Discussion Paper

Proposed HTGR Licensing Framework Approach For the PBMR

Introduction

The Advanced Reactor Policy Statement states for advanced reactors; the Commission expects, as a minimum, at least the same degree of protection of the public and the environment that is required for current generation LWRs. Thus, the Commission expects that advanced reactor designs will comply with the Commission's safety goal policy statement. Furthermore, the Commission expects that advanced reactors will provide enhanced margins to safety and/or utilize simplified, inherent, passive, or other innovative means to accomplish their safety function. 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.

The purpose of this document is to propose a Licensing Framework that establishes a consistent method for judging the acceptability and licensability of gas reactor designs, like the Pebble Bed Modular Reactor (PBMR). This framework incorporates a risk-informed approach to benefit from the extensive experience and knowledge gained over the last twenty years utilizing these methods. Any entity considering a request for a new plant license would require reasonable assurance that known and stable methods would be employed during the regulatory review and the scope of review has been pre-determined prior to a substantial investment of time and resources.

The specific objectives for developing the fundamental Licensing Framework are as follows.

- Establish appropriate quantitative acceptance goals for gas reactor design
- Establish an agreed upon method for selecting specific design basis criteria
- Establish a design specific method that incorporates a risk-informed approach to select and determine special treatment of safety significant systems, structures and components
- Establish a design specific method for determining plant technical specifications and operating requirements
- Establish a design specific guide to determine what regulatory requirements are applicable based on the above methods

Exelon is presenting the proposed framework for development, concurrence and eventual use as a way to address the applicable requirements of the Nuclear Regulatory Commission (NRC). This approach takes into account work done by the Department of Energy's (DOE) Modular High Temperature Gas Reactor

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(MHTGR) during the mid to late1980s and reviewed by the NRC Staff. It is our intent to update those methods and conclusions based on current regulatory requirements and the specific features of the PBMR design that represent a new advanced design concept. The MHTGR design structured approach is used an example during initial pre-application discussions with the NRC in order to focus on establishing a suitable standard for assessing safety of gas reactors. In addition it will demonstrate the ability to incorporate and retain the defense-in-depth philosophy along with benefiting from the advances in probabilistic tools.

This document provides a discussion of the logic and methods supporting a framework at an introductory level so that fundamental concepts may be discussed and a path to agreement can develop. Reaching agreement on a contemporary gas reactor framework is essential before moving ahead with specific design reviews.

It is envisioned that once the specific Licensing Framework objectives (outlined above) are reached, design discussions regarding the PBMR (e.g., containment, safety classification, fuel performance) can be better focused. Discussions are also anticipated regarding the license application format (i.e., SAR), since the gas reactor design is a departure from the current light water reactor based format and the proposed Licensing Framework can provide have a more natural structure of the safety case.

The framework will also focus the development of the technical basis for regulation applicability pertaining to a specific design. Therefore, the framework can guide licensees to ensure which current requirements apply, guide exemption requests, or determine if new regulatory requirements will be needed.

The proposed Licensing Framework approach consists of the following elements:

1. NRC Regulatory Mission Linkages
2. Consequence and Risk Criteria Framework

Which in turn allow:

- Selection of Licensing Bases Events
- Establishment of General Design Criteria
- Selection of Safety Significant Equipment Classification
- Identification and implementation of applicable Regulatory Guides

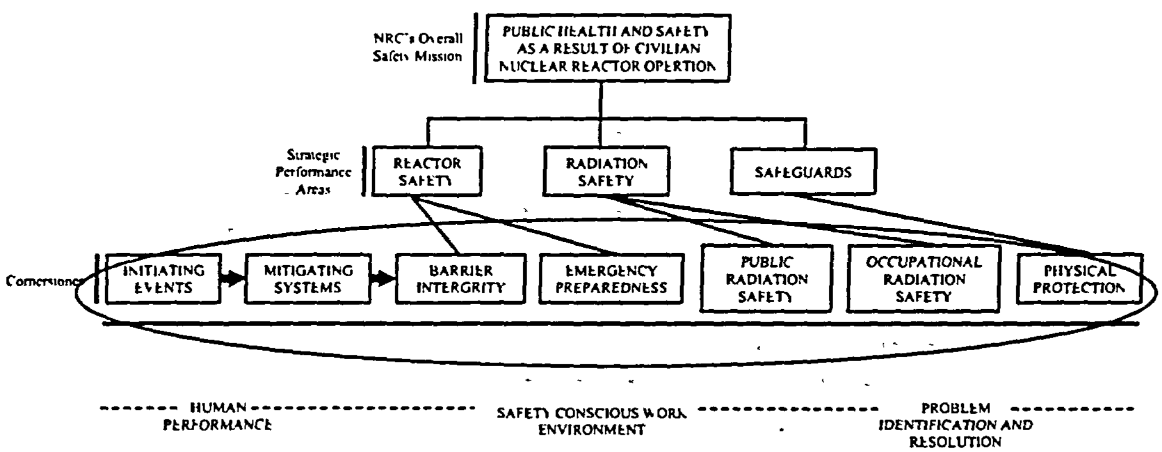
Each of these are discussed in order below:

Regulatory Mission Linkages

A technical approach to the acceptance and licensing of any design must have a clear link between the regulatory missions and the specific design attributes to be reviewed. Figure 1 displays the top level NRC mission, the public safety objective for nuclear power plants as contained in 10CFR50.57, 10CFR50 Appendix A-Introduction and in the Safety Goals, and the second-tier normal operation, accident, and safeguards objectives.

Based on these fundamental objectives, a top-down approach to the framework will be developed similar to the methods developed for the current Light Water Reactor (LWR) NRC Oversight Process.

The following logic diagram was used in developing the new NRC oversight process. The seven cornerstones became the policy "lens" of how to focus on current regulations that directly relate to the NRC oversight mission.



The MHTGR licensing approach developed similar "lenses" for focusing on areas of significance developed for gas reactor licensing acceptance. The MHTGR has many similarities to the PBMR compared to LWR examples including utilizing coated particle fuel. Since the PBMR gas reactor assessment requires a departure from the current LWR technology perspective, our proposal is to build upon the work started by the MHTGR licensing process and starts the discussion with the five areas depicted in figure 1.

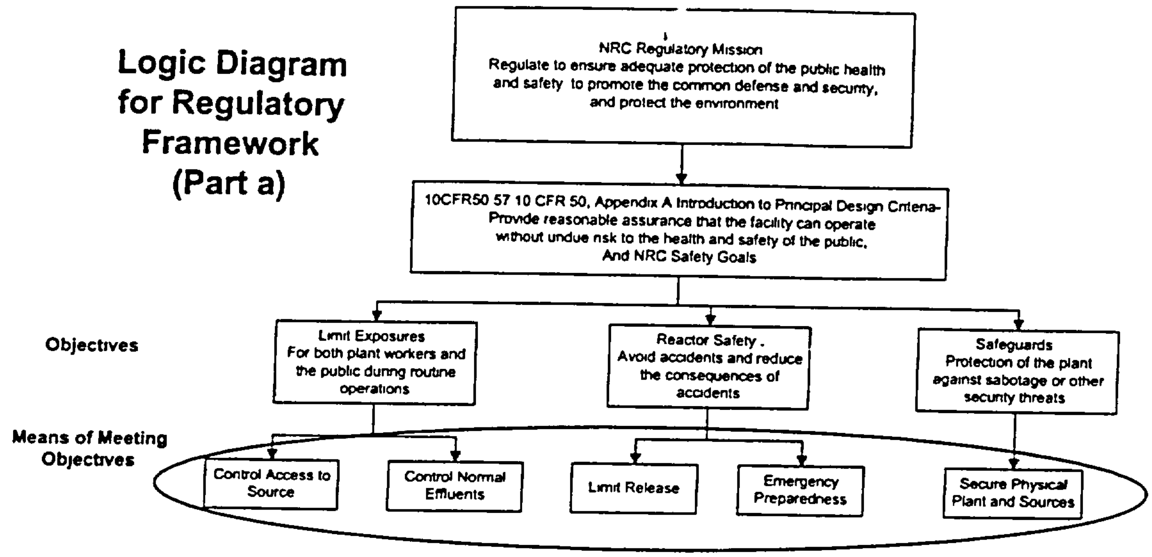


Figure 1. Regulatory Framework for PBMR

Consequence and Risk Criteria Framework

The second element of the proposed licensing framework identifies the necessary set of quantitative regulatory criteria that define the regulatory mission (ensures an acceptable level of health and safety consequences, and risks to individuals and the environment), and is at an appropriate fundamental top-level in order to fulfill the regulatory mission in its entirety. Two areas comprise this second element: identification of fundamental criteria, and establishment of a risk-informed frequency range applicable to each criterion.

<u>Fundamental Criteria</u>

The top-level regulatory criteria are direct measures of risk or consequences to the public or environment, are quantifiable, and are independent of plant design or site. The Top-Level Regulatory Criteria for the Standard MHTGR (DOE-HTGR-85002/Rev. 3) serve to illustrate the approach:

- 51 FR 28044 – Policy Statement on Safety Goals for the operation of Nuclear Power Plants and establishment of two qualitative safety goals:

  1) No more than 0.1% increase of accidental death due to all other causes. NUREG-0880 provides individual mortality risks of prompt fatality in the US as about 5×10^{-4} per year for all causes, therefore

the goal is not to increase risk by more than 5 X 10^{-7} per year to the average individual who resides at a location within one mile of the plant site boundary.

2) No more than 0.1% increase of delayed mortality risk of cancer death. NUREG-0880 provides the average rate to be 2 X 10^{-3} per year; therefore the goal is not to increase the risk by more than 2 X 10^{-6} per year to an average individual who resides at a location within 10 miles of the plant site.

- 10CFR20 – Permissible dose levels and activity concentrations in restricted and unrestricted areas.
  The numerical values in 10CFR20 are not design dependent and therefore were included as top-level criteria.

- 10CFR, Appendix I – Numerical dose guidelines for meeting the criterion "ALARA" for power reactor effluents.
  In principal the dose values were derived from LWR design features, however, the dose values represent suitable power plant allocations of the overall fuel cycle limits stated by the Environmental Protection Agency in 40CFR190 "Environmental Radiation Protection Standards for Nuclear Power Operations," and were included as top-level criteria. The cost benefit guidelines for radwaste systems were not included since it does not have a direct link to the regulatory mission.

- 40CFR190 – Environmental Radiation Protection Standards for Nuclear Power Operations.
  The numerical criteria of 40CFR190 and 10CFR50 Appendix I are complementary. Appendix I provides limits on dose due to effluents from an individual reactor, including allocations from shared facilities. 40CFR190 sets a limit on exposure from all sources, both effluent and direct from the plant's fuel cycle. One may be more limiting under certain conditions, therefore, both were considered top-level criteria, where the maximum allowable dose to any member of the public shall be the lower of the limits.

- 10CFR100 – Numerical dose guidelines for determining the exclusion area boundary, low population zone, and population center distance.
  The dose guidelines are used to judge site suitability for accident releases and were considered top-level criteria. However, the analysis assumption used in implementing these guidelines should be oriented to the characteristics of the specific reactor design. In particular, the source term guidance given in Technical Information Document 14844 for LWRs is not appropriate for advanced designs.

- EPA-520/1-75-001 – Protective Action Guide Doses for Protective Action for Nuclear Incidents.
  The rational for the selection of these dose guides is not reactor design specific. However, 10CFR50 Appendix E states that the size of the Emergency Preparedness Zone (EPZ) may be determined on a case-by-case basis for gas cooled nuclear reactors and for reactors with an authorized power level less than 250 MW thermal. Therefore, alternative implementation guidance would be developed using the PAGs as the numerical criteria for determining appropriate EPZ distances.

- 47 FR47073 – Accidental Radioactive Contamination of Human Food and Animal Feeds, Recommendations for State and Local Agencies.
  The Food and Drug Administration's (FDA) recommendations for accidental contamination of human food and animal feed have been adopted on an interim basis. Only the FDA recommendations containing numerical guidance were selected as top-level criteria.

The above top-level criteria, added to the regulatory framework logic chart in Figure 2, are a starting point for a High Temperature Gas Reactor such as the PBMR and will be reviewed to be consistent with current regulations.

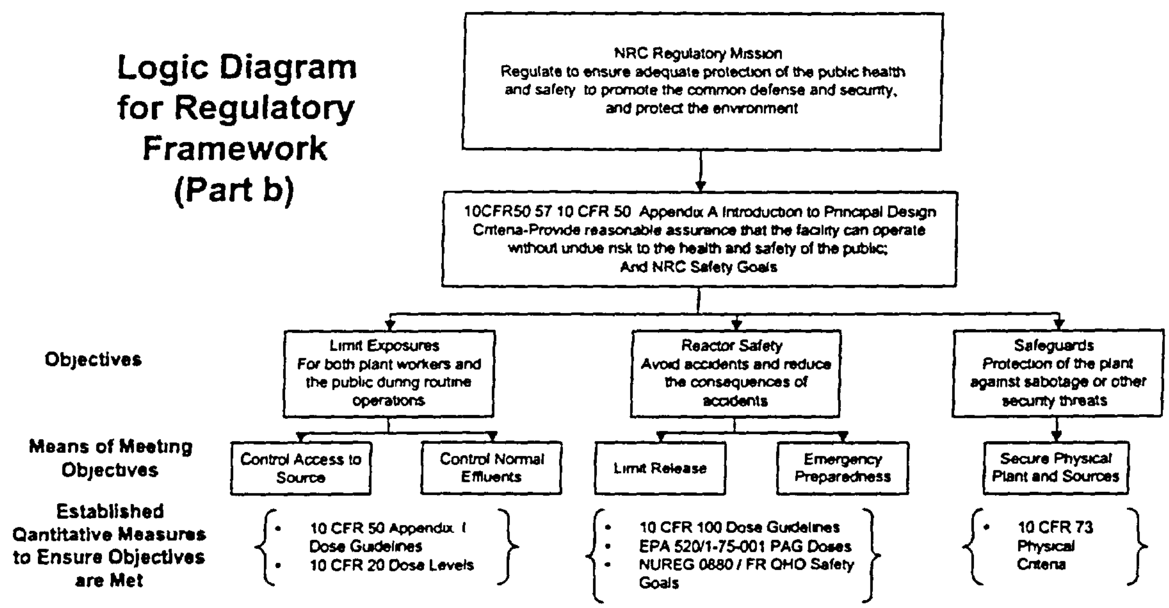


Figure 2. Regulatory Framework for PBMR with Top Level Regulatory Criteria

Applicable Frequency Range

In order to systematically apply the top-level criteria identified above and to assure they are a sufficient set to protect the public health and safety requires consideration of a spectrum of releases covering a frequency range from normal operation to very rare off-normal events. Three frequency ranges were proposed for the MHTGR. Again a similar approach will be developed for the PBMR as described below for the MHTGR.

The first region includes releases from anticipated operational occurrences (AOOs). AOOs are those conditions of normal operation, which are expected to occur one, or more times during the life of the plant. Given a forty-year plant lifetime the lower boundary for this region is 2.5×10^{-2} per plant year. The criteria selected for this region as the limiting criteria are the numerical values contained in 10 CFR 50 Appendix I since these lower requirement restricts releases during normal reactor operations, and are kept as low as reasonably achievable.

The second region, the Design Basis Event region (DBE), will bound releases from postulated events that are not expected to occur during the lifetime of the plant. This frequency range covers events that are expected to occur during the lifetime of several hundred plants, therefore, a lower limit of 1×10^{-4} per plant year has been selected. The criteria selected for this region as the limiting criteria were those contained in 10 CFR 100 as it provided quantitative dose guide limits for accidental releases for plant siting to ensure that the surrounding population is adequately protected.

The third region, Emergency Planning Basis Event (EPBE) region, considers postulated events that are not expected to occur during the lifetime of several hundred nuclear power plants. This region is to ensure that adequate emergency planning is developed as defense in depth to protect the public from the risk of exposure to radiation for unexpected events. The lower frequency for this region is implicitly contained in the acute fatality risk goal. The Policy Statement on Safety Goals – 51 FR 28044 limits the increase of this risk to 0.1% or, as described in NUREG-0880, an incremental increase of no more than 5 X 10-7 per year. Therefore, this value has been selected as the lower frequency bound for the EPBE region.

The graphical representation of the above frequency - consequence criteria is depicted in Figure 3 and provides a means to compare a plant's risk against established regulatory criteria. Providing a design that performs within these boundaries assures the fulfillment of the regulator mission; providing reasonable assurance that the facility can operate without undue risk to the health and safety of the public.

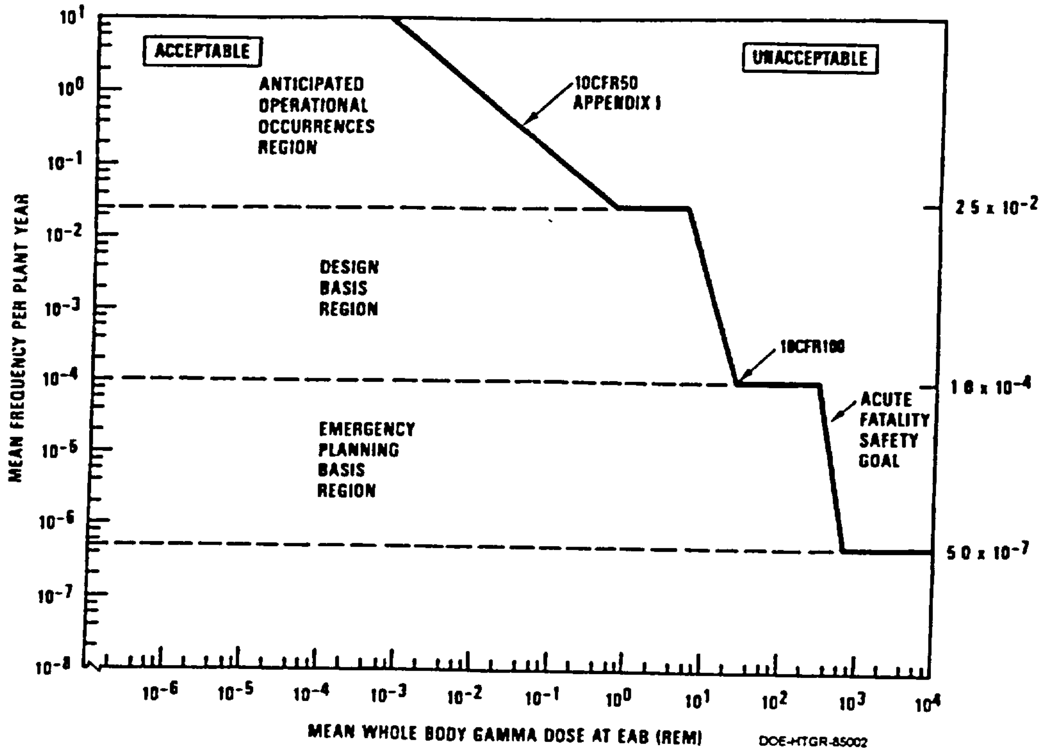


Figure 3. Frequency-Consequence Risk Chart of Top Level Regulatory Criteria

Selection of Licensing Bases Events

The Licensing Basis Events (LBEs) are one of the means by which regulators evaluate a plant's licensability. The initial set of events for a specific design is best derived utilizing probabilistic risk assessment results. These events can range from those transients anticipated to occur during routine operations to very unlikely accidents.

Having defined the regulatory criteria and the regions over which these criteria would be applied, the licensing basis events are selected. Some of events result in public dose, others do not. Families of events can be assessed together and plotted on the consequence axis based upon the frequency of a specific design. Again this method focuses the review of a specific design against the criteria established to fulfill the regulatory mission. Events that reside to the left side of the Figure 3 curve are within acceptance criteria.

Figure 4 below shows this relationship using the MHTGR as the example.

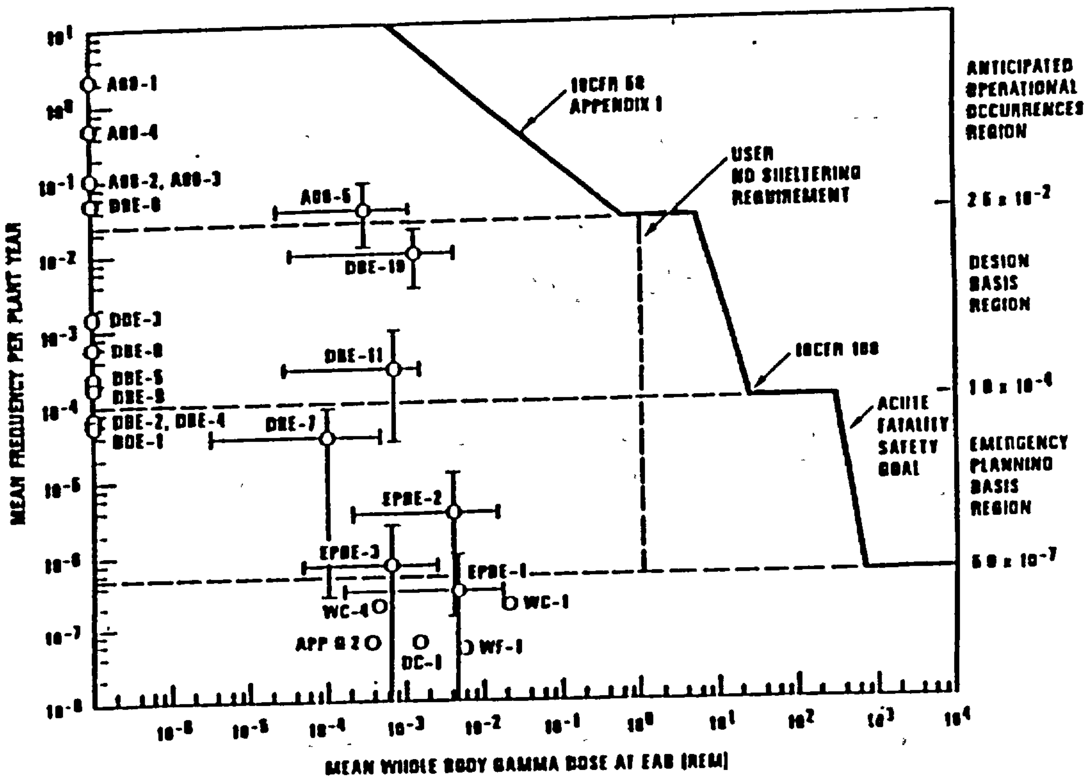


Figure 4. Comparison of MHTGR PRA Results with Top Level Regulatory Criteria

AOOs are compared against 10CFR50 Appendix I. Events within the middle region extending to 10^{-4}/plant year are defined as DBEs if there is a design feature or selection that is relied on to keep the event within the acceptable consequence region (feature prevents the event from migrating to the unacceptable region). In that respect, an event with negligible consequences can also be a DBE. DBEs were compared against 10CFR100 criteria for the MHTGR. The limiting events in the region extending to $5x10^{-7}$/plant year are selected as EPBEs, which are events beyond the design basis utilized for emergency planning.

This process identifies and establishes the complete set of LBE to be evaluated. It also focuses the evaluation to those events that have a design function that prevents radioactivity releases from exceeding the regulatory criteria on a risk-informed basis. Similarly the EPBEs and DBEs establish the appropriate emergency planning zones for a specific design. All three types of LBE are collectively compared against the Safety Goals.

A key benefit of the process is that it provides a framework for evaluating events selected from past experience or from a deterministic point of view. Events below the EPBE region can be assessed on a best estimate basis to assure acceptably low residual risk. Exercising this feature makes the method risk-informed rather than solely risk-based by introducing deterministic questioning and judgment in order to test the robustness of the design.

The PBMR PRA will be complemented with deterministic views to select the LBE in this fashion.

Establishment of General Design Criteria

Determination of the required safety functions to maintain the DBE within the acceptable consequences provides a functional statement for the general design criteria (GDC). Figure 5 provides the top tier of design functions for radionuclide retention within the fuel during off-normal events that lead to the GDC. The functions during normal operation provide guidance to the development of technical specifications.

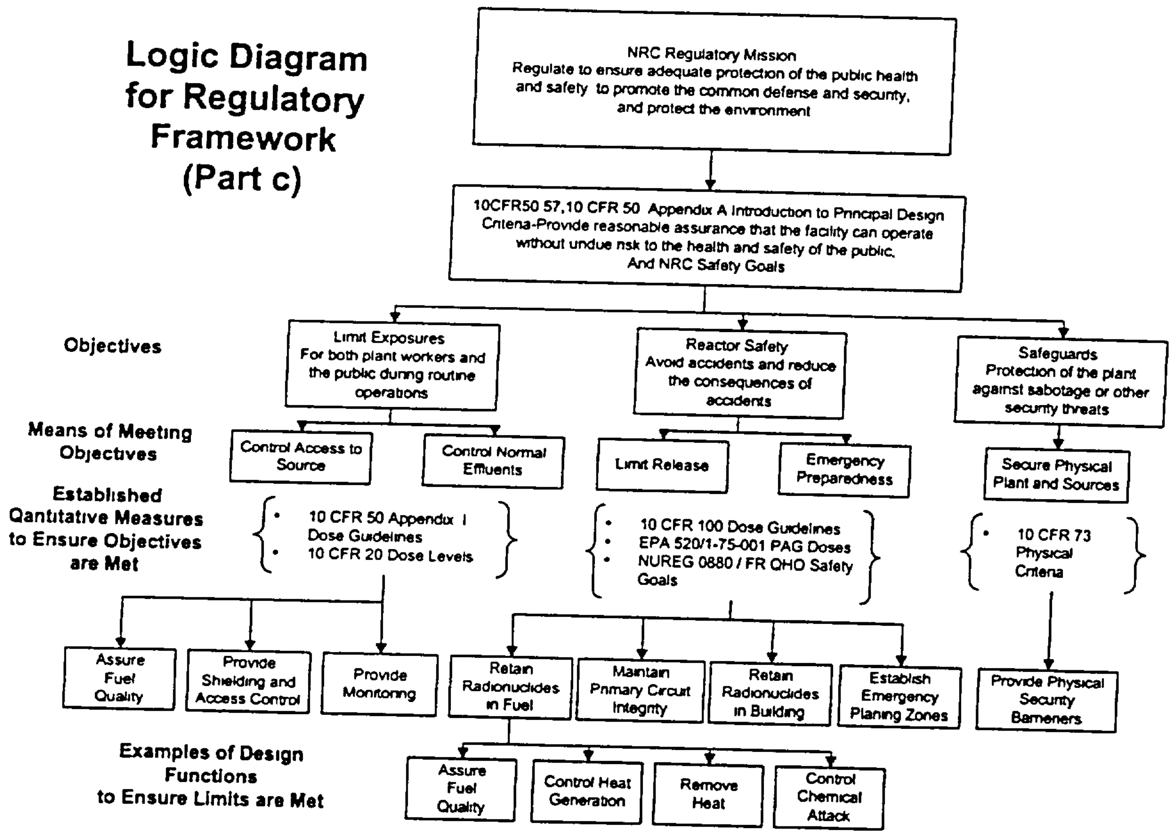


Figure 5. Regulatory Framework for PBMR with Required Safety Functions

Selection of Safety Significant Equipment Classification

Having determined the required safety functions and GDC for DBE to meet acceptable consequences, equipment can be selected to be classified as safety significant and thus requiring special treatment to assure acceptable performance. This classification focuses attention to a selected set of plant equipment that is required to perform all required functions to maintain doses under accident conditions within 10 CFR 100 limits.

The proposed method for selecting and determining design requirements for safety significant classification are generally as follows.

- For each identified DBE, classify as safety significant those systems, structures, or component design selections required to meet the DBE region dose criteria.
    - First, identify the functions relied upon for compliance with 10 CFR 100. It is at this level that functions are designated as safety significant.
    - All of the 10 CFR 100-related functions must be performed during all of the DBEs. However, in each DBE one or more of these major functions can be challenged by abnormal occurrence. Therefore, identify which design basis events present a challenge to each safety functions. By examining the DBEs a set of DBEs are identified which are most challenging to each function.
    - Finally, classify as safety significant a set of systems, structures or components, capable of accomplishing each function while considering all DBEs challenging these functions.
    - In order to satisfy economic and reliability considerations, special emphasis is placed on selecting passive systems, structures and components. Also only the aspects of the system, structure or component needed to accomplish the 10 CFR 100-related functions are classified.

- For each EPBE with consequences greater than that specified by 10 CFR 100, classify as safety significant those systems, structures, or component design selections chosen to assure that the event frequency is below the design basis region
    - This step ensures that systems, structures, or components may also be classified based on EPBE consequences.

- For each system, structure, or component classified as safety significant determine the design condition for its operation by examining all its associated DBEs and EPBEs.
    - For each system, structure or component classified as safety significant, a safety related design condition (SRDC) is defined to determine the design requirements. These SRDC are conservatively evaluated with the DBE in the SAR to show regulatory compliance.

This final step of examining the DBE with only the safety related equipment introduces a deterministic element into the overall framework.

Identification and Implementation of Applicable Regulatory Guides

The determination of fundamental safety significant functions, and their linkages to design specific review goals also provides guidance for the scope of other regulatory requirements for licensing and operation.

Summary

The use of top-down framework structure approach that uses an integrated risk-informed and deterministic licensing approach to assess advanced reactor designs like the PBMR will focus the regulatory attention on design and operational issues commensurate with their contribution of risk to the public. The use of probabilistic tools highlight design significant functions and guides the application of deterministic requirements.

This framework also offers the development of regulatory provisions for designs like the PBMR independent of Light Water Reactor deterministic licensing practices that may not apply. The approach ensures and verifies current regulations are met and provides a foundation for new gas reactor requirements and exemptions from inappropriate or unnecessary requirements.