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Important viewpoints proposed for a safety approach of HTGR reactors in Europe Final results of the EC-funded HTR-L project

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Abstract

The inherent safety features of modular High Temperature Reactors (HTRs) make events leading to severe core damage highly unlikely and constitute the main differentiating aspects compared to LWRs. Furthermore, while a known and stable regulatory environment has long been established for Light Water Reactors (LWRs), different ways of thinking may help to develop a more appropriate licensing process for HTR-based power plants.

The HTR-L project funded by the European Commission in the 5th Framework Programme was dedicated to the definition of a common and coherent European safety approach and the identification of the main licensing issues for the licensing framework of the modular HTRs. Several topics were developed during the course of this project.

Due to the characteristics of the HTR design, it has been necessary to define specific defence-in-depth requirements which have then been evaluated for implementation in the safety approach. Safety-related functions appropriate for the HTR design have also had to be identified and listed.

On one hand, the different possible solicitations of the fuel particles constituted the starting point for the identification of the accidental conditions (by means of the Master Logic Diagrams methodology); these accidental conditions were classified and the most appropriate methods to consider ultra low probability severe accidents were examined.

On the other hand, the elements constituting the source term and, in particular, the requirements for the confinement of radioactive products and the conditions required to prevent the need for a “conventional” containment structure have been discussed.

In the definition of the safety approach, attention has been paid to the need to maintain the potentially interesting economic perspectives of HTR reactors. Key issues to be addressed in the licensing process of the HTRs have also been identified. An innovative systems, structures and components classification method has been developed and rules that will govern equipment qualification proposed.

1. Introduction

The major issues related to public acceptance of nuclear technology are non-proliferation, safety and nuclear waste. It appears that HTRs could generate a significantly improved level of public

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acceptance compared to existing reactors. The inherent safety features of the modular HTR (which make events leading to severe core damage highly unlikely), its potential for use in high temperature industrial processes and the possibility of using direct cycle gas turbines are some of the main aspects that set it apart from LWRs.

The designs of High Temperature Reactors (HTRs) are very different from those of Light Water Reactors (LWRs) for which a known and stable regulatory environment has been established for many years. In LWRs the possibility of core meltdown has largely driven the safety philosophy. The existing known and stable regulatory environment established for Light Water Reactors is not well suited for the licensing of modular HTR power plants and, therefore, a different approach is necessary. A tailored set of safety requirements derived from the general consolidated principles of nuclear safety should be developed incorporating the specific characteristics of this kind of reactors.

2. The inherent safety of the modular HTR reactors

The modular HTR reactors (MHTRs) appear as very simple to operate, with inherent passive safety features and low possibility of reactivity incidents; moreover, decay heat removal can be ensured by natural convection. The main inherent safety characteristics of the HTRs are the result of several design features, i.e.:

- The use of refractory-coated fuel particles embedded in a graphite matrix which retain the fission products. Kernels coated with carbon and silicon carbide (SiC) layers have greater heat-resistance than those coated with metallic materials: this provides a unique robustness of the first barrier for the fission products (Fig. 2).
- The strong negative temperature coefficient of the core, which tends to passively shut down the reactor with relatively modest temperature rise above normal temperature.
- The use of inert, single phase helium gas as coolant and of graphite with high temperature stability and long response times as moderator.
- A very slow temperature transient of the reactor if the active cooling of the core is lost (Fig. 1). This is made possible by the high thermal inertia of the graphite and the core structure, and the low power density of the core (less than 10 MW/m^3, compared to at least 50 MW/m^3 for a LWR).
- Possibility for passive decay heat removal and core cooling. The core can be configured to have a large core surface-to-volume ratio; combined with the low power density and an annular core, this makes possible passive heat removal (by thermal radiation, heat conduction and free convection (Fig. 3)) from the core and the outer surface of the pressure vessel, even under the worst accident conditions. In these conditions the maximum fuel temperature can be maintained below the integrity limit of the ceramic-coated fuel (Figs. 1, 2 and 4).

The modular HTR represents a fundamental change in reactor design and safety approach: the safety is achieved through the combination of inherent safety characteristics of the HTRs

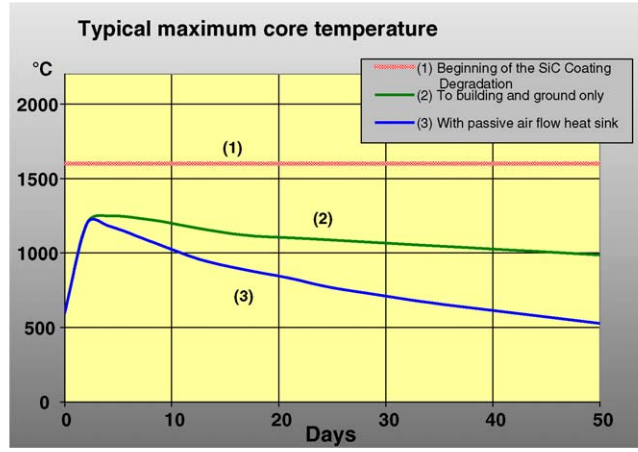

Fig. 1. Typical maximum core temperature.

design and selection of features that maximize these inherent safety characteristics.

The safety features of the modular HTR are based on the design condition that, even in the case of failure of all active cooling systems and complete loss of coolant, the fuel element temperatures would not exceed the limits at which most radioactive fission products remain confined within the fuel elements. For example (Fig. 3), the GT-MHR (LaBar, 2002) has two active heat removal systems, the power conversion system and the shutdown cooling system that can be used for the removal of decay heat. In the event that neither of these active systems is available, the reactor cavity cooling system (RCCS) surrounding the reactor vessel ensures the removal of core decay heat: this constitutes an independent passive means. Core decay heat is transferred by conduction to the pressure vessel and then by radiation from the vessel to the natural circulation RCCS. If the RCCS is assumed to fail, heat is removed by conduction into the reactor cavity walls and surrounding earth: this mechanism is sufficient to maintain maximum core temperature below the design limit.

The low core power density (about 6.5 MW/m^3 versus above 50 MW/m^3 for a LWR), the limited core diameter (effective core diameter of about 3 m) and the annular core configuration are

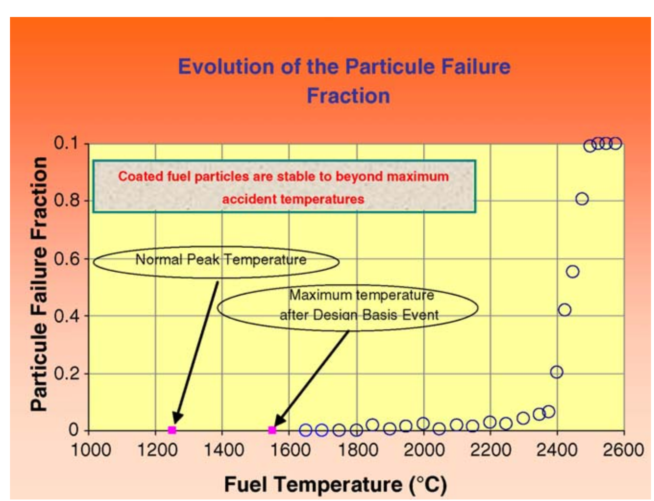

Fig. 2. Evolution of the particle failure fraction.