Part 52 (72 FR at 49437), "the purpose of the prototype plant is to perform testing of new or innovative safety features for the first-of-a-kind nuclear plant design, *as well as being used as a commercial nuclear power facility*" (emphasis added). Accordingly, the NRC anticipates that any prototype plant licensed and built would eventually be intended for commercial operation because of the substantial investment in licensing, construction, and operation of such a facility. Therefore, for the purpose of this paper, a prototype plant will be considered to be licensed under AEA Section 103 with a Class 103 license as a commercial power facility.

First-of-a-Kind Reactor

A FOAK reactor refers to the first reactor representing a standard reactor design that has been licensed, constructed, and operated. The FOAK reactor may or may not be licensed as a prototype plant. The standard reactor design could be approved or certified as a standard design approval (SDA) or design certification (DC). A standard reactor design need not have subsequent units licensed, constructed, or operated for the first unit to be considered FOAK.

Demonstration Reactor

The NRC does not have regulations specific to "demonstration reactors," nor does it use this term in its licensing processes. Accordingly, such a facility could be licensed under NRC regulations as a research or test reactor under AEA Section 104 or as a commercial facility under AEA Section 103, depending on the purpose and attributes of the facility. The term "demonstration reactor" is not used elsewhere in this document because it does not have any specific meaning within the NRC's licensing and regulatory processes.

However, the term "demonstration nuclear reactor" is used in Section 202 of the Energy Reorganization Act of 1974, as amended (ERA). ERA Sections 202(1) and (2) describe a demonstration nuclear reactor as a reactor "operated as part of the power generation facilities of an electric utility system, or when operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor." Further, the Atomic Energy Commission (AEC), the predecessor agency to the NRC and the U.S. Department of Energy (DOE), did recognize "demonstration reactors" through its Cooperative Power Reactor Demonstration Program of 1955. Through this program, the AEC assisted in the development of commercial nuclear power in the U.S. by providing limited funding, R&D, and fee waivers.

Although the NRC does not define or use the term "demonstration reactor" in its regulations, the nuclear industry, the DOE and its national laboratories, and other stakeholders use this term in various documents and media to refer to a facility that could be used to demonstrate a new technology, safety feature, or design. The term has been used in conjunction with a wide range of reactors, including testing facilities and FOAK commercial reactors that could be used to collect data and demonstrate that a particular technology can be constructed and operated safely.

For example, in 2014, DOE's Nuclear Reactor Technology Subcommittee considered focusing on "a demonstration reactor that would be used to evaluate several aspects of a selected advanced reactor technology, e.g., licensing process, safety case, operating characteristics, etc." DOE also refers to demonstration reactors in its "Vision and Strategy for the Development and Deployment of Advanced Reactors," dated January 2017, in which it describes a planning study completed in 2016 to identify "test/demonstration reactor options that would be needed to satisfy…testing and demonstration needs…including NRC licensing requirements." It also explains that this "test/demonstration" reactor "should provide further options for supporting future reactor commercialization with the expectation that a potential new test or demonstration reactor would be operational by the late 2020s if needed."

Non-Power Reactor

The NRC's regulations at 10 CFR 50.2 define a "non-power reactor" as a research or test reactor licensed under 10 CFR 50.21(c) or 10 CFR 50.22. Non-power reactors are primarily used for R&D or training. Most non-power reactors in the United States are located at universities or colleges.

A non-power reactor can also be licensed as a commercial facility. For example, the NRC issued a construction permit on February 29, 2016, for a medical radioisotope production facility (81 FR 11600; March 4, 2016).

Testing Facility or Test Reactor

The NRC's regulations at 10 CFR 50.2 define a "testing facility" as a production or utilization facility which is useful in the conduct of R&D, and licensed for operation at—

1) a thermal power level in excess of 10 megawatts, or

2) a thermal power level in excess of 1 megawatt, if the reactor is to contain:

   i) A circulating loop through the core for fuel experiments; or

   ii) A liquid fuel loading; or

iii) An experimental facility in the core in excess of 16 square inches in cross-section.

A test reactor could be licensed as a smaller scale version of an advanced reactor design. It could be used for several purposes, including (but not limited to) providing data for compliance with the NRC's testing requirements for the full scale design; or proof of concept for new or innovative designs, systems, materials, structures, or components. While a test reactor could theoretically replace or supplement the use of a prototype reactor, there may be challenges with using a test reactor for these purposes, including (but not limited to) scalability of the acquired test data, and ensuring compliance with the NRC's quality assurance requirements when the test data is applied to the full scale design.

Research Reactor

The NRC's regulations at 10 CFR 170.3 define a "research reactor" as a nuclear reactor licensed under AEA Section 104(c) and 10 CFR 50.21(c) for operation at a thermal power level of 10 megawatts or less, and that is not a testing facility. A research reactor's key output is the production of neutron and gamma radiation for experiments. While DOE operates some research reactors, the NRC does not regulate DOE research reactors.

As discussed above with respect to test reactors, research reactors could also be used for gathering test data or for proof of concept for a full scale reactor design. Research reactors also have the same challenges as test reactors when used in this way, including scalability and quality assurance.

Production Facility

A "production facility" is defined in 10 CFR 50.2 as:

(1) Any nuclear reactor designed or used primarily for the formation of plutonium or uranium-233; or

(2) Any facility designed or used for the separation of the isotopes of plutonium, except laboratory scale facilities designed or used for experimental or analytical purposes only; or

(3) Any facility designed or used for the processing of irradiated materials containing special nuclear material, except (i) laboratory scale facilities designed or used for experimental or analytical purposes, (ii) facilities in which the only special nuclear materials contained in the irradiated material to be processed are uranium enriched in the isotope U-235 and plutonium produced by the irradiation, if the material processed contains not more than 10^{-6} grams of plutonium per gram of U-235 and has fission product activity not in excess of 0.25 millicuries of fission products per gram of U-235, and (iii) facilities in which processing is conducted pursuant to a license issued under parts 30 and 70 of this chapter, or equivalent regulations of an Agreement State, for the receipt, possession, use, and transfer of irradiated special nuclear material, which authorizes the processing of the irradiated material on a batch basis for the separation of selected fission products and limits the process batch to not more than 100 grams of uranium enriched in the isotope 235 and not more than 15 grams of any other special nuclear material.

An NRC-licensed production facility could be needed for certain advanced reactor designs, for example where a molten salt and radioisotope mixture is being produced and delivered to the reactor as fuel. While the definition of production facilities is included here for context only, production facilities are considered beyond the scope of this paper.

Utilization Facility

A “utilization facility” is defined in 10 CFR 50.2 as:

(1) Any nuclear reactor other than one designed or used primarily for the formation of plutonium or U–233; or

(2) An accelerator-driven subcritical operating assembly used for the irradiation of materials containing special nuclear material and described in the application assigned docket number 50–608.

<u>Categories of Tests to be Performed by Licensees</u>

Preoperational Tests

Preoperational tests consist of those tests conducted following completion of construction and construction-related inspections and tests, but before fuel loading. Such tests demonstrate, to the extent practicable, the capability of structures, systems, and components (SSCs) to meet performance requirements and design criteria. An initial test plan addresses an applicant’s plan for preoperational and initial startup testing as described in Regulatory Guide (RG) 1.68, “Initial Test Program for Water-Cooled Nuclear Power Plants.”

Initial Startup Tests

Initial startup tests include those test activities scheduled to be performed during and following fuel loading activities. Testing activities include precritical tests, initial criticality tests, low-power tests, and power ascension tests that confirm the design bases and demonstrate, to the extent practicable, that the plant will operate in accordance with its design and is capable of responding as designed to anticipated transients and postulated accidents. An initial test plan addresses an applicant’s plan for preoperational and initial startup testing as described in RG 1.68.

Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)

ITAAC provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant is built and will operate in accordance with the design certification (for a COL referencing a design certification), the provisions of the Atomic Energy Act, and the NRC's regulations. A design certification application must contain the proposed ITAAC that are necessary and sufficient to provide such reasonable assurance. Certain preoperational tests under the initial test plan for a COL include ITAAC testing.

Integral Effects Test

An integral effects test, as described in Chapter 15.0.2, “Review of Transient and Accident Analysis Method,” of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” is an experiment in which the primary focus is on the global system behavior and the interactions between parameters and processes. It involves the examination of a large-scale system to determine the performance of various components and the interaction of subsystems. Integral effects testing is performed to demonstrate that the interactions between different physical phenomena and system components and subsystems are identified and predicted correctly. Integral effects testing is described in Step 10 of Appendix A to this document.

Separate Effects Test

A separate effects test, as described in Chapter 15.0.2 of NUREG-0800, is an experiment in which the primary focus is on a specific parameter or process. Data from separate effects tests provide localized information on the behavior of a specific part of a system. Separate effects testing is performed to demonstrate the adequacy of the physical models to predict physical phenomena that the accident scenario identification process determined to be important. Separate effects testing is also used to determine the uncertainty bounds of individual physical models. Separate effects testing is described in Step 3 of Appendix A to this document.

Prototype Test

A prototype test is defined in this document as a test that is intended to satisfy the requirements of 10 CFR 50.43(e)(2). The requirements of 10 CFR 50.43(e) allow an advanced reactor applicant's design to comply with either of two alternatives in 10 CFR 50.43(e)(1) and (e)(2). Under 10 CFR 50.43(e)(1), the NRC requires a demonstration of the performance of each safety feature, consideration of interdependent effects among the safety features, and evidence that sufficient data exist on the safety features. The alternative requirement in 10 CFR 50.43(e)(2) requires an applicant to comply through a demonstration of acceptable testing of a prototype plant, on which the NRC could impose additional requirements to protect the public and the plant staff. Therefore, a prototype plant (as defined above) would need to have prototype testing performed in order to comply with 10 CFR 50.43(e). Appendix A to this document describes the process for determining testing needs. Prototype testing is specifically described in Step 16 of Appendix A to this document.

What Are the Testing Requirements for Commercial Power Facilities?

The NRC's additional testing requirements specific to licensing advanced reactors intended as commercial power facilities under 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," and 10 CFR Part 52 are provided in 10 CFR 50.43(e). The regulation in 10 CFR 50.43(e)(1) states that the NRC will approve applications for an advanced reactor design only if (i) the performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof; (ii) interdependent effects among the safety features of the design are acceptable, as demonstrated by analysis, appropriate test programs, experience, or a combination thereof; and (iii) sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences (including equilibrium core conditions). Alternatively, 10 CFR 50.43(e)(2) allows the use of a prototype plant to fulfill the testing requirements. The regulation permits an applicant to choose either alternative. The NRC recognizes that licensing, constructing, and operating a prototype plant would require significant time and resources to plan, license, construct and operate before the plant is authorized to remove any operational restrictions necessitated by the need for prototype testing. If information is available to an applicant that would support compliance with the demonstration, analysis, and data requirement in paragraph (e)(1) and thus would not necessitate such operational restrictions, the applicant would likely choose to comply using this alternative. The process for determining testing needs, including whether a prototype plant is needed, is described in Appendix A to this document.

The use of a prototype plant to test safety features of proposed advanced reactor designs has been contemplated by the nuclear industry in the United States for many years but it has never been undertaken to date. Discussions of prototype plants and their envisioned use to support the approval and certification of advanced reactor designs appear in the Statements of Consideration for the 10 CFR Part 52 rulemaking in 1989 (54 FR 15372; April 18, 1989). The NRC later amended the testing requirements and moved them to their present location in 10 CFR 50.43(e). NUREG-1226, "Development and Utilization of the NRC Policy Statement on the Regulation of Advanced Nuclear Power Plants," issued June 1988, and SECY-91-074, "Prototype Decisions for Advanced Reactor Designs," dated March 19, 1991, discuss related background information. In SECY-91-074, the staff stated that advanced reactor designs may need testing ranging from basic R&D up to a full-size prototype plant to demonstrate that these designs are sufficiently mature to be certified. The NRC staff anticipated that testing and evaluation of an advanced reactor design would continue through the conceptual, preliminary, and final design stages. SECY-91-074 also describes a process to determine the various types of testing for a prototype plant that may be needed to determine that advanced reactor designs are sufficiently mature to be certified. The NRC expects that this process will be an integral part of the design and licensing process for advanced reactor designs. For convenience, Appendix A to this document provides the process described in SECY-91-074.

Prototype testing will generally not suffice by itself to meet the full scope of testing requirements specified in 10 CFR 50.43(e). Instead, the testing requirements should be met by using data from system and component tests conducted at other nuclear and non-nuclear facilities in combination with operational and test data from the prototype plant. Such test data from other sources may be essential to the advanced reactor licensing basis and may play a significant role in supporting the safety case for an SDA or DC if pursued.

For cases in which a FOAK plant is constructed and operated abroad or is otherwise not originally licensed by the NRC (e.g., a prototype plant funded by the U.S. Department of Defense), a prospective applicant would need to ensure that the scope and quality of all necessary test data will meet NRC requirements for allowing commercial deployment of the standard plant design. In particular, test data for a commercial nuclear power plant must be shown to meet quality assurance criteria commensurate with those in Appendix B to 10 CFR Part 50.

How Do I Determine My Testing Needs?

Enclosure 2 to SECY-91-074 describes the process for determining testing needs for a commercial nuclear power plant. Appendix A to this document includes that process in full for the reader's convenience, with changes (updates, clarifications, etc.) annotated in brackets.

To summarize the process described in Appendix A, the process for determining testing needs involves a series of questions that enable the applicant to consider the testing objectives, evaluate those objectives in ascending order of testing complexity and value, combine tests where possible, analyze the results against the regulatory requirements, and determine the acceptability or deficiency of the testing or the new reactor design. Testing could include tests of components, systems, simulators, non-nuclear or nuclear test loops, and comprehensive prototypes for determining proof of principle.

The applicant would ask the following questions:

- What are the testing objectives?
- Is testing required for component performance, reliability, feasibility, or availability?
- Is testing required for human-machine interface, instrumentation information transfer, plant automation, or operator actions?
- Is testing required to determine the performance, reliability, availability, or feasibility of systems?
- Is testing required for determining nuclear performance, physics coefficients, reactivity control, or stability?
- Is testing required for systems interactions, interdependencies, overall feasibility, integrated system performance, or reliability?
- Is testing required for other objectives?
- Is combined testing possible?
- Can the test(s) objective(s) be demonstrated with a scale test(s)?
- Did the testing successfully justify the safety claims, or should the applicant redefine the testing objective(s) or redesign the plant?

How Do I Determine Whether a Prototype Plant Is Needed?

An applicant should first complete the process for determining testing needs as described above and in Appendix A to this document. The necessary testing may encompass component tests, separate effects tests, and integral effects tests up to and including prototype testing. If an applicant determines that sufficient data are not available from component, integral, and separate effects testing to demonstrate safety features to satisfy the requirements of 10 CFR 50.43(e) before licensing, the applicant may propose that the planned FOAK reactor or standard plant design be licensed and tested as a prototype plant. The applicant may find, for example, that testing in a prototype plant can be used to reduce licensing basis analysis uncertainties (i.e., validate system design models) in relation to those derived solely from code assessment against scaled integral effects and separate effects tests from other facilities. (The potential for using a research or test reactor licensed under AEA Section 104 in lieu of a full scale prototype for this purpose is discussed later in this document.) The resulting uncertainty reductions could then be used to allow higher operating powers, higher operating temperatures, longer operating cycles, and less restrictive reactor protection system parameters, for example, for that plant or subsequent plants of the same design. The prototype plant can be considered as a transitional step between development of a particular reactor technology and full commercial deployment. The prospective applicant should, as early as possible, decide whether and how any prototype testing would support the R&D and licensing of the design.

Is a Prototype Plant Needed To Perform Fuel and Materials Qualification Testing?

If sufficient testing data and analyses are available for the NRC to reach its safety conclusions regarding fuel and material qualification testing, a prototype would not be necessary for this purpose. However, the scope of prototype testing may in some cases include irradiation testing to extend or supplement other sources of test data. Conversely, qualification test data from the prototype plant would not be expected to replace or eliminate the need for qualification data from other sources. For example, test reactors may be better able to provide safety margin data by performing fuel irradiations at well-controlled long-term operating temperatures higher than those expected in the prototype plant. Moreover, post-irradiation testing of fuel irradiated in either a test reactor or a prototype plant would typically be performed in separate facilities designed for conducting fuel tests under controlled accident heat-up or oxidation conditions and for measuring fuel integrity parameters and related fuel fission product retention and transport phenomena.

Can the NRC Determine That an Application Must Be Submitted For a Prototype Plant?

During its review of an application for a new advanced reactor design, the NRC may determine that sufficient data are not available from integral effects and separate effects testing or other sources to demonstrate safety features to satisfy the requirements of 10 CFR 50.43(e). In such cases, the NRC may determine that the FOAK power reactor facility needs to be licensed as a prototype plant in order to develop the needed test data during prototype testing. Further, the regulation at 10 CFR 50.43(e)(2) requires in part, that, "if a prototype plant is used to comply with the testing requirements, then the NRC may impose additional requirements on siting, safety features, or operational conditions for the prototype plant to protect the public and the plant staff from the possible consequences of accidents during the testing period."

When Would the NRC Impose Additional Requirements on a Prototype Plant?

Applicants are expected to propose sufficient measures to compensate for potential consequences based on uncertainties in the design for which the testing is needed. Under 10 CFR 50.43(e)(2), the NRC may impose additional requirements on a prototype plant in order to protect the public and plant staff from possible consequences of accidents during the testing period. These requirements would compensate for, among other things, technical uncertainties that exist before the testing program is complete and acceptable operation has been demonstrated. Additional requirements would be design-specific and only in areas where further verification is needed. Examples of potential preventive and mitigative compensatory measures for a prototype plant include remote siting, supplemental robust systems, supplemental emergency preparedness measures, an incrementally staged startup process, limits on operating parameters imposed by technical specifications or license conditions, or a limited duration of the license.

In determining needs for compensatory measures, an applicant should (1) conservatively estimate the relevant safety analysis uncertainties that exist before and during prototype testing, (2) predict how those uncertainties will be reduced by the testing results, and (3) evaluate the sensitivity of safety and compliance margins to the estimated uncertainties before testing. The applicant should then apply targeted compensatory measures where necessary to ensure acceptable margins of safety and compliance before and during testing in the prototype plant.

Safety feature performance and overall risk factors during the initial phases of prototype operation and testing may differ from those evaluated over the full operating lifetime of the plant. For example, calculated radionuclide releases will generally be smaller for analyzed transients and accidents that occur during the initial weeks and months of plant operation when the available core inventories of radiologically important long-lived fission products like cesium-137 and strontium-90 remain relatively small. Certain design safety functions (e.g., fuel radionuclide retention, passive shutdown, conductive cooling) may perform either more or less favorably during early plant operations than later. Safety margins during prototype plant testing could also be increased by lowering the total decay heat loads. This could be accomplished, for example, by testing from lower pre-test levels of fission power or with the lower decay heating that follows shorter periods (e.g., 1 day) of power operation.

General experience with system reliability shows that failure frequencies tend to be high when a FOAK facility is new. The expectation of higher failure rates when a FOAK plant is new should be conservatively considered in evaluating how plant risk factors and safety performance characteristics may vary with operating time during the prototype testing period.

The safety analysis of the prototype plant should address all tests included in the planned test program. Analysis uncertainties and safety margins for each kind of test should be conservatively estimated and characterized in terms of their sensitivities to when the test is first conducted during the prototype testing period. As discussed above, a given kind of test may be found to have larger safety margins, smaller uncertainties, or both, if the first test is conducted within the initial weeks or months of power operation as opposed to during later operation of the plant. Updating the assessment of analysis methods against early test results may then help reduce the estimated uncertainties for similar tests performed later.

In accordance with 10 CFR 50.43(e)(1), testing is required to demonstrate that new safety systems function satisfactorily in accordance with the safety analysis. In addition to testing, FOAK reactors are likely to have additional operational programs typical of a lead plant. These FOAK requirements and practices may include monitoring and surveillance requirements, evaluations of operating experience, and other operational programs to support the deployment of subsequent units. The goal is to ensure the design provides needed confidence for key safety functions through combinations of analysis, testing, and experience. The FOAK reactor license will include conditions or other means to define an appropriate combination of methods, possibly including acceptable testing of a prototype plant, to ensure operation of safety systems during a range of operating and accident conditions.

If the NRC or the applicant identifies compensatory requirements on operational conditions, siting, or safety features of a prototype plant, the applicant should propose approaches to delineate when each additional requirement is no longer applicable and effective and/or delineate the criteria for revoking each additional requirement on the prototype plant and other subsequent plants that are designed and licensed based on the prototype plant. In particular, the applicant should describe all necessary prototype testing and surveillance programs and the results therefrom that would provide an adequate basis for making each additional requirement unnecessary for subsequent plants.

As described above, the additional requirements placed on a prototype plant could involve additional safety features. However, prototype plants may also warrant special design features and programmatic measures to facilitate detailed inspections and sampling and to accommodate the placement and use of extra sensors and test equipment during the testing period. If the testing is successful, subsequent plants based on this design would not need to include provisions for these design features and programmatic measures.

How Would a Prototype Plant Fit into a Licensing Project Plan?

A licensing project plan describes a potential applicant’s plan to engage with the NRC during the applicant’s development of and the NRC’s review of an application for a license, certification, or approval of an advanced reactor design. Such a plan is intended to identify the desired interactions with the NRC staff, the applicant’s submittals and related NRC evaluations, dependencies on research and testing, cost and schedule, and other relevant information to facilitate the review. The plan could also include periodic meetings and discussions between the NRC staff and the potential applicant. These periodic meetings provide opportunities to ensure the scope, schedule, and costs of activities remain consistent with the potential applicant's plans or to inform the potential applicant to adjust the plans as appropriate.

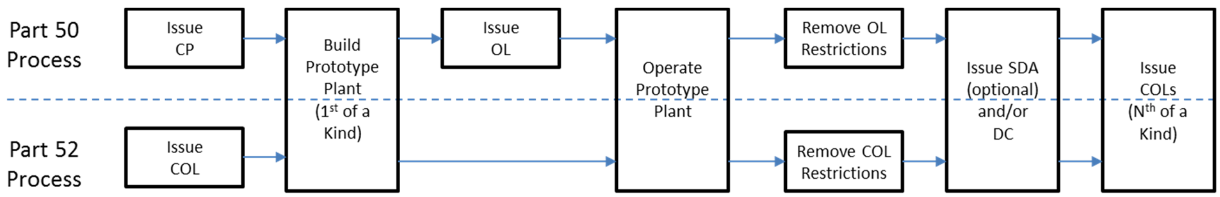
Prospective developers and applicants are encouraged to work as early as possible with the NRC to clearly define the testing to be performed in a prototype plant, including expected results and associated criteria, and to determine how to address the licensing of a prototype plant and prototype testing in the licensing project plan. Further, these interactions can be used to ensure the applicant understands what regulatory requirements would need to be satisfied in order to rely on test data used in the power plant design application (e.g., ensuring that the test program is developed and implemented under the appropriate quality controls). Prototype testing may include special surveillance and inspection programs, as well as safety testing of system performance under controlled conditions of normal and off-normal operations, transients, and accidents.

This document describes several approaches for approval, licensing, or certification of reactor designs using a prototype plant. Licensing of a prototype plant can be accomplished through the processes in 10 CFR Part 50 (construction permit (CP) followed by an operating license (OL)), or through 10 CFR Part 52 (COL). Several possible approaches for licensing a prototype plant under the 10 CFR Part 50 and 10 CFR Part 52 licensing processes are outlined in Appendix B to this document. The simplified prototype licensing process is depicted in Figure 1 below. These approaches include the potential for use of the testing conducted in a prototype plant to subsequently support an SDA under Subpart E, "Standard Design Approvals," of 10 CFR Part 52 or DC under Subpart B, "Standard Design Certifications," of 10 CFR Part 52. While either licensing process in 10 CFR Part 50 or 52 could be used to license that prototype plant as a standalone plant with no further standardization actions (e.g., obtaining a subsequent DC or SDA), this document assumes that a potential applicant's licensing project plan would include both the licensing of a prototype plant and subsequent pursuit of a DC or SDA.

Because of the variety of approval, licensing, and certification options presented in 10 CFR Part 52 and the combinations within that part and with those of 10 CFR Part 50, numerous possible approaches are available. As part of their licensing project plan, applicants are encouraged to engage the NRC as early as possible with their intended approaches for the licensing and use of a prototype plant.

It is important to note that any option selected would require an environmental review under the National Environmental Policy Act of 1969 and the NRC's regulations at 10 CFR Part 51. This includes an evaluation of severe accident mitigation alternatives for CPs, OLs and COLs, or severe accident mitigation design alternatives for DCs and SDAs. Mandatory public hearings would be conducted before a prototype plant could be licensed and constructed. Contested hearings before the NRC's Atomic Safety and Licensing Board could also occur in connection with construction permits and operating licenses under Part 50 and combined licenses under Part 52.

Figure 1
Simplified prototype plant licensing process



How Would an Application Differ for a Reactor Design with a Prototype?

For a reactor design without a prototype, all testing and analysis relied upon for compliance with 10 CFR 50.43(e)(1) must be completed before the NRC can make its safety conclusion and issue a license. For a reactor design that proposes to use a prototype, choosing to comply with 10 CFR 50.43(e)(2), some testing could be planned and accomplished using the prototype plant, in lieu of additional testing at a separate facility such as a research or test reactor. The prototype plant application would contain information specifically related to prototype testing, including but not limited to describing the specific structures, systems, or components (SSCs) that rely on the testing results, SSCs involved in the test, temporary test devices required, operational conditions or restrictions, and success criteria for the testing. Further, the designer could propose additional safety features to compensate for uncertainties in the safety analysis that would be addressed during the prototype testing.

How Would the License Issued, or the NRC's Safety Conclusions in Its Safety Evaluation, Differ for a Prototype Plant?

The NRC must be able to reach safety conclusions on any application it reviews, including standard reactor design and license applications. The standard design or license application and the NRC's safety evaluation must address the performance criteria and expected outcomes of the prototype testing that is relied upon for the safety finding in lieu of other data or analysis. Placing license conditions on a license or restrictions on a standard design could be one way to identify the necessary prototype testing outcomes. The license condition or restriction could be removed upon successful completion of prototype testing.

How Is the Prototype Testing Period Determined?

Prototype testing period is the period during which prototype testing is being performed, the plant is operating under related license conditions, and additional safety features have been installed as necessary. There is no predefined prototype testing period. The prototype testing period will be selected by the applicant based on the testing purpose. Further, although certain prototype tests may be conducted as part of the initial startup testing program, the overall duration of the prototype testing period will vary depending on the purpose and type of the testing. The testing period must be sufficient to provide assessment data to demonstrate the performance of the intended safety feature(s). For this reason, the prototype plant testing period may need to continue through equilibrium core conditions. Equilibrium core conditions may be necessary to demonstrate important fuel and core safety characteristics, such as nuclear reactivity feedback effects and the performance of fuel fission product barriers, and their variation over the reactor's operating lifetime.

The time needed to attain an equilibrium core configuration depends on the reactor technology. For example, in currently operating light water reactors, it may take four or five refueling cycles to transition from an initial core configuration starting with 100 percent fresh fuel to an essentially equilibrium core configuration. During refueling of these reactors, about one-third of the fuel is removed and replaced with fresh fuel and the remaining fuel that has been used for one or two refueling cycles is relocated within the core. As another example, in the case of the Next Generation Nuclear Plant licensing strategy for a modular high temperature gas-cooled reactor, DOE proposed a prototype demonstration period lasting at least 5 years with a 12-month refueling cycle. For designs with lifetime cores, the term “equilibrium core” would have no meaning or possibly a different meaning from that described here. Such designs may warrant the specification of additional or alternate considerations for testing that adequately addresses the variation of fuel and core safety characteristics over the operating lifetime.

The NRC encourages applicants to propose performance-based approaches and criteria for determining the necessary prototype testing period. For example, an applicant may propose a design-specific testing period that can provide an adequate basis for assessing with acceptable uncertainty the licensing-basis calculations of core physics and fuel performance behavior. Related considerations could include the degree to which safety-significant phenomena over the plant’s lifetime are represented over the proposed duration of the prototype testing program and the sensitivity of predicted safety and compliance margins to remaining code assessment uncertainties.

Is It Possible to License a Smaller Scale Reactor In Lieu of a Prototype Plant?

As previously described, “a prototype plant is *similar to* a FOAK or standard plant design *in all features and size*, but may include additional safety features to protect the public and the plant staff from the possible consequences of accidents during the testing period” (emphasis added). When the NRC defined this term, it envisioned the prototype to resemble, to the extent possible, the standard plant design with additional safety features as needed. However, the NRC understands that, for some advanced reactor designs and technologies, an applicant may seek to license, build, and operate a reactor that is smaller in scale than the standard plant design but would be used, in part, for the same kinds of testing as would be performed using a full-scale prototype plant. The smaller reactor could be licensed as a commercial facility under AEA Section 103 or a research or test reactor under AEA Section 104. There could be many reasons for choosing a smaller reactor, including cost, safety, time, and manufacturing.

The NRC could review an application for a commercial reactor that is smaller in scale than the standard plant design but intended to function as a prototype plant in some respects. If a subsequent application for a larger plant was submitted, the NRC staff would support using as much data and analysis from the smaller reactor as applicable. However, the applicant would need to ensure that scaling considerations are evaluated to ensure that the data obtained from a smaller reactor will be adequate to satisfy the 10 CFR 50.43(e) testing requirements in a subsequent application for a full-scale plant.

How Would Prototype Testing Be Done for a Multi-module Facility?

A multi-module facility is a nuclear power plant with multiple reactor modules of a standard plant design. For proposed multi-module facilities, an applicant could propose to perform prototype testing on only the first one or few reactor modules. This testing could be performed on a facility in which the modules are sufficiently independent such that multi-module effects of the entire facility do not need to be tested. The conduct of prototype testing in any reactor module of a multi-module facility could make the entire plant meet the regulatory definition of a prototype plant. For example, test results from the first reactor module could be used to support the eventual approval or certification of the reactor module design while also satisfying related technical specifications or license conditions on subsequent modules in the prototype plant whose operations are subsequent to those of the first module. In principle, the applicant could use more than one reactor module in the prototype plant to address different testing and surveillance needs. For example, one module could address surveillance testing needs for normal power operating conditions while another undergoes safety testing under controlled or simulated transient or accident conditions (e.g., passive shutdown testing, passive decay heat removal testing). Moreover, concurrent testing on multiple prototype reactor modules could reduce schedules.

For multi-module facilities that share systems between reactors (e.g., shared control rooms, heat exchangers, power conversion units, feed water systems, heat sinks), it may be necessary to conduct prototype tests that address interactions between modules. The necessity of conducting such multiple reactor tests in a multi-modular prototype plant would depend on the potential safety significance of the effects of these interactions and whether the analysis of such effects can be adequately verified by other means.

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APPENDIX A

PROCESS FOR DETERMINING TESTING NEEDS

Reprint of: SECY-91-074, “Prototype Decisions for Advanced Reactor Designs,” dated March 19, 1991, Enclosure 2, as annotated

Note: This appendix is included for the reader’s convenience. Several annotations [in brackets] have been added for clarity.

Introduction

The staff proposes the following process for determining the type of demonstration facilities that may be needed for the certification-by-test approach under Part 52 of Title 10 of the *Code of Federal Regulations* (10 CFR [Part] 52). These facilities will enable the applicant to perform tests in order to justify the performance characteristics and safety claims regarding a new reactor design or design feature not previously licensed by the [NRC] staff. The process enables the applicant to consider the testing objectives, evaluate those objectives in ascending order of testing complexity and value, combine tests where possible, analyze the results against the regulatory requirements, and determine the acceptability or deficiency of the testing or the new reactor design. The process begins whenever the staff challenges the applicant's bases for the safety claims or performance characteristics of a new reactor design.

The types of possible testing include tests of components, systems, simulators, non-nuclear or nuclear test loops, and comprehensive prototypes for determining proof of principle. The applicant may consider the least burdensome type of testing that provides the safety-related insights required to substantiate the applicant's bases. For instance, the applicant may consider component testing first and only consider the most burdensome type of testing (the testing of a full-scale prototype) as a last resort. The actual item being tested may be prototypical of the item under consideration (e.g., component or system), it may be scaled in size, or it may be limited in the features modeled. For each type of test, the objectives of the test will determine the appropriate degree of test similarity to the matter under consideration. Table 1 briefly relates the types of tests to the item under consideration. “Full-scale prototype” is defined as a full-size plant representing the first-of-a-kind (FOAK) facility in all features and size [refer to the definitions of the term “prototype” in 10 CFR 50.2 and 10 CFR 52.1]. The prototype need not include the power production systems, similar to the fast flux test facility (FFTF) [a 400 megawatt-thermal liquid sodium-cooled test reactor owned by the U.S. Department of Energy and located at the Hanford site in southeastern Washington]. The prototype could include additional safety features to protect the public, the plant staff, and the plant itself from the possible consequences of failures during the testing period. An alternative to the construction of a prototype could be the testing of a special feature or system combined with a rigorous and robust start-up testing program at the FOAK plant.

When this process is applied to a component, system, or sub-system and testing requirements are identified, it is important that the testing requirements be evaluated at the overall plant design level. Combinations of tests could provide more representative safety insights and reduce the burden of the overall testing program. More importantly, combining tests may increase assurance that a particular departure from existing technology does not result in unidentified interdependent effects among the safety systems.

The following describes the individual steps of the process. The step numbers in front of paragraphs correspond to the numbers in the lower part of the symbols (boxes, diamonds, and circles) in the simplified process diagram shown in Figure 1.

Process Description

[The following paragraph discusses the need for prototype testing in terms of the NRC's review of an application and its finding of an insufficient safety basis. However, the process for determining testing needs should actually begin during the design phase and well before the submission of an application to the NRC. Potential applicants are strongly encouraged to interact with the NRC staff through pre-application interactions, with a focus on new and unique design features and the safety rationale supporting their performance. Potential applicants should pursue a structured approach for each SSC and for each safety function to be performed and document their rationale for deciding whether analysis, existing data, or new testing is needed to demonstrate safety performance. Furthermore, potential applicants may consider submitting Technical Reports during the pre-application phase discussing the analytical tools, experimental results, operating experience, and expert judgement that will be used to demonstrate the safety performance of the design. During pre-application interactions, potential applicants should discuss with the NRC the structured approach they pursued to determine the sufficiency of analysis, data, and testing needed. Ideally, there would never be a situation where the NRC makes an insufficient basis finding during the review of an application, and pre-application interactions would ideally result in a lower likelihood of such a finding. This would in turn result in a more efficient and effective review of the application.]

The process is applied to each performance or safety claim made for the new design. Different claims may indicate the need for different levels of testing. The process for determining the appropriate testing option begins when the staff finds the applicant's bases to be insufficient for substantiating the performance or safety claims made by the designer or implied in the design. This finding would indicate that attempts to use analytical tools, experimental results, operating experience, and expert judgement have failed to provide adequate justification of the design. The staff may determine the justification to be insufficient because of the size of the uncertainties associated with the design or because of the magnitude of the consequences that could result if a safety feature fails to perform its function. To apply the process, the applicant would begin in box 1 and then identify the type(s) of test(s) for each safety claim (circles 3, 5, 7, or 9, as appropriate) for all of the safety claims before proceeding to box 12.

1. Identify and define testing objectives.

To select the appropriate type of test(s) or prototype, the applicant must clearly define the objectives. The applicant should select objectives and subordinate objectives to define the results desired from the testing process. The objectives will determine the type of testing to be conducted. Therefore, the applicant should carefully consider the objectives for completeness and clarity. The applicant should identify testing objectives separately for each performance or safety claim. In Figure 1, the applicant would combine tests in decision box 12 of the process diagram, after identifying all testing requirements that may be necessary.

Next, the applicant would evaluate the test objectives identified for each claim to select the appropriate level of testing that is needed. The applicant would begin the process by considering the simpler testing options before considering the more extensive options.

2. Is testing required for component performance, reliability, feasibility, or availability?

In this step, the applicant would identify those testing objectives for determining the acceptability of component performance, the reliability of component functions, the feasibility of using a component in the proposed way, the availability of the component to perform its function, the ability of the component to perform in adverse environments (i.e., environmental qualification), and other attributes of the component.

In the advanced reactor designs under development, designers are reducing the redundancy and diversity of components to simplify the new designs. Consequently, the new designs (especially the SBWR and AP-600) [these designs were considered to be new in 1991] rely on the reliability of components to maintain or exceed the safety levels associated with current plants. If the operating history of a component in current nuclear plants or in similar installations does not support the use of the component in new reactor designs that demand high reliability, the applicant may choose testing to demonstrate that the component meets these demands.

Therefore, in determining the need to conduct component tests, the applicant should carefully consider the reliability demands of the component imposed by the new reactor design. The applicant should assess the component's reliability by considering the operating history of the component in current plants. The applicant could do this by considering the similarity of equipment and operating environments, evaluating the redundancy and diversity of the design, and evaluating any modifications or changes incorporated into the new design.

If the purpose of the test is component performance, reliability, etc., then a component test should be adequate to satisfy the test objective and thereby substantiate the safety claim. Refer to the following discussion [in box 3] for this type of test.

3. Component test(s) or separate effects test(s) are required.

The applicant would conduct a component test to verify the performance of a component, such as a valve, a pump, a breaker, or a relay. The test may be required if a component has been significantly redesigned, will be used in a new or innovative way, or has not operated in the past with the reliability needed in the new plant design. The test should generate data to be used to substantiate the performance of the component during both normal and off-normal operating conditions in the plant.

In developing the advanced reactor designs being considered by the industry, designers are increasing the reliance on component reliability and performance, as redundancy and diversity are reduced (simplification). Because many of the components in the new designs are used in current plants (e.g., motor-operated valves, check valves, breakers, and relays), reliability data exists for their performance in nuclear plant conditions. In some cases, the performance of individual components may not be sufficient for the reliability requirements imposed by the new designs. Designers have achieved reliability in current plants by means of redundancy and diversity. In such cases, the designer may need to test these components to demonstrate that the reliability in the new reactor environment is sufficiently improved from their reliability in the existing plants to allow the component to be used in the new design.

With the component testing program, the applicant should demonstrate that the performance of the component fulfills the safety claims directly related to the component's performance. This program could include environmental qualification, seismic qualification, and quality class. Applicants should conduct such tests where high operating cycles can be achieved in short periods of time. To address the issue of age-related degradation in developing the testing plan, the applicant must carefully consider the advantages and disadvantages of conducting accelerated aging tests in relation to testing naturally aged components. The applicant should include in this decision process the results of the NRC's Nuclear Plant Aging Research Program [this program is no longer active, but its work was used in nuclear plant license renewal].

4. Is testing required for man-machine interface, instrumentation information transfer, plant automation, or operator actions?

In this step, the applicant would identify those testing objectives that focus on the human performance element in the design that might be the basis for safety claims about the new reactor design. If, for example, the design depends heavily on operator actions (or inactions) that reactor operating experience has shown to be unreliable, then the applicant may need to perform tests to determine the level of human performance that is needed. In this step, the applicant would also identify the testing required to substantiate safety claims concerning plant automation features that have not been confirmed in existing reactor experience or by testing.

The new reactor designs use much more automation for processing information [compared to that of current operating reactors], displaying the status of systems, and controlling plant operation. In some cases, applicants have proposed major changes in the control room design that involve computer display and manipulation of data for the operators. In such cases, the ability of operators to control the new automated plants cannot be demonstrated from current plant operating history. Therefore, applicants may need to test the manner in which operators interact with automated plant systems for monitoring and control (including related computer systems and software).

The applicant should base the decision to conduct simulator tests, construct mock-ups or otherwise test the interaction of humans with the automated plant on the considerations of design differences between the new and current plants, the current philosophy of procedures and practices, and the consequences of operator inaction and erroneous intervention.

If the objective to be tested meets these qualifications, then the applicant may need a simulator or mock-up in order to satisfy the testing objective. Refer to the following discussion [in box 5] for this type of test.

5. Simulator or mock-up test(s) are required.

A simulator or mock-up test is (1) a computer model of the plant or a part of the plant that is used to test operator performance or (2) a model of a portion of the plant that is used to test the reliability of the operators to perform in that area. The applicant could perform these tests using a full operations simulator, mock-ups and simulations of control panels, or mock-ups of plant areas to test accessibility, maintenance reliability, or other factors.

In developing the new reactor designs, applicants have proposed different control and instrumentation features. These features are not familiar to operators in current light water reactors, and very little performance and reliability data may be available for evaluating the ability of the systems to meet performance specifications and reliability goals.

Applicants should design tests in these areas so as to evaluate both the human and the equipment elements associated with the proposed designs. For such a test, the applicant may need to develop procedures for operators to follow. These procedures might become part of the certified [or licensed] design, depending on the amount of operator action and interaction required. In these types of tests involving human interactions, it is very difficult to completely model all of the factors that affect plant operators in normal and other-than-normal situations. The applicant should evaluate the uncertainties associated with operator performance in these simulated tests to determine the acceptability of the design.

6. Is testing required to determine the performance, reliability, availability, or feasibility of systems?

In this step, the applicant would identify those testing objectives for determining the acceptability of system performance, the reliability of system performance, the feasibility of using a system in the proposed way, the degree of availability of the system to perform its function, or other attributes of the system.

In the simplified reactor designs, passive systems would perform many safety functions that active systems perform in current plants. These passive systems rely on the natural circulation of coolant, gravity-driven flows, and the injection of coolant by pressurized gas. These systems would depart from the design philosophy of current plants by replacing diverse, redundant, active systems with passive designs that need high reliability rather than redundancy and diversity.

In determining to test such systems, the applicant must, therefore, consider the very high demands for reliability placed on these systems and their contribution to overall safety and reliability of the plant. The applicant should provide significant assurance that the passive systems can be initiated from any plant operating condition, including off-normal conditions, and that these passive systems can function as claimed in the new design. The designer should assess the uncertainty associated with the ability to operate the system as designed (system feasibility), system reliability, and system availability.

If the purpose of the test is as discussed, then a system test should be adequate to satisfy the test objective and substantiate the safety claim. Refer to the following discussion [in box 7] for this type of test.

7. Systems test(s) or non-nuclear integral loop test(s) are required.

The applicant would use a system test to verify the performance of a system that includes new, untested features, eliminates levels of diversity and redundancy used in current plants, or claims to have high reliability not substantiated by operating history in existing plants. The test should generate data to be used to substantiate the performance of the system during plant normal and off-normal operating conditions. Depending on the objectives, the test may be a partial scale or a full-size system loop.

The advanced light water reactor (ALWR) designs use systems that operate differently from the technology associated with current LWRs. In many of the systems, after initial actuation of the system (which is mostly an active function), the systems function passively by natural circulation, gravity flow, or pressurized gas. The need for the high reliability of these systems may require testing to demonstrate the reliability or to reduce the uncertainties of performance to acceptable levels.

The applicant should develop these tests to evaluate the performance, the feasibility, and the reliability of the systems. These tests should demonstrate the availability and reliability of the system to function in all operating modes, including off-normal conditions as designed.

8. Is testing required for determining nuclear performance, physics coefficients, reactivity control, or stability?

In this step, the applicant would identify those testing objectives that could validate or substantiate the acceptability of reactor physics performance and could demonstrate the performance of the core in normal and off-normal operating conditions. Such tests could validate the reactor coefficients and their stability over the range of known operating conditions, including off-normal and severe accident conditions, from the conditions at the initial core load up to and including the equilibrium core.

The new reactor core designs differ in varying degrees from the current LWR core designs. The applicant should carefully consider the basic characteristics of the core design, including its stability and control margins for reactivity, and the stability of any neutronic and thermal-hydraulic interactions, as they may affect the stability and control margins of the reactor. The core performance should be predictable and should exhibit favorable (negative) reactivity coefficients (void, temperature, moderator, doppler, pressure, and power) in normal and other-than-normal operating conditions.

Many analytical models are available to evaluate the behavior of existing core designs. However, the applicant should carefully consider the application of a particular model to a specific new core design in terms of applicability of the model, the completeness of the analytical results (have all normal and off-normal operating conditions been considered), and the uncertainties associated with the model. The applicant should consider this type of test if analytic models reveal that the design would diverge from the safety envelope generally associated with current reactor operating philosophy or if the analytical models yield unacceptable uncertainty levels.

If the purpose of the test is as discussed, then the applicant may need to perform a critical facility test in order to satisfy the test objective and thereby substantiate the safety claims associated with the physics and performance characteristics of the reactor core. Refer to the following discussion [in box 9] for this type of test.

9. Critical testing facility is required.

The applicant would construct a critical testing facility [likely a testing facility licensed under AEA Section 104] to verify the reactor physics and performance characteristics of the reactor core. Using this facility, the applicant would perform tests to verify all reactor coefficients and their stability during all normal and off-normal conditions. Such a test should model the thermal-hydraulics of the core so as to reveal changes that may occur in the reactivity coefficients. These types of tests can range from individual assemblies in test reactors to independent loops designed to model sections of the reactor core.

These tests should be designed to reduce any uncertainties associated with the design and performance of the core. The testing program should model and test all conceivable operating conditions and environments to establish the safety of the core design. This testing program may actually require a series of tests beginning with fuel tests in a test reactor followed by tests of bundles or a partial core in a test facility. Finally, the applicant may test a section of the core for overall performance, reactivity coefficients, and shutdown mechanisms.

10. Is testing required for systems interactions, interdependencies, overall feasibility, integrated system performance, or reliability?

In this step, the applicant would identify those testing objectives for validating or substantiating that interacting and interdependent systems in the plant perform acceptably and for demonstrating the performance of these systems in normal and off-normal operating conditions. The objectives could be directed at assuring that failures of ancillary systems do not cause failures in safety systems, which could result in unacceptable behavior or consequences during operation, including off-normal and severe accident conditions.

In the design of any complex process, particularly in a power generating facility fueled by a nuclear core, the systems are highly interdependent both in their ability to function successfully and to propagate failures. Many systems must operate according to design to ensure the plant produces power safely. The failure of a system may affect the ability of a related system to function properly, which could significantly increase the consequences of the failure.

Therefore, the applicant should base the decision to consider multiple system tests on the degree of interdependency of systems in the proposed design, the redundancy and diversity of the systems that may reduce the consequences of individual system failures, the possibility of synergistic effects from the interactions of various phenomena or systems, and the susceptibility of the design to failures that propagate through one or more systems. As with other testing options, multiple systems test decisions must consider the reliability of the multiple systems compared to the demands placed on the systems by the safety analysis. In addition, the applicant must consider the level of uncertainty associated with the performance and interdependencies of the systems, and the consequences to the plant and the public if one system fails and limits the ability or inhibits the function of other systems to protect the plant and the public.

If the purpose of the test is as discussed, then the applicant should determine whether the testing objectives can be combined with other tests or met with a test of a scale model or a partial plant. Refer to the discussion in boxes 12 and 13 for this decision.

11. Is testing required for other objectives?

In this step, the applicant would identify those testing objectives that have not already been covered in decision boxes 2, 4, 6, 8, and 10. Once the applicant has identified the purpose of the test, the applicant should determine whether the testing objectives can be combined with those of other tests or met with a test of a scale model or partial plant. Refer to the following discussion for this decision.

In this section of the process, the applicant should combine, where appropriate, one or more of the testing options identified in the evaluation of the entire plant design.

12. Is combined testing possible?

In this step, the applicant should consider possible combinations of tests. In evaluating each performance or safety claim against the criteria in the previous decision boxes, the applicant had identified testing requirements. Once all of these tests are identified, the applicant should consider the combinations of tests that can improve the overall confidence of testing results and can achieve economic savings in the testing program. Where tests involve phenomena related to each other, common sense suggests that the combined testing would give higher confidence to the results and may identify synergistic effects. In this step, the applicant would compare the objectives and features of the tests indicated to identify opportunities to combine tests.

Where combinations are possible, the applicant would move to boxes 15 or 16 to develop the integrated test plans. If combinations are not feasible, then the applicant would move to box 14 to consider separate test(s).

13. Can test(s) objective(s) be demonstrated with scale test(s)?

The applicant would use this decision point to determine whether the test objectives can be satisfied by tests of scale models or partial plants. The applicant may perform such tests to demonstrate new phenomenon in the design that have not been justified in currently licensed plants. The applicant may conduct the test to determine seismic responses to input spectrum or other attributes of the design. Testing may range in size and scope from small phenomena tests to larger component or systems interactions tests.

14. Conduct separate test(s).

If a certain test(s) cannot be combined with other tests and scale testing is not possible, then the designer would conduct the separate tests. The NRC staff may review the testing plan and observe the conduct of the tests.

15. Conduct partial scale test(s).

The applicant may test scale models to substantiate safety claims associated with limited interactions of systems, structures, and components. This type of test depends significantly on the validity of the scaling factors. Therefore, the applicant should consider the need to carefully and thoroughly analyze these relationships to the full-size design.

When combined testing is possible, the applicant can perform tests of partial-scale systems or loops, where the scaling factors can be justified. With these tests, the applicant can establish performance parameters and basic design proof-of-principle. The applicant must take care in using the results of scale model tests because some phenomena can only be evaluated in full-scale tests.

16. Conduct full-scale integrated test(s) or prototype test.

The designer can now develop the integrated test(s) that satisfies the objectives of each of the contributing test(s). The designer can perform these test(s) to justify claims where the testing objectives cannot be satisfied by scale model tests (from box 13 in Figure 1). The designer or the NRC staff may decide that a test of a full-scale prototype [as defined in 10 CFR 50.2 or 10 CFR 52.1] is required.

A full-scale prototype is defined as a full-size nuclear plant, which represents the FOAK plant, and is prototypical of the new design in all features, size, and performance. Such a prototype would include the reactor core, the nuclear steam supply system (NSSS), the balance-of-plant systems, and the ancillary systems as they would be built in the "production" model plants [i.e., a commercial nuclear power plant]. The prototype may not include the power production systems, similar to the FFTF. The prototype could include additional safety features to protect the public, the plant staff, and the plant itself from the consequences of unanticipated failures during the testing period. The function of each system in the prototype must accurately represent the function specified in the final design in order to justify the design for [licensing or] certification under [10 CFR Part 50 or] 10 CFR Part 52.

In addition to physically constructing the prototype, the applicant must design the testing program to test the full range of design features and safety claims associated with the plant. Some features may not be testable in the prototype without damaging and possibly destroying the plant, resulting in consequences that are unacceptable. For these features and design functions, the prototype test must be performed at partial power levels or be supplemented with other types of tests (e.g., special features tests or component tests) to validate the behavior of the design without the extreme consequences that could result if the feature were tested in the full-size plant. The applicant would need a comprehensive testing program and a program for ensuring safety while the uncertainties of the plant are being tested.

The prototype for an advanced reactor design may need some additional safety features to compensate for the uncertainties in the design that the prototype is intended to test. However, the applicant would have to ensure that the additional safety features would not affect the test program. For example, if a design is proposed without a containment, the ability of such a plant to protect the public would be very uncertain if the safety systems failed and a release occurred. Therefore, the prototype might be built at an isolated site that would minimize the threat of exposure to the public from atmospheric dispersion of accidental releases, or the prototype could be built inside a containment designed to capture any release from the plant under all postulated conditions. New designs with less diversity and redundancy in safety systems or with boundaries that rely on highly reliable equipment may require extra trains or components that can be used if the reliability of the system or component is not as high as expected. The backup system or component, which is only intended for the prototype, could be used to perform the function if the primary equipment were to fail. In such tests, if the backup equipment were used, it would indicate a failure of the plant design, the assumptions, or the reliability of the equipment. Therefore, the safety claim and the design would not be sufficient for the NRC staff to [license or] certify the new design under [10 CFR Part 50 or] 10 CFR Part 52.

The applicant would conduct the tests identified herein and prepare a report of the results to support its request for certification. The NRC staff could review the testing plan and observe the conduct of the tests.

17. <u>Did the testing successfully justify the safety claims</u>?

The designer and ultimately the NRC must determine the acceptability of the test results of both integrated and separate tests. The data must be reviewed to determine whether they support the performance and safety claims.

18. <u>The safety claims are justified</u>.

If the data successfully substantiates the performance and safety claims, then this certification-by-test approach has demonstrated that the advanced reactor design can be [licensed or] certified under [10 CFR Part 50 or] 10 CFR [Part] 52. The process for determining necessary testing is now complete.

If the testing results fail to substantiate the performance and safety claims or fail to reduce the uncertainty levels sufficiently, then either the testing program has failed or the design cannot perform acceptably. The applicant would move to box 19.

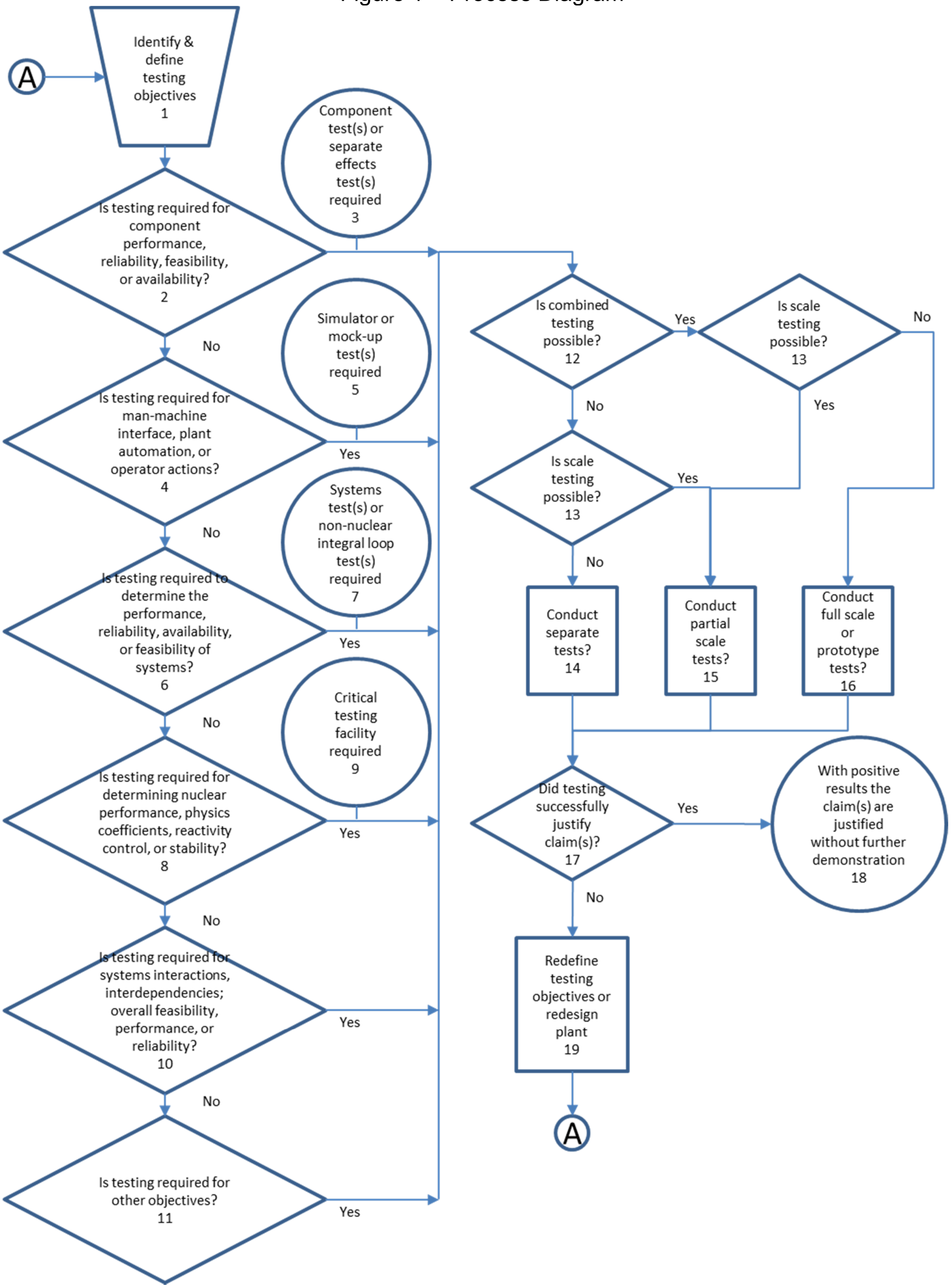
19. Redefine the testing objective(s) or redesign the plant.

In this step, the applicant would revise the testing objectives if the results have failed to substantiate the performance and safety claims. If, during this evaluation, the applicant identifies weaknesses in the testing methods or the objectives, the applicant would return to box 1 to redefine the objectives and redesign or modify the testing program to achieve positive results. If the proposed design cannot meet the performance and safety claims, then the applicant would revise the final design and perform the necessary testing to support certification of the revised final design.

Table 1

Type of Test	Feature to be Tested
special feature(s) test (e.g., control room simulator)	man-machine effects, human error rates
separate effects test (e.g., counter-current flow heat transfer)	heat transfer coefficients
non-nuclear integral loop test (e.g., Semi-scale, FIST, ROSA-4)	thermal-hydraulics, efficacy of ECCS
critical facility	basic physics characteristics, dynamic reactivity characteristics
partial scale reactor test	engineering feasibility of reactor systems, systems interactions
full-scale reactor test	engineering feasibility of entire reactor plant, extensive systems interactions, synergistic effects

Figure 1 – Process Diagram



APPENDIX B

OPTIONS FOR USING A PROTOTYPE PLANT TO ACHIEVE A DESIGN CERTIFICATION OR STANDARD DESIGN APPROVAL

This appendix describes various options for an applicant to use a prototype plant as part of its licensing project plan to achieve a design certification (DC) or standard design approval (SDA). One option is to apply for a SDA only after satisfactory completion of all planned prototype testing, or to apply for a restricted SDA before prototype testing and an unrestricted SDA or DC rule after successful completion of prototype testing. Another option for licensing and operating the prototype plant is to use either the construction permit (CP) and operating license (OL) processes under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," or the combined license (COL) process under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." All options would arrive at the same regulatory safety conclusions for the certified design. These options are described in further detail below.

A. <u>10 CFR Part 50 Process for Prototype Licensing and Testing</u>

A 10 CFR Part 50 approach for licensing and testing a prototype plant in support of a CP and OL application could proceed as follows:

(1) The prospective owner of a first-of-a-kind (FOAK) plant submits a CP application to the U.S. Nuclear Regulatory Commission (NRC) under 10 CFR 50.34(a). Under 10 CFR 50.34(a)(8), CP applications are required to identify and provide a schedule for the research and development (R&D) that must be completed before completion of construction to confirm the adequacy of the design. The applicant and designer identify testing requirements not fulfilled before the start of construction for which they propose to perform prototype testing in the FOAK unit. A prototype plant would necessitate the identification and scheduling of any additional supporting R&D that must be completed during the prototype testing period. The prospective owner may conduct such R&D activities outside the prototype plant, but some of these activities may also involve surveillance and testing in the prototype plant. Note that the applicant could also elect to submit more detailed final plant design information at the CP stage.

(2) The NRC issues the CP under 10 CFR 50.35 after reviewing the preliminary plant design information in the applicant's preliminary safety analysis report and determining the suitability of the prospective site.

(3) During the construction of the plant, the CP holder develops final design and site-specific information and prepares plans for operation and testing.

(4) The CP holder submits an OL application to the NRC under 10 CFR 50.34(b). The OL application describes the systems and components that need prototype testing, provides the plans and timing for performing those tests in the prototype plant, and specifies the criteria for satisfactory test results.

(5) The NRC issues the OL under 10 CFR 50.57 and authorizes operation of the facility. The OL has license conditions, including technical specification limits, for plant operation and testing that are met contingent upon completing the planned tests with satisfactory results. The licensee monitors the prototype plant's operation and the planned testing in

the prototype plant to verify that the results satisfy the relevant license conditions. Upon completion of the planned testing programs for the prototype plant, the licensee reports, and the NRC verifies, that the test results are satisfactory and the relevant license conditions have been met. These license conditions for the prototype plant could then be revised through a license amendment request. These license conditions may or may not be required for subsequent plants licensed under either 10 CFR Part 50 or 10 CFR Part 52, depending on the results of the prototype plant testing.

Using the 10 CFR Part 50 licensing option for constructing and operating the prototype plant, a 10 CFR Part 52 approach in support of an SDA <u>in parallel</u> with the OL could proceed as follows:

(1) The prospective owner of a FOAK plant submits a CP application to the NRC under 10 CFR 50.34(a). Under 10 CFR 50.34(a)(8), CP applications are required to identify and provide a schedule for the R&D that must be completed before completion of construction to confirm the adequacy of the design. The applicant and designer identify testing requirements not fulfilled before the start of construction for which they propose to perform prototype testing in the FOAK unit. A prototype plant would necessitate the identification and scheduling of any additional supporting R&D that must be completed during the prototype testing period. The prospective owner may conduct such R&D activities outside the prototype plant, but some of these activities may also involve surveillance and testing in the prototype plant. Note that the applicant could also elect to submit more detailed final plant design information at the CP stage.

(2) The NRC issues the CP under 10 CFR 50.35 after reviewing the preliminary plant design information in the applicant’s preliminary safety analysis report and determining the suitability of the prospective site.

(3) During the construction of the plant, the CP holder and the developer of the standard plant design develop final design and site-specific information and prepare plans for operation and testing.

(4) The developer of the proposed standard plant design applies for an SDA under 10 CFR 52.135 with linkages to the prototype testing program.

(5) In parallel, the CP holder submits an OL application to the NRC under 10 CFR 50.34(b). The OL application incorporates detailed plant design information from the SDA application. The OL application describes the systems and components that need prototype testing, provides the plans and timing for performing those tests in the prototype plant, and specifies the criteria for satisfactory test results.

(6) The NRC issues the SDA under 10 CFR 52.143 with restrictions that translate to license conditions and revision criteria for technical specification limits on the prototype facility that can be met contingent upon satisfactory results from testing completed at the prototype facility.

(7) The NRC issues the OL under 10 CFR 50.57 and authorizes operation of the facility. The OL has license conditions, including technical specification limits, for plant operation and testing that are met contingent upon completing the planned tests with satisfactory results. The licensee monitors the prototype plant’s operation and the planned testing in the prototype plant to verify that the results satisfy the relevant license conditions. Upon completion of the planned testing programs for the prototype plant, the licensee reports, and the NRC verifies, that the test results are satisfactory and the relevant license conditions have been met. These license conditions for the prototype plant could then

be revised through a license amendment request. These license conditions may or may not be required for subsequent plants licensed under either 10 CFR Part 50 or 10 CFR Part 52, depending on the results of the prototype plant testing. To the extent that prototype testing eliminates the need for restrictions on future COLs, these restrictions on the associated SDA can be removed in a subsequent revision.

(8) Once the SDA restrictions have been removed, the SDA holder can apply for a DC under 10 CFR 52.45.

(9) The NRC issues the DC under 10 CFR 52.54 without restrictions related to the prototype facility.

Using the 10 CFR Part 50 licensing option for constructing and operating the prototype plant, a 10 CFR Part 52 approach in support of an SDA or DC in series with the OL could proceed as follows:

(1) The prospective owner of a FOAK plant submits a CP application to the NRC under 10 CFR 50.34(a). Under 10 CFR 50.34(a)(8), CP applications are required to identify and provide a schedule for the R&D that must be completed before completion of construction to confirm the adequacy of the design. The applicant and designer identify testing requirements not fulfilled before the start of construction for which they propose to perform prototype testing in the FOAK unit. A prototype plant would necessitate the identification and scheduling of any additional supporting R&D that must be completed during the prototype testing period. The prospective owner may conduct such R&D activities outside the prototype plant, but some of these activities may also involve surveillance and testing in the prototype plant. Note that the applicant could also elect to submit more detailed final plant design information at the CP stage.

(2) The NRC issues the CP under 10 CFR 50.35 after reviewing the preliminary plant design information in the applicant's preliminary safety analysis report and determining the suitability of the prospective site.

(3) During the construction of the plant, the CP holder and the developer of the standard plant design develop final design and site-specific information and prepare plans for operation and testing.

(4) The CP holder submits an OL application to the NRC under 10 CFR 50.34(b). The OL application includes detailed plant design information from the standard plant design. The OL application describes the systems and components that need prototype testing, provides the plans and timing for performing those tests in the prototype plant, and specifies the criteria for satisfactory test results.

(5) The NRC issues the OL under 10 CFR 50.57 and authorizes operation of the facility. The OL has license conditions, including technical specification limits, for plant operation and testing that are met contingent upon completing the planned tests with satisfactory results. The licensee monitors the prototype plant's operation and the planned testing in the prototype plant to verify that the results satisfy the relevant license conditions. Upon completion of the planned testing programs for the prototype plant, the licensee reports, and the NRC verifies, that the test results are satisfactory and the relevant license conditions have been met. These license conditions for the prototype plant could then be revised through a license amendment request. These license conditions may or may not be required for subsequent plants licensed under either 10 CFR Part 50 or 10 CFR Part 52, depending on the results of the prototype plant testing.

(6) The developer of the proposed standard plant design applies for an SDA under 10 CFR 52.135 or DC under 10 CFR 52.45. The SDA or DC application incorporates detailed plant design information from the OL application and ensures the performance of safety functions using analysis, testing, and experience, including the testing and experience from the prototype plant.

(7) The NRC issues the SDA under 10 CFR 52.143 or DC under 10 CFR 52.54 without restrictions related to the prototype facility.

B. <u>10 CFR Part 52 Process for Prototype Licensing and Testing</u>

A 10 CFR Part 52 approach for licensing and testing a prototype plant in support of a COL application <u>in series</u> with an SDA or a DC application could proceed as follows:

(1) The prospective owner of a FOAK plant submits a custom COL application to the NRC under Subpart C, "Combined Licenses," of 10 CFR Part 52 for a custom COL that includes all necessary standard plant design information. In this instance, the term "custom" refers to a COL application that does not reference a previously-reviewed and approved or certified design such as in a DC or an SDA. The custom COL application describes the specific design safety features that need prototype testing, provides the plans and timing for performing those tests, and specifies the criteria for satisfactory test results. The applicant and designer identify testing requirements not fulfilled before the start of construction for which they propose to perform prototype testing in the FOAK unit.

(2) The NRC issues the COL under 10 CFR 52.97 after reviewing the standard plant design information in the applicant's final safety analysis report and determining the suitability of the prospective site, as well as the specific design safety features that need prototype testing, the plans and timing for performing those tests, and the criteria for satisfactory test results.

(3) Based on the prototype plant's operation and the planned testing in the prototype plant, the licensee verifies that the results satisfy the affected license conditions.

(4) Upon completion of the planned testing programs for the prototype plant, the licensee reports and the NRC verifies that all planned testing achieved satisfactory results. These license conditions for the prototype plant could then be revised through a license amendment request. These license conditions may or may not be required for subsequent plants licensed under either Parts 50 or 52, depending on the results of the prototype plant testing.

(5) The developer of the proposed standard plant design applies for an SDA under 10 CFR 52.135 or a DC under 10 CFR 52.45 and references the prototype testing performed in the COL.

(6) The NRC issues the SDA under 10 CFR 52.143 or DC under 10 CFR 52.54 without restrictions related to the prototype facility.

A 10 CFR Part 52 approach for licensing and testing a prototype plant in support of a COL application <u>in parallel</u> with an SDA application could proceed as follows:

(1) The prospective owner of a FOAK plant submits a custom COL application to the NRC under Subpart C, "Combined Licenses," of 10 CFR Part 52 for a custom COL that

includes all necessary standard plant design information. In this instance, the term "custom" refers to a COL application that does not reference a previously-reviewed and approved or certified design such as in a DC or an SDA. The custom COL application describes the specific design safety features that need prototype testing, provides the plans and timing for performing those tests, and specifies the criteria for satisfactory test results. The applicant and designer identify testing requirements not fulfilled before the start of construction for which they propose to perform prototype testing in the FOAK unit.

(2) In parallel with the custom COL application, the developer of the proposed standard plant design applies for an SDA under 10 CFR 52.135 and references the prototype testing program in the COL application. The SDA application should provide all necessary standard plant design information that the prospective owner included in the custom COL application for the prototype plant.

(3) The NRC issues the COL under 10 CFR 52.97 after reviewing the standard plant design information in the applicant's final safety analysis report and determining the suitability of the prospective site, as well as the specific design safety features that need prototype testing, the plans and timing for performing those tests, and the criteria for satisfactory test results.

(4) The NRC issues the SDA under 10 CFR 52.143 with restrictions on future COLs that translate to license conditions and revision criteria for technical specification limits on the prototype facility that can be met contingent upon satisfactory results from testing completed at the prototype facility.

(5) Based on the prototype plant's operation and the planned testing in the prototype plant, the licensee verifies that the results satisfy the affected license conditions.

(6) Upon completion of the planned testing programs for the prototype plant, the licensee reports, and the NRC verifies, that all affected license conditions have been met by satisfactory test results. These license conditions for the prototype plant could then be revised through a license amendment request. These license conditions may or may not be required for subsequent plants licensed under either 10 CFR Part 50 or 10 CFR Part 52, depending on the results of the prototype plant testing. To the extent that prototype testing eliminates the need for restrictions on future COLs, these restrictions on the associated SDA can be removed in a subsequent revision.

(7) Once the SDA restrictions have been removed, the SDA holder can apply for a DC under 10 CFR 52.45.

(8) The NRC issues the DC under 10 CFR 52.54 without restrictions related to the prototype facility.

Another 10 CFR Part 52 approach for licensing and testing a prototype plant in support of a COL application <u>in series</u> with a DC application could proceed as follows:

(1) The developer of a proposed standard plant design submits a DC application to the NRC under 10 CFR 52.45. The DC application describes the specific design safety features that need prototype testing, provides the plans and timing for performing those tests, and specifies the criteria for satisfactory test results. The designer identifies testing requirements not fulfilled before the start of construction for which prototype testing would be required in the FOAK unit.

(2) The NRC issues the DC under 10 CFR 52.54 with restrictions on future COLs, such as license conditions and revision criteria for technical specification limits on the prototype facility that are met contingent upon satisfactory results from planned testing completed at the prototype facility.

(3) The prospective owner of a FOAK plant submits a COL application to the NRC under Subpart C, “Combined Licenses,” of 10 CFR Part 52 that references the DC.

(4) The NRC issues the COL under 10 CFR 52.97 after reviewing the applicant’s final safety analysis report and determining the suitability of the prospective site, as well as the specific design safety features that need prototype testing, the plans and timing for performing those tests, and the criteria for satisfactory test results.

(5) Based on the prototype plant’s operation and the planned testing in the prototype plant, the licensee should verify that the results satisfy the affected license conditions.

(6) Upon completion of the planned testing programs for the prototype plant, the licensee reports, and the NRC verifies, that all affected license conditions have been met by satisfactory test results. These license conditions for the prototype plant could then be revised through a license amendment request. These license conditions may or may not be required for subsequent plants licensed under either 10 CFR Part 50 or 10 CFR Part 52, depending on the results of the prototype plant testing. To the extent that prototype testing eliminates the need for restrictions on future COLs, these restrictions on the associated DC can be removed in a subsequent amendment.

(7) The DC holder can apply for an amendment to the DC under 10 CFR 52.75.

(8) The NRC issues the DC under 10 CFR 52.54 without restrictions related to the prototype facility.

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