Enclosure 1: Functional Containment Performance Criteria Background

One of the fundamental safety functions of nuclear power reactors is limiting the release of radioactive materials from the facility. The designs of the containment systems for most plants licensed by the U.S. Nuclear Regulatory Commission (NRC) serve to reduce the consequences of a defined postulated accident so that a particular facility may fulfill siting requirements as defined in Title 10 of the *Code of Federal Regulations* (10 CFR). The design-basis accidents for large light-water reactors (LWRs) include loss-of-coolant accidents with breaks in piping containing water at high temperatures and pressures. The need for the containment structures to retain radioactive materials following a break of a pipe with high-energy fluid led to the development of the pressure-retaining (large dry) and pressure-suppression containment designs used for LWRs.[1] Non-LWR technologies have operating conditions, coolants, and fuel forms that differ from LWRs. These differences may allow, or require, different approaches to limiting the release of radioactive materials.

The U.S. Atomic Energy Commission (AEC) established various rules and guidance for designing, siting, constructing, and operating the first commercial reactors. Many of the NRC's current regulations and practices can be traced to those that the AEC defined in the early 1960s. Like today, the early development of commercial nuclear power included consideration of many technologies and designs. In 1965, the Nuclear Safety Information Center (NSIC) at the Oak Ridge National Laboratory (ORNL) prepared a useful history for the AEC related to the development of containment designs. The report, ORNL-NSIC-5, "U.S. Reactor Containment Technology: a Compilation of Current Practice in Analysis, Design, Construction, Test, and Operation," defined reactor containment as follows:

> Reactor containment is a general term which, for the purpose of this report, is defined to include all structures, systems, mechanisms, and devices that can be provided to attain with a high degree of reliability some specified attenuation in the radioactivity presumed to be released from the primary system in a reactor accident and might otherwise be released to the surrounding environment. Most containment enclosures generally incorporate some radiation shielding in order to restrict the direct radiation exposure therefrom in the event of a major fission-product release. Containment is usually not required for routine operations and need not be absolute, and, in fact, generally is not. Containment systems are normally referred to as "leak-tight" structures, which, in reality, leak a finite amount. Thus as a consequence, containment systems may consist of integrated complexes of structures, processes, and subsystems, which combine to control the activity release in a prescribed manner with a high degree of reliability. To the extent that activity may also be released from refueling buildings and chemical processing plants, similar containment and other engineered safeguard features are commonly provided with these facilities also.

ORNL-NSIC-5 summarizes the containment designs provided for early plants and those developed for the first generation of commercial nuclear plants. The report offers possible

---

[1] Requirements and practices for LWRs have evolved over decades and have increasingly considered events beyond those originally used to establish plant design features. Venting of LWR containments is an element within severe accident management guidelines for operating pressurized- and boiling-water reactors, which were developed as part of the response to the accident at Three Mile Island. The possible need to vent containments to avoid an uncontrolled release of radioactive material from a failed containment is also included in severe accident management for advanced LWRs and previous non-LWR designs reviewed by the NRC (e.g., the Clinch River Breeder Reactor).

approaches for non-LWRs to reflect the specific coolants and operating conditions associated with gas-cooled and sodium-cooled reactors. The report mentions a pressure-venting or pressure-relieving containment design as a likely candidate for gas-cooled reactors. A pressure-venting containment design was subsequently used for the Fort St. Vrain high-temperature gas-cooled reactor (HTGR), which was licensed by the AEC and operated from 1979 to 1989.

The NRC has engaged in several prelicensing interactions and developed policies and guidance to support the potential licensing of advanced reactor facilities. The NRC first issued the Policy Statement on the Regulation of Advanced Reactors in Volume 51 of the *Federal Register* (FR), page 24643, on July 8, 1986 (51 FR 24643), with an objective to provide all interested parties, including the public, with the Commission's views concerning the desired characteristics of advanced reactor designs. The policy statement identifies attributes that should be considered in advanced designs, including highly reliable and less complex heat removal systems, longer time constants before reaching safety system challenges, reduced potential for severe accidents and their consequences, and use of the defense-in-depth philosophy of maintaining multiple barriers against radiation release.

The use of performance standards for advanced reactors, rather than prescriptive requirements, was a topic of particular interest in developing the policy statement. The NRC solicited stakeholder views on several questions during the development of the policy statement and included the section, "Commission Position Regarding Policy Statement Questions," in the final policy statement. The following Commission Position is of particular relevance to the current activities and addresses functional containment performance requirements:

> *Question 1:* Should NRC's regulatory approach be revised to reduce dependence on prescriptive regulations and, instead, establish less prescriptive design objectives, such as performance standards?[2] If so, in what aspects of nuclear power plant design (for example, reactor core power density, reactor core heat removal, containment, and siting) might the performance standards approach be applied most effectively? How could implementation of these performance standards be verified?
>
> *Commission Response:* Many of the Commission's existing regulations, criteria, and guidelines are of a nonprescriptive nature, and the extent to which the Commission's proposed safety goals, (which are also of a nonprescriptive nature) will be used in the regulation of nuclear reactors is currently being evaluated. In the review and regulation of advanced reactors the Commission intends to make use of existing and future regulations where they are applicable to advanced reactors. Many such regulations are expected to be of a nonprescriptive nature. The areas where existing regulations and guidelines would be used include: quality assurance, equipment qualification, external events, sabotage, fire protection, radiation protection, and operator training and qualification. In developing additional criteria and guidance to address those characteristics which differ from LWRs less prescriptive criteria will be considered. The use of less prescriptive criteria will depend upon the design in question and the ability to

[2] Additional information on the distinctions between prescriptive and performance-based approaches can be found in a 1999 Commission-approved white paper (Agencywide Documents Access and Management System (ADAMS) Accession No. ML003753601) and NUREG/BR-0303, "Guidance for Performance-Based Regulation" (ADAMS Accession No. ML023470659).

> verify compliance with the criteria. Advanced reactor designers are encouraged as part of their design submittals to propose specific review criteria or novel regulatory approaches which NRC might apply to their designs.

Beginning in the 1980s, the staff has considered potential performance standards for key safety functions for advanced reactors, including the retention of radioactive materials, because many of the existing prescriptive requirements were developed specifically for LWRs. The NRC interacted with the U.S. Department of Energy (DOE) and reactor developers in the late 1980s and early 1990s about the potential licensing of non-LWR designs. These activities resulted in the publication of assessments such as NUREG-1368, "Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor," issued February 1994 (ADAMS Accession No. ML063410561) and NUREG-1338, "Draft Preapplication Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor (MHTGR)," issued in December 1995 (ADAMS Accession No. ML052780497). The staff identified a number of potential policy issues during the assessments of advanced reactor designs. The staff included the following proposal for performance criteria for containments in SECY-93-092, "Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and CANDU 3 Designs and Their Relationship to Current Regulatory Requirements," dated April 8, 1993 (ADAMS Accession No. ML040210725):

> The staff proposes to utilize a standard based upon containment functional performance to evaluate the acceptability of proposed designs rather than to rely exclusively on prescriptive containment design criteria. The staff intends to approach this by comparing containment performance with the accident evaluation criteria.
>
> - Containment designs must be adequate to meet the onsite and offsite radionuclide release limits for the event categories to be developed as described in Section A to this paper within their design envelope.[3]
>
> - For a period of approximately 24 hours following the onset of core damage, the specified containment challenge event results in no greater than the limiting containment leak rate used in evaluation of the event categories, and structural stresses are maintained within acceptable limits (i.e., [American Society of Mechanical Engineers] ASME Level C requirements or equivalent). After this period, the containment must prevent uncontrolled releases of radioactivity.

In the staff requirements memorandum (SRM) for SECY-93-092 dated July 30, 1993 (ADAMS Accession No. ML003760774), the Commission approved the staff's proposed approach for considering containment functional performance when assessing advanced reactor designs

---

[3] The various sections of SECY-93-092 describe the relationships and dependencies among issues such as licensing-basis events, source terms, and containment performance criteria. These same relationships were discussed in the followup paper, SECY-03-0047, and are also reflected in the more recent activities related to the Next Generation Nuclear Plant (NGNP) and the staff's current proposal described in Enclosure 2. The staff generally addressed the issues in SECY-93-092 and SECY-03-0047 in terms of "advanced reactors," which at the time focused on the specific sodium-cooled and gas-cooled reactor designs participating in the preapplication studies. The NGNP was limited to gas-cooled reactor designs. Questions sometimes arise as to whether the staff findings and Commission decisions from these activities are applicable to other non-LWR technologies and designs.

SECY-03-0047, "Policy Issues Related to Licensing Non-Light-Water Reactor Designs," dated March 28, 2003 (ADAMS Accession No. ML030160002) included staff recommendations to address several policy issues. Relating to containment, the policy issue was described as: "Under what conditions can a plant be licensed without a pressure retaining containment building (i.e., a confinement building instead of a containment)"? The staff recommended that the Commission take the following actions:

- "Approve the use of functional performance requirements to establish the acceptability of a containment or confinement structure (i.e., a non-pressure-retaining building may be acceptable provided the performance requirements can be met)."

- "If approved by the Commission, develop the functional performance requirements using as a starting point guidance contained in the Commission's July 30, 1993, SRM and the Commission's guidance on the other issues contained in this paper."

The Commission remained willing to consider functional containment concepts but deferred deciding on the staff's proposal. Instead, the Commission directed the staff to develop performance criteria and options for future consideration. Specifically, the Commission stated the following in the SRM for SECY-03-0047, dated June 26, 2003 (ADAMS Accession No. ML031770124):[4]

> The Commission has disapproved the staff's recommendation for issue 6 related to the requirement for a pressure retaining containment building. At this time there is insufficient information for the Commission to prejudge the best options and make a decision on the viability of a confinement building. The staff should develop performance requirements and criteria working closely with industry experts (e.g., designers, EPRI, etc.) and other stakeholders regarding options in this area, taking into account such features as core, fuel, and cooling systems design. The staff should pursue the development of functional performance standards and then submit options and recommendations to the Commission on this important policy decision.

The staff updated the Commission in SECY-05-0006, "Second Status Paper on the Staff's Proposed Regulatory Structure for New Plant Licensing and Update on Policy Issues Related to New Plant Licensing," dated January 7, 2005 (ADAMS Accession No. ML043560093), on the development of a technology-neutral framework and possible approaches to resolving policy issues remaining from SECY-03-0047. The paper used the terminology of the time in referring to the issue as "containment versus confinement" and described possible performance criteria with a preference for the following:

---

[4] The staff's description of the issue in SECY-03-0047 as "Under what conditions can a plant be licensed without a pressure-retaining containment building (i.e., a confinement building instead of a containment)?" and the related SRM that stated " … At this time there is insufficient information for the Commission to prejudge the best options and make a decision on the viability of a confinement building. …" have resulted in some uncertainty regarding the NRC's position on this issue. A purpose of this paper is to affirm the Commission's openness to performance-based requirements instead of prescriptive or deterministic performance standards for a pressure-retaining or essentially leak-tight structure as the primary means of retaining fission products for advanced reactor designs. The staff's proposal for a technology-inclusive, risk-informed, performance-based methodology for establishing functional containment performance criteria is provided in Enclosure 2.

> The containment must adequately reduce radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories (including within the design-basis category, selected credible events having the potential for high consequence source terms) and have the capability to establish controlled leakage and controlled release of delayed accident source term radionuclides.

SECY-05-0006 noted that there was no consensus among stakeholders on a single descriptive term such as "containment," "confinement," "vented low-pressure containment," "reactor building," or "containment structure." Stakeholders indicated that each term implied a specific reactor technology with specific functions and specific functional performance requirements and criteria that were not necessarily applicable to every new reactor technology. However, regardless of the term, all "containment" designs provide or support accident prevention and accident mitigation functions. A combination of civil structures (e.g., buildings) and systems provide these functions. The paper identified technology-neutral functions and possible technology-neutral functional performance requirements and criteria for the containment.

As a follow-up to SECY-05-006, the NRC addressed the concept of functional containment and related advanced reactor issues, such as ensuring sufficient defense in depth, in an advanced notice of proposed rulemaking (ANPR) published on May 4, 2006 (71 FR 26267). In the ANPR, the NRC asked for stakeholder feedback on questions related to containment functional performance standards. In SECY-07-0101, "Staff Recommendations Regarding a Risk-Informed and Performance-Based Revision to 10 CFR Part 50," dated June 14, 2007 (ADAMS Accession No. ML070790253), the staff requested that the Commission defer the rulemaking activity until after the development of the licensing strategy for the NGNP or the receipt of an application for design certification or a license for the Pebble Bed Modular Reactor. In the SRM for SECY-07-0101, dated September 10, 2007 (ADAMS Accession No. ML072530501), the Commission approved the staff's recommendation to defer the rulemaking activity. As described in SECY-16-0021, "Discontinuation of Rulemaking Activities," dated February 29, 2016 (ADAMS Accession No. ML15336A324), and the related SRM dated May 19, 2016 (ADAMS Accession No. ML16141A044), subsequent changes to the NGNP project ultimately led to the rulemaking activities being discontinued.

Although the NRC did not pursue a rulemaking as envisioned in SECY-05-0006 and the subsequent ANPR, the staff continued interactions with stakeholders on policy issues related to advanced reactors. These interactions centered on the NGNP project and a series of white papers prepared by the Idaho National Laboratory (INL). The white papers were intended to help resolve key licensing issues, including functional containment performance criteria. Following interactions with DOE, INL, and the Advisory Committee on Reactor Safeguards, the staff provided feedback on the white papers to DOE's Office of Nuclear Energy in a letter dated July 17, 2014 (ADAMS Accession No. ML14174A734). Enclosure 1 to that letter (ADAMS Accession No. ML14174A774) summarized the staff's views on four key licensing issues and offered the following response to DOE's request for feedback on functional containment performance standards:[5]

> Consistent with the positions presented in SECY-05-0006, the staff agrees with the following description of a performance standard for a functional containment,

[5] The staff provided feedback on proposals specifically developed for the NGNP project, which helped inform, but may be different than the technology-inclusive approach provided in Enclosure 2. The feedback to DOE in July 2014 cautioned that the views expressed on the NGNP white papers were from the staff and subject to change and to future consideration by the Commission.

which DOE/INL provided during assessment interactions in July and October 2012 (ML12223A151, ML13198A115):

The upper tier performance standard for the functional containment for the NGNP should be to ensure the integrity of the fuel particle barriers (i.e., the kernel and coatings of the TRISO-coated fuel particles) rather than to allow significant fuel particle failures and then need to rely extensively on other mechanistic barriers (e.g., the helium pressure boundary and the reactor building). This standard should be characterized by [the following]:

- [Ensuring] radionuclide retention within fuel during normal operation with relatively low inventory released into the helium pressure boundary (HPB).
- Limiting radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria (i.e., 10 CFR 50.34 and EPA PAGs) at the EAB with margin for a wide spectrum of off-normal event sequences.
- Maintaining the capability to establish controlled leakage and controlled release of delayed accident source term radionuclides.

An additional set of functional containment performance standards that the staff already accepted in SECY-05-0006 is to directly or indirectly accomplish the following accident prevention and mitigation safety functions:

- Protect risk-significant SSCs from internal and external events.
- Physically support risk-significant SSCs.
- Protect onsite workers from radiation.
- Remove heat to prevent risk-significant SSCs from exceeding design or safety limits.
- Provide physical protection (i.e., security) for risk-significant SSCs.

The question of functional containment performance standards also arose in connection with development of guidance on principle design criteria for advanced reactor designs. The staff issued Regulatory Guide (RG) 1.232, "Guidance for Developing Principal Design Criteria for Non-Light Water Reactors," in April 2018 (ADAMS Accession No. ML17325A611). RG 1.232 includes acceptable design criteria for any non-LWR technology (advanced reactor design criteria (ARDC)), as well as criteria developed for two specific technologies—sodium-cooled fast reactors (SFRs) and Modular High Temperature Gas Cooled Reactors (MHTGR). Criterion 16, "Containment Design," for the three technology categories is as follows:

ARDC-16 (same as GDC)

Reactor containment and associated systems shall be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

SFR-16

A reactor containment consisting of a low-leakage, pressure-retaining structure surrounding the reactor and its primary cooling system shall be provided to control the release of radioactivity to the environment and to ensure that the reactor containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

The containment leakage shall be restricted to be less than that needed to meet the acceptable onsite and offsite dose consequence limits, as specified in 10 CFR 50.34 for postulated accidents.

MHTGR-16

A reactor functional containment, consisting of multiple barriers internal and/or external to the reactor and its cooling system, shall be provided to control the release of radioactivity to the environment and to ensure that the functional containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

The RG provides the following rationale for MHTGR-16:

> The term "functional containment" is applicable to advanced non-LWRs without a pressure retaining containment structure. A functional containment can be defined as "a barrier, or set of barriers taken together, that effectively limit the physical transport and release of radionuclides to the environment across a full range of normal operating conditions, AOOs [anticipated operational occurrences], and accident conditions."
>
> Functional containment is relied upon to ensure that dose at the site boundary as a consequence of postulated accidents meets regulatory limits. Traditional containment structures also provide the reactor and SSCs important to safety inside the containment structure protection against accidents related to external hazards (e.g., turbine missiles, flooding, aircraft).
>
> The MHTGR functional containment safety design objective is to meet 10 CFR 50.34, 52.79, 52.137, or 52.157 offsite dose requirements at the plant's exclusion area boundary (EAB) with margins.

The RG describes the staff's rationale for referring to the current GDC 16 for the ARDC as follows:

For non-LWR technologies other than SFRs and MHTGRs, designers may use the current GDC to develop applicable principal design criteria. The assumed degree of leak tightness for a containment is used within safety analyses and plant performance requirements to confirm onsite and offsite doses are below limits as specified in 10 CFR 50.34. It is also recognized that characteristics of the coolants, fuels, and containments to be used in non-LWR designs could share common features with SFRs and MHTGRs. Hence designers may propose using the SFR-DC-16 or MHTGR-DC 16 as appropriate. Use of the MHTGR-DC 16 will be subject to a policy decision by the Commission.[6]

Completing the non-LWR design criteria has been an important first step to address the unique characteristics of non-LWR technologies. At the same time, the NRC acknowledged the future benefits to further risk informing the non-LWR design criteria and recognizes the possibility of either revising the RG or accepting alternative design criteria in other guidance documents or applications. ARDC 16 is an example of guidance that could be revised or supplemented as a result of Commission direction to resolve the key policy and technical issues related to functional containment performance criteria.

6 RG 1.232 states that "Some of the concepts discussed in the RG are policy issues that may require NRC Commission review and approval. Examples are functional containment performance requirements and the use of specified acceptable system radionuclide release design limits in place of specified acceptable fuel design limits. The NRC has not had the opportunity to fully consider these as they are specific to non-LWR designs." The Commission stated in the SRM for SECY-03-0047 that the staff should develop functional containment performance standards and then submit options and recommendations to the Commission. MHTGR-16 includes a performance-based approach to determining functional containment performance criteria that is consistent with the methodology described in Enclosure 2 and being recommended for Commission approval. Since most of the staff's activities related to the issue of functional containment have involved MHTGRs, the staff is using this paper as an opportunity for the Commission to affirm that the staff's proposal may be incorporated into technology-inclusive guidance for all non-LWR designs.