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Core concept of a passive-safety fast reactor "METAL-KAMADO" and reactivity coefficients

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Abstract

New concept of a passive-safety simple fast reactor "METAL-KAMADO" with metallic fuels is presented, which has same concept as a passive-safety thermal reactor "KAMADO". A fuel element of the "METAL-KAMADO" consists of metallic fuel (U−10%Zr) and cooling holes of He gas flow. These fuel elements are located in a reactor water pool of atmospheric pressure (0.1 MPa) and low temperature (<60 °C). In case of LOF, decay heats of fuel elements are removed by natural heat transfer from surfaces of the fuel elements to the reactor water pool.

Preliminary neutronic calculations of the "METAL-KAMADO" show possibility of high burn-up of more than 120 GWd/t with 10% enriched U−Zr fuel. Reactivity coefficients of the core are also discussed.

Keywords: Passive-safety; Metallic fuel; Simple design; Effective use of uranium resource

1. Introduction

We have proposed new concept of a passive-safety thermal reactor "KAMADO", which has negligible possibility of core melting and flexibility of total reactor power scale. The reactor core of KAMADO consists of fuel elements of graphite blocks, which have UO_2 fuel rods and cooling water/steam holes (Matsumura et al., 2002, 2003, 2005a,b; IAEA-TECDOC, 2006).

In present paper, we will present new concept of a passive-safety fast reactor "METAL-KAMADO" with metallic fuels, which has same concept as a passive-safety thermal reactor "KAMADO". A fuel element of the "METAL-KAMADO" consists of metallic fuel (U−10%Zr) and cooling holes of He gas flow, which has some similarity with the tube-in-shell concept of a FBR fuel element (Hiraoka et al., 1991). These fuel elements are located in a reactor water pool of atmospheric pressure (0.1 MPa) and low temperature (<60 °C). In case of LOCA (Loss of coolant accident), LOF (Lose of flow), decay heat of the fuel element is removed by natural heat transfer from surfaces of the fuel element to the reactor water pool.

Preliminary neutronic calculations of the "METAL-KAMADO" show possibility of high burn-up of more than 120 GWd/t with 10% enriched U−10%Zr fuel. Reactivity coefficients of the core are also discussed.

2. Concept of reactors and fuel elements

Fig. 1 shows basic concepts of the present reactor designs of KAMADO and METAL-KAMADO. Cooling materials are fed from bottom of fuel elements in both concepts. Cooling materials are heated in reversed U-type holes in the fuel elements. The passive-safety fast reactor METAL-KAMADO has similar design to KAMADO except for He gas of coolant. Heated He gas is transported to a gas turbine and/or a steam generator (SG). These fuel elements are located in reactor water pools of atmospheric pressure (0.1 MPa) and low temperature in both concepts. Main differences between KAMADO and METAL-KAMADO are designs of fuel elements.

Fig. 2 shows basic concepts of fuel elements of KAMADO and METAL-KAMADO. A fuel element of KAMADO is

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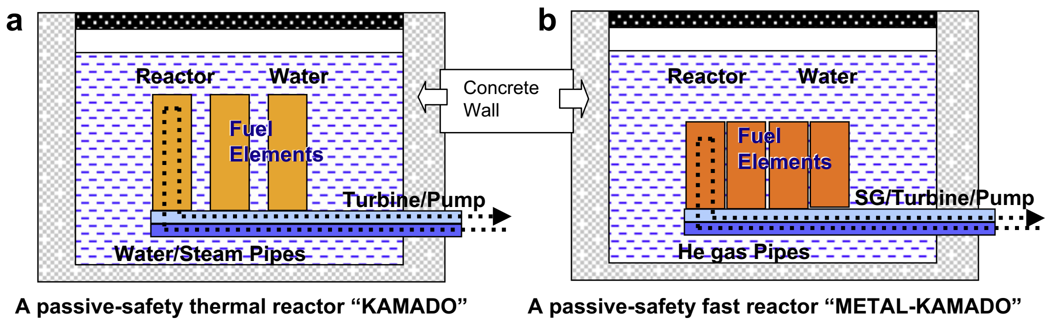

Fig. 1. Overviews of (a) "KAMADO" and (b) "METAL-KAMADO".

composed of UO_2 fuel rods and cooling water tubes in a graphite block. In METAL-KAMADO, a fuel element is composed of U−10%Zr metallic fuel and cooling He gas holes. Cooling He gas holes are located in the U−10%Zr metallic fuel.

In normal power operation of METAL-KAMADO, the fuel element is cooled with He gas flow in the holes [(1) in Fig. 2(b)]. In case of loss of coolant/flow accidents, decay heat is removed from surface of the fuel element and decay heat cooling holes [(2) in Fig. 2(b)], which are connected with the reactor water pool directory. In the passive-safety thermal reactor concept of KAMADO, reactor is shutdown passively with negative void reactivity coefficients in case of accidents. In the passive-safety fast reactor concept of METAL-KAMADO, loss of He gas has negligible reactivity effect due to small cross-section of He. However, there is small amount of water/steam between fuel elements and in decay heat cooling holes. In normal power operation of METAL-KAMADO, void ratios of these water/steam are very high (e.g. more than 80%) due to high temperature of fuel elements. Present very high void ratios contribute harder neutron energy spectrum of METAL-KAMADO core design, and higher conversion/breading ratio. In reactor shutdown, re-flooded water contributes cooling of decay heat. Reactivity coefficients and neutronic passive-safety feature are discussed in next section.

A fuel element is attached to a cooling He gas pipe using flange. A fuel element is refueled by taking the flange off and exchanged with an entire fuel element. The present concept has simple plant system design without a reactor pressure vessel, ECCS, and others.

Metallic fuels are used in water cooled research reactors and sodium cooled fast reactors such as EBR-II (Sackett, 1997). As metallic fuel shows remarkable swelling due to burn-up, 30% of smear density is used in present concept design similar to EBR-II fuel. As sodium bonding cannot be used in METAL-KAMADO fuel elements, He gas bonding is adapted.

Fuel volume ratio of 40% is used in present concept design for improving conversion/breeding ratio and burn-up of the fuel. This high fuel volume ratio was made possible with tube-in-shell type fuel element concept. Volume ratios are 46% for cooling He gas, 11% for structure material, 3% for water/steam between fuel elements and in decay heat cooling holes, respectively. Inner diameter of a cooling He hole is set to be 10 mm for cooling performance of 20 kW/m with reasonable He gas flow rate.

Table 1 shows basic parameters of KAMADA and METAL-KAMADO. Electric power output is set to be 300 MWe for passive-safety thermal reactor KAMADO design. Present METAL-KAMADO design has larger electric power output of 1000 MWe to reduce neutron leakage of the core and improve neutronic core performance. Both of KAMADO

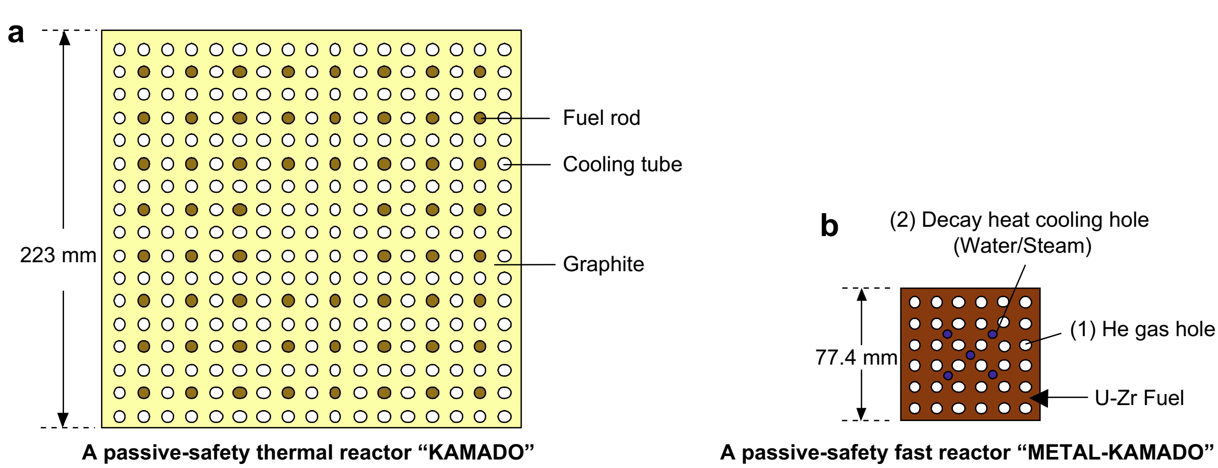

Fig. 2. Tentative fuel element concepts of (a) "KAMADO" and (b) "METAL-KAMADO".