—SUMMARY—

Making Core Melt Accidents Impossible in a Large 2400-MW(t) Reactor

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INTRODUCTION

How can high power levels be achieved in nuclear reactors while making major core damage accidents impossible? We propose that with the use of molten salts, the Advanced High-Temperature Reactor (AHTR) may be built in sizes up to 2400 MW(t) with this capability. This exceeds the 600 MW(t) size of the modular high-temperature gas-cooled reactor (MHTGR)—the reactor concept that currently has the best capability to avoid these accidents.

To prevent reactor core damage from decay heat, the fuel must not reach its failure temperature. If core cooling is lost, the core temperatures can be controlled by a combination of (1) absorbing decay heat in the structure of the reactor and (2) transporting heat to the environment. Decay heat decreases with time; thus, reactors with large heat capacities to absorb the initial decay heat require smaller decay heat removal systems to avoid high temperatures that fail the fuel.

REACTOR DESCRIPTION

The AHTR[1] is a high-temperature reactor that uses coated-particle graphite-matrix fuels and a molten-fluoride-salt coolant. The fuel is the same type that is used in MHTGRs, with fuel failure requiring temperatures exceeding 1600ºC. The molten-salt coolant is a mixture of fluoride salts, typically containing a mixture of zirconium, sodium, and other fluoride salts with freezing points near 400ºC and atmospheric boiling points of ~1400ºC. The reactor operates at atmospheric pressure. At operating conditions, the salt heat-transfer properties are similar to water. The reactor vessel is located in an underground silo (Fig. 1).

The passive decay-heat cooling system of the AHTR consists of two components: (1) the heat capacity inside the reactor vessel and (2) the air-cooling system, which is assumed to have failed in a beyond-design-basis accident such as the scenario being considered herein. When the passive decay-heat system is operating, it takes 50 hours before the reactor reaches its nominal peak temperature following the loss of normal cooling. The slow heat-up of the reactor vessel is a consequence of three factors: (1) high heat capacity of the fuel, (2) high heat capacity of the molten salt, and (3) effective heat transfer by natural circulation of the molten salt. Because of the circulating molten salt, the entire reactor core and the large salt pool are maintained at about the same temperature.

BEYOND DESIGN BASIS ACCIDENT

If the reactor vessel fails (loss of decay-heat cooling system), molten salt coolant from the reactor vessel fills the bottom of the silo. The reactor vessel contains sufficient salt to keep the reactor core flooded. The circulating molten salt between the reactor vessel and silo efficiently transfers heat from the reactor vessel to the silo wall. The silo wall contains low-cost thick steel rings, similar to those used in the mining industry to maintain deep mine shafts. These rings efficiently conduct heat up the wall to an annular ring of a secondary solidified molten salt. The melting secondary salt flows into and floods the silo. The steel ring and the secondary salt provide a large additional heat capacity to absorb heat.

The molten-salt coolant has a boiling point of ~1400ºC, 200ºC below the fuel failure temperature. The secondary salt has a lower boiling point. Consequently, boiling salt prevents fuel failure. The cooler temperatures of the steel result in a frozen layer of salt on the silo surface and condensing salt components above the liquid salt level. The molten salts, steel rings, and condensing of condensing of salt components distribute heat uniformly over the silo surface.

The AHTR with the same vessel dimensions as the MHTGR can have a much higher rate of decay heat generation (reactor power) without major fuel damage in a beyond design basis accident.

- The heat capacity of the molten salt (coolant and secondary silo salt) is large compared with those of helium and air.

- The efficient liquid heat transfer reduces temperature drops between the hottest fuel and silo wall with full use of the heat capacity of all components. In contrast, the hottest fuel assembly in the MHTGR has a temperature near 1600ºC while the outer reactor vessel is below 600ºC and the silo temperature is even lower. These large temperature drops are needed to move heat by conduction or natural circulation of a gas.

- The steel ring, molten salt, and boiling/condensing salt ensure a uniform high silo temperature to efficiently dump heat to the ground.

The assumptions, options for the secondary-salt, peak salt temperatures under different assumptions, tradeoffs, and the major uncertainties are described in the paper.

REFERENCES

1. C. W. Forsberg, P. F. Peterson, and P. S. Pickard, “Molten-Salt-Cooled Advanced High-Temperature Reactor for Production of Hydrogen and Electricity,” *Nuclear Technology* 2003 (in press).

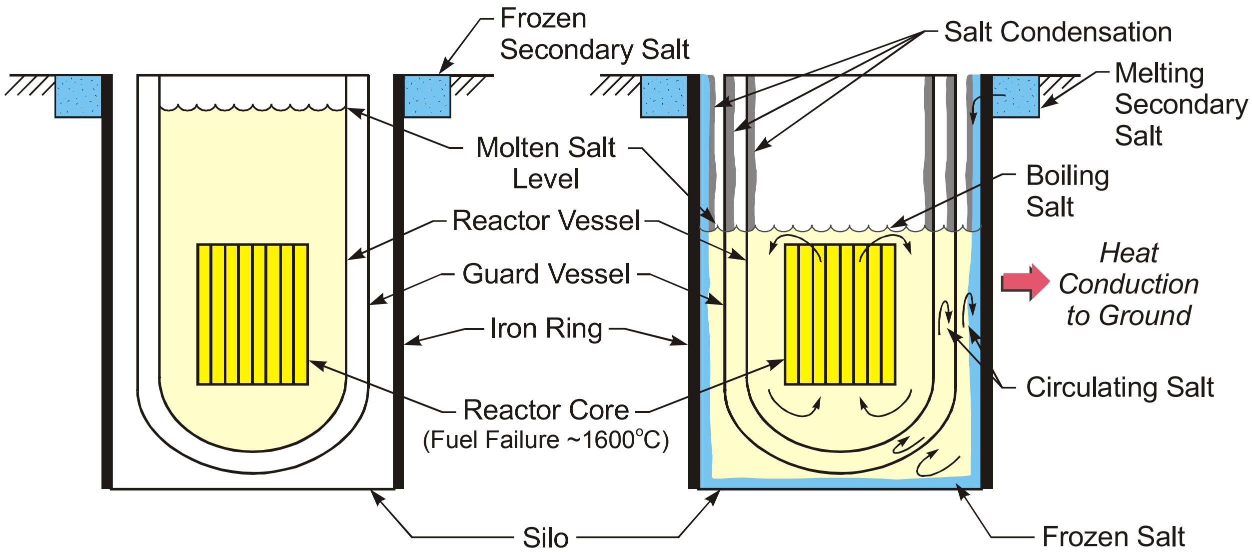

Fig. 1. Reactor and Silo Before and After an Accident.