Exelon Generation
200 Exelon Way
KSA3-N
Kennett Square, PA 19348

Telephone 610.765.5661
Fax 610.765.5545
www.exeloncorp.com

Exelon[SM] Generation

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U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Subject: Submittal of Pebble Bed Modular Reactor Containment Design Position Paper

Attached is an Exelon Generation Company (EGC), LLC position paper which documents EGC's initial approach to the Pebble Bed Modular Reactor (PBMR) containment design relative to applicable U.S. NRC regulatory policy. The information contained in this paper is not being provided to the NRC for review and comment. Rather this information is being provided as a guide for future NRC pre-application interactions regarding containment policy if PBMR licensing activities were to be resumed.

If you have any questions or concerns regarding this matter, please contact R. M. Krich or me.

Sincerely,

Kevin F. Borton
Manager, Licensing

Attachment

cc: Farouk Eltawila, Office of Nuclear Reactor Research
James Lyons, Office of Nuclear Reactor Regulation
Amy Cubbage, Office of Nuclear Reactor Regulation
Stuart Rubin, Office of Nuclear Reactor Research

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Attachment

"Pebble Bed Modular Ractor Containment Design
Position Paper"

Exelon Generation Company

Submitted May 31, 2002

10 Pages

Exelon Generation Company
Pebble Bed Modular Reactor Containment Design
Position Paper

The purpose of this paper is to document the current Exelon Generation Company (EGC) position and initial approach to address the Pebble Bed Modular Reactor (PBMR) containment design relative to applicable U.S. NRC regulatory policy. The information contained in this paper is not being presented to the NRC for review and comment since it is preliminary. Rather this information is being provided as a guide for future NRC pre-application interactions regarding containment policy if PBMR licensing activities were to be resumed. This paper describes the current PBMR containment design, the current NRC policy regarding containment covering advanced reactor designs and severe accidents. EGC considers these areas to be the pertinent aspects relating to NRC containment policy; however, it is also recognized that there may be other regulatory issues to consider regarding a future licensing approach.

Preliminary PBMR Containment Design and Philosophy

This section contains a description of the PBMR containment preliminary design. However, it is not intended to compare the design to US NRC requirements.

The PBMR containment building design incorporates several levels of defense against both internal and external challenges. The building itself is designed to withstand a Safe Shutdown Earthquake of a magnitude that includes most sites in the world. It also provides for the exclusion of damage due to non-commercial airplane crash, tornados, flooding, etc. Within this building there is an integral structure that supports and encompasses the main heat production and heat removal systems carrying high-pressure high temperature helium (see Figure 1). The probabilities of leaks in these helium pressure-retaining systems vary from expected to highly unlikely depending on the leak size. Small leaks are anticipated operational occurrences while the probability of catastrophic failure of large high-energy components is very low due to design requirements.

The high leakage containment system has an assumed normal leak rate of about 100% of the containment volume per day. Under normal operating conditions the heating, ventilation and air conditioning (HVAC) system circulates and filters the containment air with a final high efficient particulate air (HEPA) filter and activated charcoal filter in the exhaust duct. This filtration removes biologically important radioactive isotopes (e.g., iodine) from the air but offers no resistance to noble gases and Carbon-14. Small leaks in the primary helium pressure boundary are handled by the HVAC system ensuring that anticipated releases of radioactive material from containment are negligible. In order to protect the containment from possible damage due to the sudden failure of piping or other breaks up to an area of 33 cm^2, provision is made for a relief path from all areas where such breaks may occur. Such areas are provided with rupture panels that fail long before the containment system design pressure is reached and the resulting pressure is relieved through a shaft that opens to the roof (see Figure 1). In the case that such a leak occurs in a system that cannot be isolated, the complete helium inventory of the Main Power System will be lost to the environment through this shaft. The shaft is fitted with a device to automatically close this relief path once the pressure pulse has passed and as a backup a manually operated closure mechanism is also included. This ensures that normal containment conditions can be restored with a high degree of certainty shortly after the event. Thus, even if the breach in the pressure boundary is not immediately sealed, any later releases of fission products from the core, due to gradual heat-up of the fuel, will remain within the containment system. The HVAC system is fitted with mechanisms to protect it against undue pressures and temperatures. This again provides assurance that restarting the normal circulation of the containment atmosphere will be highly reliable.

Even if all the measures detailed here are not activated, the PBMR core design is such that only a limited amount of additional fission products will be released from the fuel. Once the reactor and containment are depressurized there is little driving force to vent additional radioactive material to the environment. Furthermore, taking deposition within the containment into account, the radiation dose at the edge of the EPZ is still low enough to not require off-site protective actions.

CONTAINMENT SYSTEM

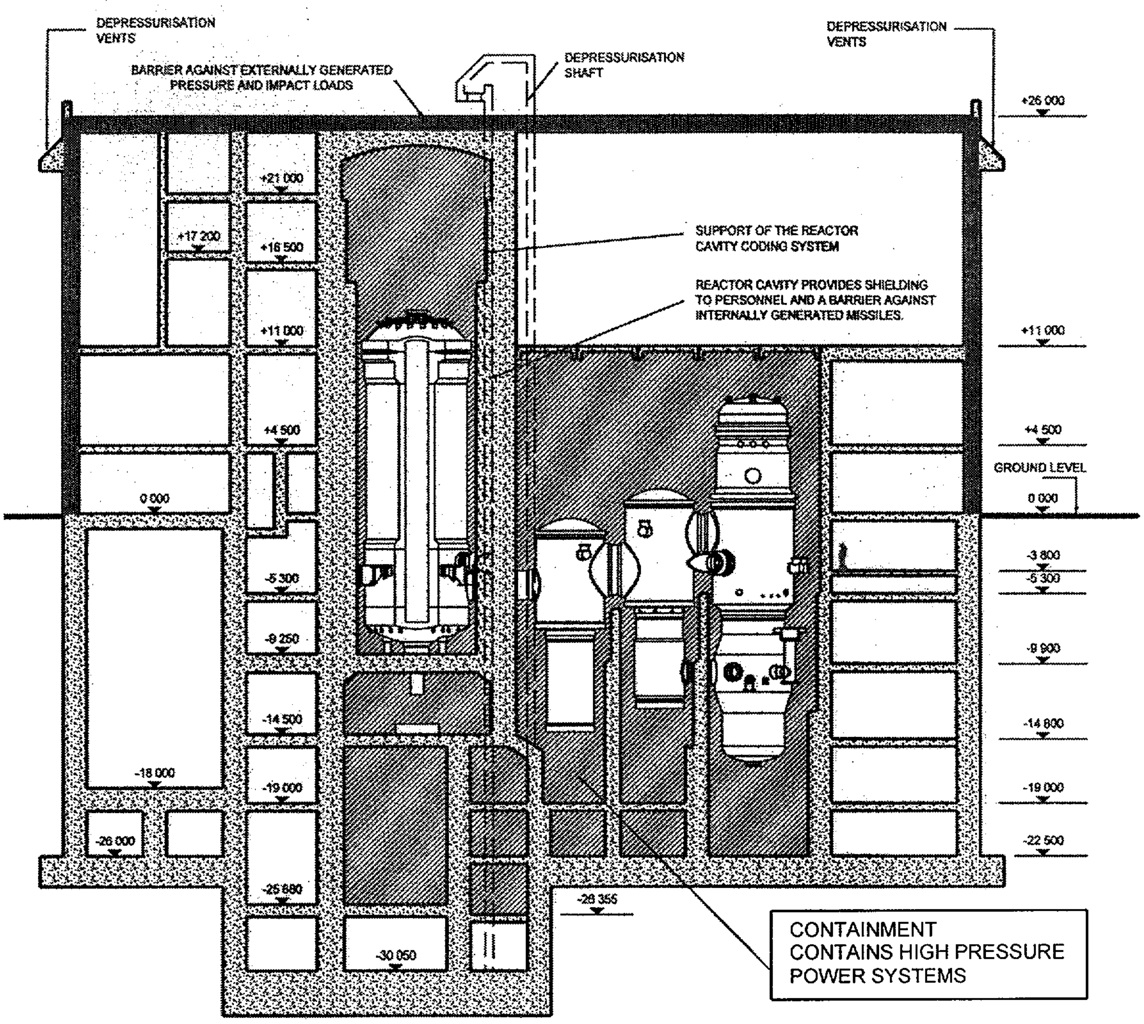

Figure 1.

Current Regulatory Policy

In the mid 1980's, the U.S. NRC issued an Advanced Reactor Policy that encouraged designers to utilize innovative design features with passive and inherently safe design characteristics for improved safety margins. The Modular High Temperature Gas-Cooled Reactor (MHTGR), which was reviewed by the NRC in the late 1980's as an advanced reactor, had a safety design approach and containment that is very similar to that of the PBMR (i.e., the design does not have a conventional leak-tight, light water reactor (LWR) containment; the containment will immediately vent and not retain the gases from rapid depressurization of the primary helium pressure boundary system; and the containment will have a leak rate of not greater than one building volume per day after depressurization).

In a Staff Requirements Memorandum (SRM) dated July 30, 1993 the Commissioners approved the NRC staff's recommendations contained 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," which pertained to leak-tight containments, by stating the following:

> *"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 NRC staff proposed this approach by comparing containment performance with the accident evaluation criteria provided in SECY 93-092 as follows.

- *"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."*

- *"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 levels (i.e., ASME Level C requirements or equivalent). After this period, the containment must prevent uncontrolled releases of radioactivity."*

SECY 95-299, "Issuance of the Draft of the Final Pre-application Safety Evaluation Report (PSER) for the Modular High-Temperature Gas-Cooled Reactor (MHTGR)" reaffirmed this NRC position.

> *"...the Commission decided that a conventional LWR, leaktight containment should not be required for advance reactor designs. It approved the use of containment*

functional design criteria for evaluating the acceptability of proposed containment designs rather than the use of prescriptive design criteria."

"This position for containment allows the acceptance of containments with leak rates that are not "essentially leak tight" as required in GDC 16 for LWRs."

This NRC position clearly recognizes the acceptability of the use of containment systems other than a conventional LWR leak-tight containment.

PBMR Design Meets the Regulatory Position for Containment Functions for Advanced Reactors

The PBMR safety design approach is fundamentally different from existing reactors. The focus on public and environmental safety has resulted in the selection of an evolutionary fuel design, which literally shaped and sized the reactor core to achieve an overall design where any consequence is limited to within the site boundary.

The PBMR containment system provides the following defense-in-depth.

- The PBMR fuel itself has a radionuclide barrier consisting of coatings that surround individual micro-spheres or fuel kernels and prevents the migration of radionuclides to the helium during normal operation and during accidents. This barrier design is effective since each fuel kernel has its own heat resistant pressure-retaining barrier, and the individual barriers retain very small quantities of fuel and fission products.
- The PBMR adds an additional layer of defense against radiological release events, which is preventive. The attributes of the PBMR design include the size of the reactor core, low power density, high thermal inertia (i.e., high heat capacity), fission product inventory limitation by means of on-line refueling, and the selection of evolutionary coated fuel particles. This arrangement precludes the possibility of event conditions that will cause the loss of the first radionuclide barrier: the coated fuel kernel. The PBMR also incorporates design attributes which ensure the first barrier (i.e., the coatings) can contain the radionuclides at the source (i.e., the fuel kernel) by passive means and without operator action for many days. Long-term actions are simple and insensitive to error.
  - The PBMR fuel performance (i.e., fuel coating integrity) has been demonstrated and therefore predictable: furthermore, fuel performance can be monitored during plant operation.
    - Extensive in-reactor and out-of-reactor testing that envelops a wide spectrum of design events has been performed.
    - Continuous on-line monitoring of circulating activity will assure real time monitoring of fuel performance throughout plant life.
- Similar to the traditional approach for fission product barriers, the PBMR core and primary helium pressure boundary system are enclosed within steel vessels. The

PBMR steel vessels and associated piping boundary are designed and fabricated to American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code requirements for both normal operation and accident conditions similar to LWRs.

- Finally, the containment building is a reinforced concrete structure that encloses the Reactor Pressure Vessel (RPV) and the Power Conversion Unit (PCU), which forms the outer fission product barrier. This barrier performs the following multiple functions.

  - The Reactor Cavity is that part of the containment building that encloses the RPV. The containment building and Reactor Cavity form a structural barrier and are designed to withstand significant external forces due to man-made and natural sources including small aircraft impacts and tornadoes.

  - The containment building is also vented. The containment is normally closed to the external environment and operates at lower than atmospheric pressure. This aspect is similar in design and function to the secondary containment structures for Boiling Water Reactors. Venting to atmosphere relieves any increase in pressure within the containment due to a range of breaches in the primary helium pressure boundary. Small leaks can be vented by means of the HVAC system. Medium to large leaks or breaks are vented through a dedicated pressure relief shaft to atmosphere. The design of the pressure relief shaft is such that quick acting valves in the HVAC system close to protect the HVAC system and a rupture panel in the depressurization route opens at a pre-determined pressure allowing the gas to escape to atmosphere. After release of the excess pressure, the shaft is closed automatically by a damper mechanism. A manual back-up closure mechanism is provided should this damper fail to operate. After isolation of the pressure relief shaft, the building controlled leakage integrity is restored and the HVAC is allowed to resume the conditioning of the environment inside the containment and return it to a sub-atmospheric pressure.

  - Any radioactive release that occurs during the venting of the high-pressure helium pressure boundary system would be significantly below regulatory levels because the amount of radioactive material that could be released is equal to the normal circulating activity in the helium at the time of the release. The PBMR is designed to prevent large inventory releases early in any event due to the individual fuel kernel coatings and the gradual and limited core heat up due to the core's size, low power density, high thermal inertia, and overall fission product inventory limitation described above. The amount of radioactive material in the helium is continuously monitored during plant operation and limited by the plant's operating license. If these limits were to be approached, the plant would be required to shutdown before they were exceeded. Furthermore, unlike an LWR, which continues to build up pressure due to the generation of steam after it is shutdown and thus provides a driving force for the further release of radioactive material, the PBMR does not continue to build up pressure after the helium has been released. Therefore, there is no driving force for the release of radioactive material after the initial depressurization. Once the pressure in the containment building is relieved and the vent is re-closed, there would be no pressure buildup within the building and no further pressure-driven releases would occur.

- In addition to HVAC filtration, the primary pressure vessel and associated piping, and the containment building also provide radionuclide hold-up and deposition functions.

A conventional LWR leak-tight containment superimposed on the PBMR containment system would not increase safety and would not serve the defense-in-depth objectives. None of the over 50 commercial gas cooled reactors worldwide have a conventional LWR containment. PBMR design basis event consequences result in offsite doses that are at background levels or do not exceed protective action guideline levels at the site boundaries; therefore, the addition of a conventional containment would have no measurable safety improvement.

In summary, PBMR design features reduce accident consequences by means of an aggregate barrier design that incorporates fuel, core design, primary pressure boundary, containment systems, building structures, and mitigative systems designs. NRC SECY 95-299 addressed this consideration as follows.

> *"5.2.2 Containment Performance*
> *This issue involves whether an advanced reactor design should be allowed to employ alternative approaches to the traditional "essentially leak-tight" containment structures for the current generation of LWRs to provide for the control of fission product releases to the environment. If the overall safety of a plant design is improved (i.e., smaller accident dose consequences outside the containment) by reducing the requirements on the containment and increasing the integrity of fuel on an advanced reactor design, then there is an incentive to improve the fuel and there is a basis for accepting a different containment design."*

PBMR Containment Design Consideration of the Severe Accident Policy Statement

The Severe Accident Policy Statement states that "the Commission intends to take all reasonable steps to reduce the chances of occurrence of a severe accident involving substantial damage to the reactor core and to mitigate the consequences of such an accident should one occur" (50 Federal Register (FR) at 32139). The Policy Statement further states that new plants will be acceptable with respect to severe accident concerns if they meet the following criteria.

- Demonstrate compliance with the TMI requirements in 10 CFR § 50.34(f) "Contents of applications: technical information";

- Demonstrate resolution of applicable Unresolved Safety Issues and the medium and high priority Generic Safety Issues;
- Completion of a Probabilistic Risk Assessment (PRA) and consideration of severe accident vulnerabilities exposed by the PRA; and
- Completion of NRC staff review that stresses deterministic engineering analysis and judgment complemented by the PRA.

The first three criteria listed above were subsequently codified by rulemaking, and now constitute requirements for a design certification or a combined license (i.e., 10 CFR 52.47(a)(1)(ii), (iv) "Contents of applications," and (v); 10 CFR 52.79(b) "Contents of applications; technical information"). Therefore, with respect to these criteria, the Severe Accident Policy Statement does not impose any new requirements on the PBMR beyond those already imposed by 10 CFR 52, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants." Furthermore, with respect to the last criterion, EGC's licensing approach for the PBMR[1] indicates that a variety of different deterministic considerations can be included in an application for a combined license, including defense-in-depth, safety margins, and existing regulations and guidance to the extent applicable to the PBMR. Therefore, the fourth criterion in the Severe Accident Policy Statement is also addressed by the PBMR.

In addition to the four criteria listed above, the Severe Accident Policy Statement states that there is a need for "a balance between accident prevention and consequence mitigation," and it provides extensive explanatory material on this principle (i.e., 50 FR at 32141). For example, the Policy Statement states that:

- An applicant should explore "the need for additional design or operational features to mitigate the consequences of core-melt accidents";
- Large, dry containments may be sufficient to mitigate a wide spectrum of core melt accidents, and "[i]ntegrated systems analysis will be used to explore whether other containment types exhibit a functional containment capability equivalent to that of large, dry containments";
- "It is clear that core-melt accident evaluations and containment failure evaluations should continue to be performed for . . . all future plant designs"; and
- "Design features should be emphasized that reduce the risk of early containment failure."

These principles are clearly intended for LWRs. If applied to the PBMR, they could be problematic since the containment for the PBMR is not equivalent to a large, dry

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1 EGC letter dated August 31, 2002 to U.S. Regulatory Commission, Attachment "Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States." Also see NRC letter dated March 26, 2002, "NRC Staff's Preliminary Findings Regarding Exelon Generation's (Exelon's) proposed Licensing Approach for the Pebble Bed Modular Reactor (PBMR)."

containment, and since the accident analyses for the PBMR will not assume core melt because it is not credible for the PBMR.

There are several other provisions in the Policy Statement that were explicitly intended for LWRs, and therefore, it may not be necessary to apply these principles to the PBMR and other innovative designs. For example, in issuing the Policy Statement, the NRC stated the following.

- *"It is assumed in this Policy Statement that, over the next 10 to 15 years, utility and commercial interest in the United States will focus on advanced light waters reactors that involve improvements but are essentially based on the technology that was demonstrated in the design, construction, and operation of more than 100 of these plants in the United States."* (50 FR at 32140).

Therefore, the Policy Statement principles above were primarily intended for LWRs and should not be applied to the PBMR given its other innovative features for preventing core melt and preventing fission product releases to the environment.

SECY-93-092 also contains criteria governing the selection of accidents and the source term. In particular, SECY-93-092, Enclosure 1, Section A states that the categories of events must include: 1) design basis accidents, and 2) accidents with a lower likelihood than design basis accidents. In addition to these two classes of events, the SECY also states:

> *"A set of events will be selected deterministically [by the NRC] to assess the safety margins of the proposed designs, to determine scenarios to mechanistically determine a source term, and to identify a containment challenge scenario."*

These deterministically selected events may have frequencies below 10^{-7}/yr, and are classified as "bounding events." For the MHTGR and PRISM, the NRC deterministically postulated a number of bounding events, stated that these events must be considered as licensing basis events, and required the pre-applicant to account for these events in determining the source term and containment performance.

The proposed licensing approach for the PBMR is consistent with this event selection methodology.

- The PBMR includes a Design Basis Event (DBE) region and an Emergency Planning Basis Event (EPBE) region. The EPBEs have frequencies that are lower than the DBEs and include events with a lower boundary frequency of 5×10^{-7}/yr. This value is within the range considered in SECY-93-092.
- In addition to DBEs and EPBEs, low frequency events postulated by the NRC will be evaluated.

- As discussed in the proposed licensing approach for the PBMR, the PBMR design will also include a balance between prevention and mitigation of events.
- The PBMR will have a containment (albeit, not a low leakage containment), and the design of the PBMR will ensure that the consequences DBEs and EPBEs will comply with their respective offsite dose limits.
- The source term will be based upon mechanistically determined releases for DBEs and EPBEs.

The PBMR will comply with the four criteria contained in the Severe Accident Policy Statement cited above, as follows. Although the Severe Accident Policy Statement criteria recommend that plants have a containment equivalent to a large, dry containment and a containment capable of mitigating a core melt, these recommendations appear to be intended exclusively for LWRs. Based upon subsequent guidance issued by the NRC in SECY-93-092, the containment and source terms for non-LWRs need to account for design basis events, lower frequency events down to about 10^{-7}/yr, and deterministic "bounding events" postulated by the NRC, while ensuring that the consequences of these events comply with their respective dose limits. The proposed licensing approach for the PBMR conforms to this guidance.

Conclusion

The preliminary PBMR containment design will meet the latest NRC policy regarding containment since the policy focuses on containment function and not leak-tight goals. The PBMR design can be shown to provide components or systems that can inherently or passively protect separate multiple barriers to the potential release of radioactive material to the environment. Finally, it can be demonstrated that the PBMR containment design is consistent with the Severe Accident Policy Statement.