Conceptual Design of a Fluidized Bed Nuclear Reactor

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Abstract—A new type of nuclear reactor is presented that consists of a graphite-walled tube partly filled with TRISO-coated fuel particles. Helium is used as a coolant that flows from bottom to top through the tube, thereby fluidizing the particle bed. Only when the coolant flow is large enough does the reactor become critical because of the surrounding graphite that moderates and reflects the neutrons.

The fuel particle designed for this reactor is strongly undermoderated and has a temperature coefficient of reactivity that is sufficiently negative. The outer diameter is 1 mm with a fuel kernel diameter of 0.26 mm. The fuel enrichment (16.7%) and the core inventory (120 kg of uranium) inherently limit the maximum power to 16 MW(thermal).

A lumped-temperature point-kinetics model has been made that describes the fluidization of the particle bed, coupled to the thermal hydraulics and the neutronics of the core. The model has been linearized around the stationary solution, and the transfer function from coolant mass flow rate perturbations to reactor power fluctuations has been calculated. From a root-locus analysis, the reactor operation is shown to be stable with respect to small variations of the coolant mass flow rate around the stationary operation points.

Transient analyses with the nonlinear reactor model show that for the three transients considered (a step in the coolant mass flow rate, a decrease of the coolant inlet temperature, and a loss of heat sink), the fuel temperature remains well below 1600°C. Recommendations are made for further research.

I. INTRODUCTION

To meet the growing demand of electricity in the world, new nuclear reactors should be developed that are superior to the present ones with respect to safety, economics, waste management, nonproliferation, etc. For this reason, the U.S. Department of Energy and other organizations emphasized at the PHYSOR’2000 meeting the need for so-called fourth-generation reactors and have initiated the Nuclear Energy Research Initiative to stimulate the development of these reactors.¹

This paper describes a conceptual design of a fluidized bed nuclear reactor that can be used as a starting point for the development of a fourth-generation reactor. The integrity of the reactor is ensured by the fact that its safety philosophy is based on physics laws only and that its fuel consists of TRISO-coated particles that can withstand very high temperatures. Helium is used as a coolant, which offers the advantages of a high core outlet temperature and the use of a highly efficient direct-cycle gas turbine. The design is very simple, which allows for modularity during the manufacturing. Furthermore, no active devices are needed to control the reactor because it is a self-regulating thermostatic installation. In other words, the reactor’s power is automatically adapted to the needs of the grid.

The fluidized bed reactor concept is not new. Sefidvash published many papers² on the design of a fluidized bed nuclear reactor fueled with spherical fuel elements with a diameter of 8 mm that are lifted by an upwardly flowing light water coolant. Recently, the dynamic stability of such a reactor was investigated,³ and it was shown that in this respect, a fluidized bed reactor is similar to conventional reactors. A similar concept with spherical fuel elements with a diameter of 10 mm has been published by Mizuno et al.⁴ In this reactor concept, the water that is used for the fluidization of the fuel elements is allowed to boil. A concept more similar to ours is the pellet suspension reactor (PSR) developed by Harms and his colleagues.⁵ In this reactor, micro fuel