Draft White Paper
"Functional Containment" Performance Criteria
November 2017 Draft – Released to Support Public Discussions

Contributing activities within the NRC's implementation action plan for improving its regulatory readiness for non-light water reactor (non-LWR) designs includes developing guidance for a flexible non-LWR regulatory review process (Strategy 3) and identifying and resolving policy issues (Strategy 5). An issue identified during interactions with stakeholders is defining appropriate performance criteria for the design features serving to retain radionuclides within facilities over a range of possible events. This draft white paper has been prepared and is being released to support ongoing public discussions. This draft paper has not been subject to NRC management and legal reviews and approvals, and its contents should not be interpreted as official agency positions. Following the public discussions (including a public meeting scheduled for December 14, 2017), the staff plans to continue working on this paper as well as other activities defined in the agency's vision and strategies document. This white paper and related interactions with stakeholders will be considered in a paper the staff plans to discuss with the Advisory Committee on Reactor Safeguards and subsequently provide to the Commission in early 2018.

PURPOSE:

The purpose of this draft white paper is to support discussion of the staff's proposal for a risk-informed, performance-based approach to establishing performance criteria for structures, systems, and components and corresponding programs that serve to limit the release of radioactive materials from future advanced reactors.

SUMMARY:

- Background (Enclosure 1)
    - "Functional containment"
    - Performance criteria

Note that Enclosure 1 is under development and is not included in this draft of the white paper

- Need to resolve;
    - Goal to better align regulatory and design/development processes
    - Increased number & diversity of advanced reactor designs
- Proposed Approach
    - Risk informed, performance based
    - Aligned to overall framework being developed (Enclosure 2)

ENCLOSURE 1: BACKGROUND

Note that this enclosure is under development

Content is expected to reference previous Commission Papers and related Staff Requirements Memoranda as well as external documents related to MHTGR, NGNP and other programs

ENCLOSURE 2: RISK INFORMED PERFORMANCE BASED PERFORMANCE CRITERIA

Introduction

The staff described efforts to prepare for possible licensing of non-light water reactor (non-LWR) technologies in "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML16356A670). The staff developed implementation action plans (IAPs) to identify specific activities that the NRC will conduct in the near-term, mid-term, and long-term timeframes (ADAMS Accession Nos. ML17165A069 and ML17164A173). The IAPs included the following strategies to meet the objective of achieving regulatory readiness:

Strategy 3: Develop guidance for a flexible non-LWR regulatory review process within the bounds of existing regulations, including the use of conceptual design reviews and staged-review processes

Strategy 5: Identify and resolve technology-inclusive policy issues that impact the regulatory reviews, siting, permitting, and/or licensing of non-LWR nuclear power plants (NPPs)

Contributing activities related to these strategies include:

- Establish and document the criteria necessary to reach a safety, security, or environmental finding for non-LWR applicant submissions. The criteria and associated regulatory guidance are available to all internal and external stakeholders.

- Determine and document appropriate non-LWR licensing bases and accident sets for highly prioritized non-LWR technologies.

- Identify, document and resolve (or develop plan to resolve) current regulatory framework gaps for non-LWRs.

- Analyze and resolve technology-inclusive non-LWR policy issues

Background information on the policy issues related to non-LWR design features serving to limit the release of fission products is provided in Enclosure 1. Much of the discussion on this topic has been focused on high-temperature gas-cooled reactor (HTGR) technologies and the roles of the fuel coatings and reactor building to contain or confine radioactive materials. The policy issue addressing the retention of fission products using a "functional containment" versus a prescriptive requirement for an essentially leak tight building was partially resolved in previous papers and Commission decisions. An important item remaining to be fully resolved is to define appropriate performance criteria for design features serving to limit the release of radioactive materials. The NRC and reactor developers have long recognized the need to resolve this issue to support further development and licensing of HTGRs. Current activities related to advanced reactors includes a large number of non-LWR technologies and designs, including molten-salt reactors (MSRs). The NRC staff routinely meets with developers and other stakeholders in the advanced reactor community. The stakeholders identified during these interactions that resolving remaining issues of functional containment performance criteria is an important item to support further development of various non-LWR designs.

The resolution of this issue also supports ongoing activities on Strategy 3 related to establishing criteria for safety decisions, identifying appropriate licensing basis and accident sets, and resolving current regulatory gaps. As described in the IAPs, the staff's efforts to better define an overall licensing framework for non-LWRs are a logical extension of other efforts to better incorporate risk-informed, performance-based approaches into the regulatory process. Such efforts for light water SMRs is described in SECY-11-0024, "Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews," dated February 18, 2011 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML110110688). The integrated framework described in SECY-11-0024 were subsequently incorporated into guidance documents such as the introduction to NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition." The current interactions with stakeholders in the non-LWR community provides an opportunity to consider various interrelated issues and to coordinate the resolution of performance criteria for retaining radioactive materials within reactor facilities with efforts such as defining licensing basis events and evaluating emergency planning zones.

DISCUSSION

DESIGN FEATURES FOR RADIONUCLIDE RETENTION

Enclosure 1 provides a summary of the historical discussions and interactions related to the policy issues on design features for limiting the release of fission products from non-LWR designs. Many aspects of those discussions are rooted in how requirements evolved for the currently operating large LWRs and the role of pressure-retaining or pressure-suppression containment buildings for both design-basis accidents and beyond-design-basis events. At the same time, the previous papers on this topic acknowledge that non-LWRs designs would include different events, phenomena, and would reflect attributes identified in Advanced Reactor Policy Statement. The staff included the following recommendation 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).

> Containment:
>
> 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 [Accident Evaluation] to this paper within their design envelope.

- 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., ASME Level C requirements or equivalent). After this period, the containment must prevent uncontrolled releases of radioactivity.

The Commission approved the staff's recommendations in the Staff Requirements Memorandum (SRM) dated July 30, 1993 (ADAMS Accession No. ML003760774). The staff subsequently recommended in SECY-03-047, "Policy Issues Related to Licensing Non-Light-Water Reactor Designs" (ADAMS Accession No. ML030160002), that the Commission approve the use of functional performance requirements to establish the acceptability of a containment or confinement structure. The Commission stated the following in the associated SRM (ADAMS Accession No. ML031770124).

> 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.

Since the early 2000's, the staff has interacted with stakeholders and made progress in areas directly and indirectly related to developing functional performance standards for design features serving to retain radioactive materials within non-LWR facilities. The use of risk-informed, performance-based approaches within licensing decisions and other regulatory areas has continued to evolve for operating reactors and for reactor designs being developed. The NRC worked closely with DOE to develop a licensing strategy for the Next Generation Nuclear Plant (NGNP) Program and the staff reviewed major elements of a licensing framework for the related HTGR designs. The NRC also identified and responded to lessons learned from events such as the terrorists' attacks in 2001 and the Fukushima accident in 2011. The evaluation and response to the lessons learned from these events included a more integrated approach to considering risks and ensuring appropriate measures were in place to prevent or mitigate events potentially involving losses of safety functions and control of radioactive materials.

Figure 1 shows a general risk assessment approach[1] with consideration of a basic hazard such as radioactive materials; measures or barriers to prevent a top-level event such as core damage in a LWR or equivalent damage state for non-LWRs; and mitigation or recovery measures such

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[1] ISO-31010, "Risk management – Risk assessment techniques" describes the process as: "Bow tie analysis is a simple diagrammatic way of describing and analyzing the pathways of a risk from causes to consequences. It can be considered to be a combination of the thinking of a fault tree analyzing the cause of an event (represented by the knot of a bow tie) and an event tree analyzing the consequences. However the focus of the bow tie is on the barriers between the causes and the risk, and the risk and consequences."

as severe accident design features, siting and emergency planning. The staff is currently interacting with advanced reactor stakeholders regarding various areas represented in the figure. Examples include interactions with the joint DOE/industry Licensing Modernization Project in developing approaches to identify and address plant internal events and external events, developing security design considerations and exploring possible alternatives to current security requirements, assessing siting-related guidance, and developing a proposed rule with alternative requirements for emergency planning zones. The interrelationships between these activities and with the associated performance criteria for design features used to retain radioactive materials within a plant require an integrated approach to resolving issues and developing a regulatory framework for non-LWRs.

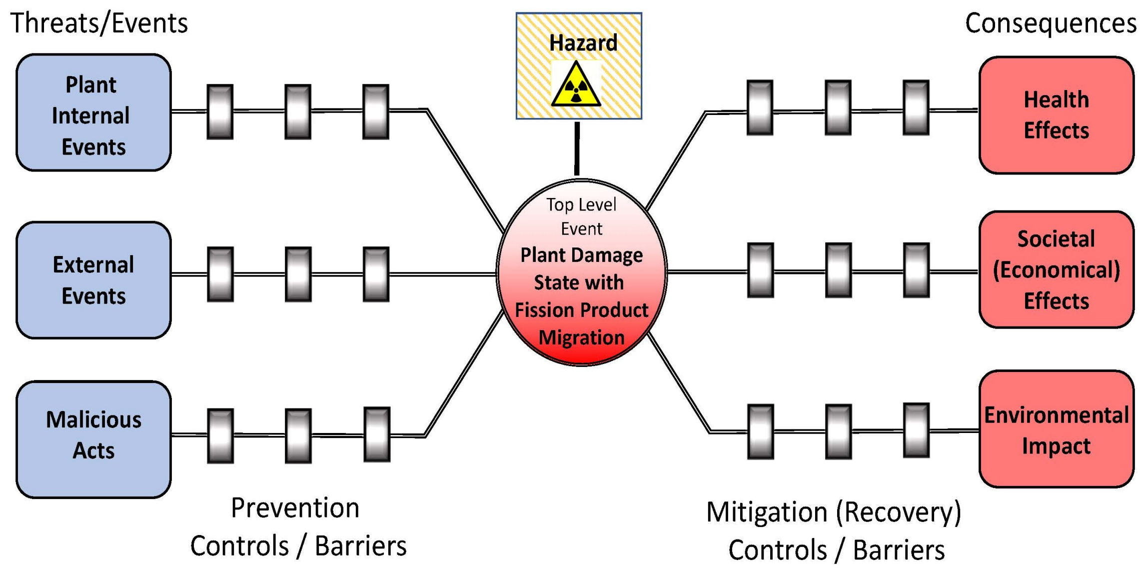

Figure 1: Risk Management - Barrier Assessment (Bow Tie) Methodology

The integrated methodology represented in Figure 1 is consistent with NRC's longstanding policies to use risk-informed performance-based approaches for decisionmaking and establishing regulatory requirements. Additional levels of analyses are performed to assess various controls and barriers in terms of their availability and capability to prevent or mitigate releases. Developers of specific reactor designs consider the potential consequences associated with a reactor technology and power level, which corresponds to the hazard in Figure 1, and are able to assess the benefits and related costs of potential barriers to prevent or mitigate a plant damage state comparable to core damage used for LWRs. The number and nature of barriers is based on the identified events, the underlying hazard (i.e., amount and form of radioactive materials), and the uncertainties associated with capabilities and availability of other controls and barriers.

The staff described in previous papers provided to the Commission that the performance criteria for what was termed "functional containment" design features were tied to radionuclide release limits for various event categories. The discussions often consisted of comparing the roles and characteristics of the physical enclosure for a non-LWR to the primary containment buildings for LWRs. Such discussions led to expressions such as “functional containment” and “containment versus confinement” related to the design of HTGRs and other non-LWR technologies. Remaining questions about “functional containment” performance criteria hamper the ability of reactor developers to make critical design decisions. The contributing activities for Strategy 3 within the staff’s IAPs are intended to reduce such regulatory uncertainties facing developers of non-LWR designs. The specific activities include interactions with stakeholders and recognize that an integrated approach is needed such that developers can effectively assess features to manage risks to the public and the associated costs of possible prevention or mitigation barriers. This paper defines a general structure of a larger, technology-inclusive framework from which logical performance criteria are derived for specific design features. Additional details related to the framework will be developed through interactions with stakeholders and will be provided to the Commission in subsequent papers. However, now is an appropriate time to address how performance criteria would be defined – including those for “functional containment.”

The near-term IAPs include activities that can be pursued largely within the bounds of existing regulations. The staff’s interactions with stakeholders such as the Licensing Modernization Project are taking advantage of existing regulations, the work completed under the NGNP Program, and lessons learned from light-water SMR and non-LWR projects. The NRC-DOE joint initiative to develop sets of advanced reactor design criteria are an example of current activities and progress in this area. The staff’s interactions with stakeholders during the development of Draft Regulatory Guide DG-1330, “Guidance for Developing Principal Design Criteria for Non-Light Water Reactors,” resulted in the following design criterion and supporting rationale for “functional containment” for modular high-temperature gas-cooled reactors:

> Containment design.
> 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.
>
> <u>Rationale</u>
> 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, and accident conditions.”

The general approach described below elaborates on the discussions in SECY-93-047 and DG-1330. The basic framework is built around the identification and categorization of licensing-basis events. Like the system that has evolved for operating reactors, event categories are developed considering factors such as estimated frequencies. Acceptance criteria are defined for each category considering potential consequences and ensuring sufficient defense in depth within the design and operation of any nuclear power plant. As described in the licensing strategy for the NGNP Project, there is general consensus between the NRC staff and stakeholders on identifying events using a combination of risk assessment tools (e.g., probabilistic risk assessment (PRA)) and deterministic methods, including engineering judgment. The staff has found that the inclusion of both considerations – risk assessments and deterministic methods – is necessary and sufficient to overcome occasional differences in emphasis on one element versus the other.

Figure 2 shows the logic for categorizing events developed by the Licensing Modernization Project starting from the structure used within the NGNP Program. The approach is similar to what has evolved for LWRs with some adjustments to more clearly address low-frequency events and to be technology-inclusive for various non-LWR designs. The figure is being provided to illustrate the general organization of events but the staff is not ready to request Commission-level decisions on the specifics within the figure. The staff is continuing to interact with stakeholders to reach alignment on some topics such as the demarcation of categories and ensuring consistency across the assessments of prevention and mitigation controls and barriers for various events and consequences. These interactions are not expected to result in changes to the general approach or overall organization of events. The structure is sufficiently defined to show the categories and how related acceptance criteria would be derived along with additional consideration of deterministic methods to address uncertainties and ensure sufficient defense in depth. The NRC needs to establish an agreed upon general structure for event categories to support defining the role and performance criteria for design features serving to retain radioactive materials within non-LWR facilities.

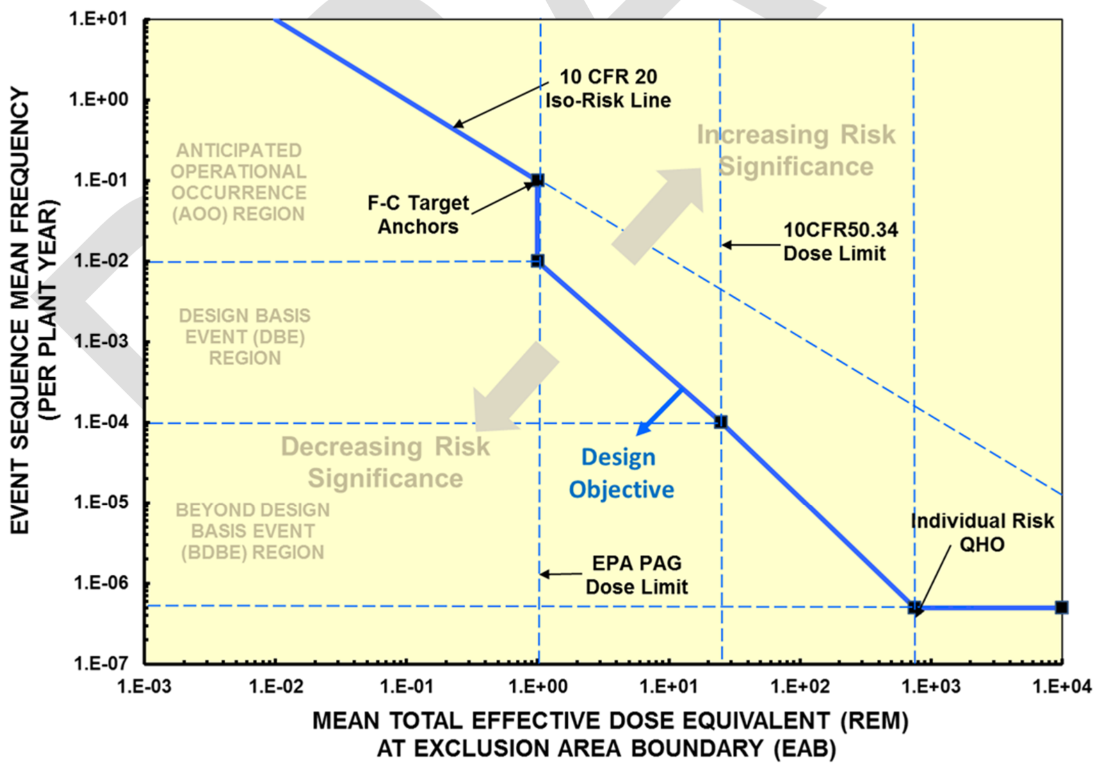

Figure 2 – Licensing Modernization Project Licensing Basis Event Categories and Frequency-Consequence Target

The staff proposes for the baseline framework for non-LWRs to adopt the set of event categories developed under the NGNP Program and continued in current interactions with the Licensing Modernization Project. Although the structure and terminology differ slightly from the current system for LWRs, each category in Table 1 has accepted high-level performance criteria that generally align with current requirements and practices. The event categories are described in Table 1:

Table 1 – Non-LWR Event Categories

Category	Description
Normal Operations	Normal operations define initial conditions for licensing basis events. Radiological doses resulting from normal operation are controlled by limiting routine effluent releases to below regulatory requirements (i.e., Part 20 limits)
Anticipated Operational Occurrences (AOO)	AOOs encompass planned and anticipated events (e.g., frequencies exceed approximately 10^{-2} per plant-year). The radiological doses from AOOs are required to meet a fraction of the normal operation public dose requirements (i.e., Part 20 limits) which are established for annual dose rates due to both events and planned effluent releases. AOOs are used to set operating limits for normal operation modes and states. Design features and programmatic controls are established to limit AOO frequencies and consequences in terms of offsite doses and success of preventive controls and barriers (e.g., integrity of fuel cladding or coatings).
Design Basis Events	Design Basis Events (DBEs) encompass unplanned off-normal events not expected in the plant's lifetime, but which might occur in the lifetimes of a fleet of plants (i.e., event frequencies in the range of 10^{-4} to 10^{-2} per plant-year). The radiological doses from DBEs are required to be a fraction of accident public dose requirements (e.g., 10 CFR 50.34) as shown on the sliding illustrative F-C target in Figure 2. Design features and programmatic controls are established to limit DBE frequencies and consequences in terms of offsite doses and success of preventive controls and barriers (e.g., integrity of fuel cladding or coatings). The identification and evaluation of DBEs provide input to the selection of design basis accidents (DBAs) discussed below.

Beyond Design Basis Events	Beyond Design Basis Events (BDBEs) are rare off-normal events whose frequencies range from a very low value (e.g., approximately 10^{-7} or 10^{-8} per plant-year to 10^{-4} per plant-year. BDBEs are evaluated to ensure that they do not pose an unacceptable risk to the public and to provide input to the selection of DBAs. Design features and programmatic controls are established to limit BDBE frequencies and consequences in terms of offsite doses and success of preventive barriers (e.g., integrity of fuel cladding or coatings) or mitigation barriers (e.g., severe accident design features).
Design Basis Accidents	DBAs are the safety analysis report Chapter 15, “Accident Analyses,” which are prescriptively derived from the DBEs by assuming that only SSCs classified as safety-related are available to deal with the event. The public consequences of DBAs are conservatively calculated and assessed against 10 CFR 50.34 limits, similar to DBAs analyses for existing LWRs. DBAs have historically been used to define safety margins for SSCs and establish limiting conditions for operation.

A methodology to define performance criteria for specific design features, such as those serving to limit the release of radionuclides can be constructed based on the above event categories and the need to fulfill critical safety functions as currently incorporated into the NRC’s general design criteria and similar international standards. The three critical safety functions are controlling reactivity, removing heat, and retaining radioactive materials.[2] Figure 3 shows a top-down approach to establishing performance criteria for plant features using accepted event categories and safety functions. For each event category, performance criteria would define specific functions to be performed by a structure, system, or component (SSC) of a facility, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design. The design of each SSC would be determined based on the aggregation of performance requirements for each event category and critical safety function as well as other potential roles that a designer may choose for that SSC. In the case of a building surrounding a reactor system, Figure 3 lists several potential uses that are discussed later in this enclosure.

[2] The term critical safety functions has been used in other historical contexts that include supporting or contributing functions to the three primary functions mentioned here. Examples include those safety functions addressed within emergency operating procedures for LWRs and evaluations for non-LWRs including specific areas such as protection against chemical interactions.

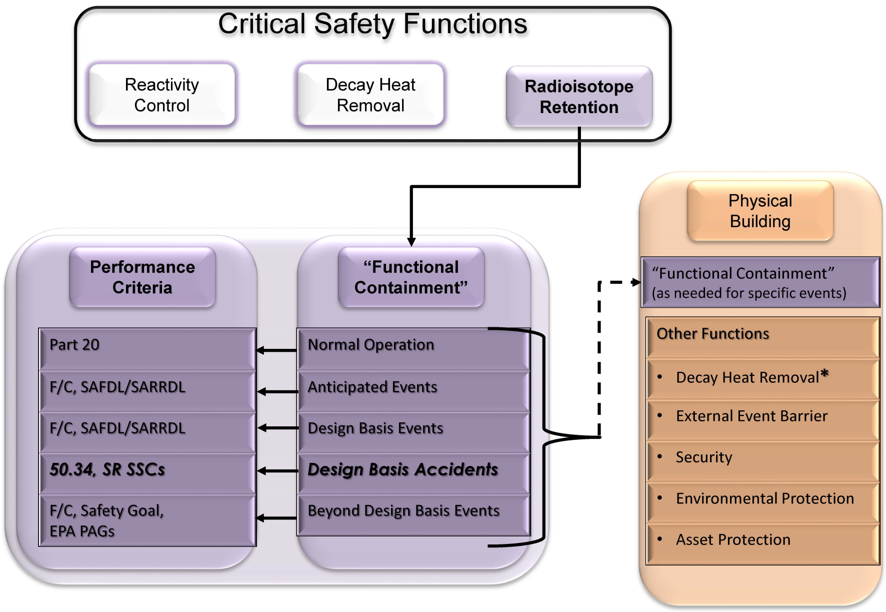

Figure 3: Derivation of Performance Criteria

As can be seen from Figure 3, performance criteria for the design features associated with retaining radionuclides within a facility will be established based on the range of event categories and the related success criteria for each category. Plant equipment and normal operational controls are needed to limit effluent releases during normal operations and other limits on normal operations define possible initial conditions for other event categories. Success criteria for AOOs and DBEs include a graded scale for potential offsite doses based on event frequencies (i.e., below a frequency/consequence (F/C) target) and demonstration that prevention barriers limit the migration of fission products within the facility. Examples of acceptance criteria used for AOOs and DBEs include specified acceptable fuel design limits (SAFDLs) similar to LWRs and specified acceptable radionuclide release limits (SARRDLs) used for HTGRs. DBAs are similar to current accident analyses described in Chapter 15 of safety analysis reports, which credit only safety related design features and show that offsite doses are below the regulatory limits in 10 CFR 50.34 (e.g., 25 Rem at exclusion area boundary over worst 2 hour period). BDBEs are assessed to ensure design features and programmatic controls keep the estimated frequencies and consequences below values corresponding to the NRC's safety goals, which are reflected in the F/C targets. It is anticipated that many non-LWR developers will incorporate design features to limit potential offsite doses to values below those that could justify alternative offsite emergency planning requirements (e.g., less than the Environmental Protection Agency (EPA) Protective Action Guidelines (PAGs). Requirements are defined for specific SSCs by aggregating the design features and programmatic controls needed to meet the success criteria for each event category.

The staff acknowledges that the above discussion establishes more of a performance-based methodology than a definitive or prescriptive set of performance criteria for “functional containment” or other design features. In addition, the staff is continuing interactions with stakeholders to reach agreement on several technical issues such as lower bounds for event frequencies and some details on establishing SARRDLs for non-LWR technologies. However, the NRC staff and non-LWR developers need to establish a logical path forward to complete the Strategy 3 activities defined in the near-term IAPs and resolve interrelated policy issues such as establishing functional containment performance criteria. The need for an integrated and consistent approach to address both prevention barriers and mitigation barriers is especially important to developers needing to make key design decisions. The design decisions require an ability to assess tradeoffs between possible costs for various design features as well as possible operating and maintenance costs for prevention and mitigation barrier alternatives. Commission approval at this time of the general overall framework as it relates to “functional containment” performance criteria would allow the staff and stakeholders to continue interactions and resolve other technical and policy issues. The description of a performance-based methodology is appropriate given the variety of technologies and designs being developed. The Commission would have opportunities for review and final say in how this activity expands to other areas and how it is ultimately reflected in regulations and for each design via the normal licensing or certification processes.

OTHER REQUIREMENTS FOR PHYSICAL ENCLOSURES

Any commercial reactor is expected to have the coolant system and other key SSCs housed within some type of physical enclosure. If serving no other purpose, such an enclosure would serve to protect a valuable asset from the elements. Many discussions of “functional containment” and “containment versus confinement” have focused on the design attributes for the physical enclosure and its possible roles in providing defense in depth as a mitigation barrier for DBEs and BDBEs. As shown in Figure 3, a physical building could serve this purpose and have associated performance criteria based on the event category for which it is serving to retain radionuclides. The physical enclosure usually referred to as a primary containment structure for LWRs is safety related because of its role in DBAs and also has design features important for evaluating and protecting against BDBEs. The various reactor sizes and technologies being considered by non-LWR developers may or may not result in the need to credit design features of the physical enclosure for retaining radionuclides within the facility. The performance-based methodology previously discussed would determine what requirements were imposed on the physical enclosure for the critical safety function of retaining radionuclides. Examples in past interactions with non-LWR developers have included cases where attributes such as fuel form and system heat capacities reportedly limit the migration of radionuclides and alleviate the need for the design to credit physical enclosures retaining radionuclides for DBAs.

Whether or not a physical enclosure is needed to limit the release of radionuclides for one or more event categories, the staff and developers have recognized that structures may serve other purposes and be used to meet specific NRC regulations. The staff included discussions of such other purposes in papers such as SECY-2005-06, “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). Examples of potential roles of physical enclosures beyond the retention of radionuclides include but are not limited to:

- Structural support to primary cooling systems;
- Supporting the decay heat removal critical safety function via structural support for and housing of backup or emergency cooling such as reactor cavity cooling systems;
- Prevention barrier against external events such as flooding and wind loadings;
- Design feature credited in aircraft impact assessments;
- Physical security design feature credited in preventing or delaying adversaries; and
- Design feature credited during environmental assessments of severe accident mitigation design alternatives.

In most examples, the physical enclosure is serving as or supporting a preventive barrier for the threats or events shown in Figure 1 (i.e., internal events, external events, and malicious acts). Performance criteria related to these functions (e.g., characteristics needed to address design basis flooding or wind loadings) would be added to requirements, if any, related to fulfilling the critical safety function of radionuclide retention. In such cases, an aggregation of performance requirements would determine the final design for a building or other physical enclosure. The consideration of various events and roles for SSCs and using various performance criteria to reach the final design of each SSC is consistent with current practices and the definition of the design basis for specific SSCs for currently operating plants.