D881013

The Honorable Lando W. Zech, Jr.
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Chairman Zech:

SUBJECT: PREAPPLICATION SAFETY EVALUATION REPORT FOR THE MODULAR HIGH TEMPERATURE GAS COOLED REACTOR

Introduction

During the 342nd meeting of the Advisory Committee on Reactor Safeguards, October 6-7, 1988, and in previous meetings of the Committee and our Subcommittee on Advanced Reactor Designs, we reviewed a draft of the subject Safety Evaluation Report (SER). During these meetings, we had the benefit of discussions with representatives of the NRC staff and its consultants, with representatives of the Department of Energy (DOE), and representatives of General Atomics, the chief design contractor for the Modular High Temperature Gas Cooled Reactor (MHTGR). We also had the benefit of the documents referenced.

The MHTGR concept is a product of a joint DOE/industry program to develop a design for a nuclear power plant using HTGR technology and having important inherently safe characteristics. The NRC staff is reviewing the concept under the advanced reactor policy to help assure that the final design will develop along lines acceptable to the NRC.

The draft SER indicates that the staff believes the conceptual design is generally satisfactory and that work directed toward eventual certification should continue. The staff has provided a number of conditions along with this endorsement and also believes that a continuing program of research and development will be necessary to support final design and eventual licensing.

We are in general agreement that design and development should continue along the lines outlined by the NRC staff. We can agree to moving forward, however, only because we understand that an NRC endorsement at this time does not imply a final commitment either to the general design or to its details. We believe that ongoing research and development can resolve important safety issues before licensing. We have a number of comments discussed below about the design.

Key Features of the MHTGR

The MHTGR differs in important ways from existing light water reactor (LWR) plants and from previous gas cooled reactor plants, including several new safety characteristics. The goal of the designers is that the improved safety features will more than make up for the absence of others (e.g., containment). They believe the MHTGR design will provide a plant that is safer than LWRs.

Safety of the MHTGR is keyed to properties of its unique fuel particles. Millions of these microspheres of enriched uranium oxycarbide, each the size of a grain of sand, are in the reactor core. Each fuel particle is coated with four successive protective shells that includes a buffer layer of a porous carbon and then bonded with others into a fuel rod which is, in turn, sealed in vertical holes in graphite blocks. These graphite blocks provide neutron moderation and are the chief structural material in the core.

The maximum fuel particle temperature in normal operation will be about 1150~C. An expected very small fraction of defective particles will cause a measurable, but acceptably low, level of chronic fission-product activity in the coolant and reactor systems.

So long as the particles are maintained below 1600~C, fuel, transuranics, and fission products will be retained by the particle coatings, with very high efficiency. At temperatures above about 2000~C, failures of particle coating will become significant, and above about 2300~C the coatings will fail completely. All other safety features of the reactor systems are designed to assure that particles will remain below 1600~C over a wide range of challenges and circumstances.

It is expected that temperatures can be maintained below 1600~C, in any conceivable reactor transient, because of two favorable characteristics of the reactor core: (1) Strong negative reactivity changes with increased temperatures in fuel or moderator and (2) Large thermal inertia of the core and fuel structure.

It is also expected that temperatures will be maintained below 1600~C even with loss of normal decay heat removal because of the following important features:

(1) The same strong temperature-reactivity effects will assure a very low equilibrium power even with failure of reactivity control and shutdown systems.

(2) At these low or decay power levels, if normal heat transfer systems fail, all heat can be removed from the reactor by a passive heat transfer system that permits atmospheric air to flow by natural convection through a cavity surrounding the reactor vessel. Under these conditions, the reactor core and the vessel will attain temperatures only slightly above their normal operating values.

(3) If this passive heat removal system should become unavailable (e.g., by blockage of air flow), heat at low power or at decay heat levels would be transferred from the reactor cavity by conduction directly to the earth surrounding the reactor building. Under these conditions, fuel would remain below 1600~C, but the reactor vessel would eventually heat to well beyond its normal operating temperature. Whether the reactor could be returned to normal operation after exposure of the vessel to such overtemperature is problematic at the present time. But, the vessel would remain sufficiently intact for the safe removal of decay heat.

The passive heat transfer functions in items (2) and (3) above require that the reactor core and vessel be small enough so that heat transfer can be accomplished without core temperatures becoming excessive. This dictates the reactor size and leads to the modular design and the long, small-diameter core.

The reactor core is normally cooled by inert helium gas circulated through the core at high pressure. Certain improbable failures of the reactor vessel could permit air to enter the core. However, air flow through the core by natural convection would be at a very low rate. With this restricted supply of oxygen, oxidation of graphite would be so slow that after many hours only a small fraction of the graphite would be consumed and the core would remain structurally intact. Even if the graphite should burn, through some undetermined mechanism, the indications are that the graphite temperature would be well below the 1600~C critical temperature for the fuel particles. The combination of nuclear decay and combustion heat would not be expected to increase core temperature to greater than 1600~C.

The Safety Issues

The challenge in assuring that the key safety characteristics claimed for the MHTGR design are realized in an actual plant is, in simplest terms, in assuring that the following issues are adequately addressed:

(1) Fuel particles must have the retention capabilities attributed to them and this must be assured with recognition of inevitable variability and imperfection in the fuel particles and their compaction process. This will require a higher level of quality in manufacture than has been achieved and must be experimentally verified.

(2) The reactivity and temperature-reactivity characteristics used in safety analyses are based on limited data. Further verification of these characteristics as a function of fuel burnup, core shuffling, and a variety of operational transients is needed.

(3) Inadvertent ingress of water or steam into the core must be precluded with high reliability. Water or steam could cause corrosion and mechanical damage to the graphite and would also add a positive reactivity contribution. This seems to be a possible complication of, for example, steam generator tube failures that is not present in LWRs. Internal flooding of the underground reactor cavity could lead to similar problems.

(4) There must be assurance that decay and low-power heat transfer can be accomplished without causing excessively high core temperatures. Performance of the passive atmospheric cooling system and the ability to conduct heat to the surrounding earth must be demonstrated.

(5) The structural properties of the graphite must be demonstrated and assured.

(6) Some of the important safety benefits of the design (e.g., passive decay heat removal and resistance to graphite burning) depend upon the core geometry remaining unperturbed. Questions of seismic resistance, effects of aging, and the possible cascading effects of certain reactor accidents remain to be fully answered.

A major issue is whether a conventional containment structure or some other mitigation system or process should be required. Neither the designers, the NRC staff, nor the members of the ACRS have been able to postulate accident scenarios of reasonable credibility, for which an additional physical barrier to release of fission products is required in order to provide adequate protection to the public. This does not mean that a conventional containment should not be provided or required as further defense in depth against unforeseen and unforeseeable events. However, it does mean that the design basis for a containment would have to be arbitrary, not altogether unlike what was done in the early days for LWRs. We believe that the decision to require a containment will have to be made on the basis of technical judgment, with appropriate consideration of the effects on other technically based safety features now a part of the design. In addition, there may be safety and economic tradeoffs between provision for containment and provision for passive decay heat removal.

Recommendations

A substantial program of research and development must be continued to support the final design for the MHTGR. This program should concentrate on providing assurances relative to the safety issues we have discussed above.

General Atomics has generated extensive data on fuel performance, but a comprehensive program on the reference fuel appears to be needed. This would include testing of irradiated fuel, fuel from large-scale manufacturing, and fuel exposed to a variety of environmental conditions and temperatures such as might be encountered in possible accidents.

A hot critical experiment may be necessary. The core is of an unusual geometry and has nuclear characteristics different from those in previous HTGRs. Assuring that the safety response of the plant is as predicted will require comprehensive information on the reactivity characteristics of the core over a broad range of normal and accident conditions.

More extensive analysis is needed of the response of the plant to accidents that might change the core geometry. Certain accident scenarios can be hypothesized that would affect core geometry and influence coolant distribution and reactivity characteristics.

A prototype should be built and appropriately tested before design certification.

Concepts for a containment or another sort of physical mitigation system require further study.

Finally, there are two issues identified in our letter to you dated July 20, 1988, "Report on Key Licensing Issues Associated With DOE Sponsored Reactor Designs," that we believe should be given early consideration as the design of this plant progresses. These issues are related to design for (1) resistance to sabotage and (2) operation and staffing. The appropriate excerpts from that letter are attached.

Additional comments by ACRS Members Forrest J. Remick and Charles J. Wylie, and William Kerr are presented below.

Sincerely,

William Kerr
Chairman

Additional Comments by ACRS Members Forrest J. Remick and Charles J. Wylie

In general, we agree with our colleagues in the above letter. However, we cannot in good conscience recommend a design of a nuclear power plant for design certification which does not have a conventional containment or other mitigation system which would serve as a more robust external barrier than is currently proposed to protect the public from radiological releases.

The designers of the MHTGR deserve much credit for their effort to incorporate inherent and passive safety features in the design concept. However, even though we believe that the proposed design has a good potential for providing enhanced safety, experience has shown that new reactor designs have technical unknowns. Because of the possible technical unknowns, the known uncertainties associated with the postulated inherent and passive safety features and the lack of experience with operation of a reactor of this new design, we do not recommend these reactors for design certification without a more extensive external barrier consisting either of a conventional containment structure or other appropriate mitigation system.

We think it important that the ACRS and the Commission make this technical judgment at this time in order that the designers of this promising reactor concept have ample opportunity to thoroughly consider alternate designs.

Additional Comments by ACRS Member William Kerr

I remind the Commission of the comments on containment included in the Committee's letter of July 20, 1988, namely:

> "We are not prepared at the present time to accept these approaches to defense in depth as being completely adequate. Further, we are not prepared at this time to accept the arguments that increased prevention of core melt or increased retention capacity of the fuel provide adequate defense in depth to justify the elimination of the need for conventional containment structures. This is not to say that we could not decide otherwise in the future, in response to an unusually persuasive argument."

That is still my position on the containment issue. I would add only that I have not yet heard the "persuasive argument."

References:

1. Office of Nuclear Regulatory Research, "Pre-Application Safety Evaluation Report for the Modular High Temperature Gas Cooled Reactor," dated August 1988 (Predecisional Draft)
2. Stone & Webster Engineering Corporation (DOE Contract), HTGR-86-024, "HTGR Preliminary Safety Information Document for the Standard MHTGR," Volumes 1-5, 1986
3. GA Technologies, Inc. (DOE Contract), DOE-HTGR-86-011, "HTGR Probabilistic Risk Assessment for the Standard Modular High Temperature Gas-Cooled Reactor," Volumes 1-2, January 1987

Attachment:

Excerpts from July 20, 1988 ACRS Letter, "Report on Key Licensing Issues Associated With DOE Sponsored Reactor Designs"