U.S. DEPARTMENT OF ENERGY
INTERNATIONAL NUCLEAR ENERGY RESEARCH INITIATIVE
DOE/CEA

ABSTRACT

Development of Improved Models and Designs for Coated-Particle Gas Reactor Fuels

Primary Investigator (U.S.): David Petti, Idaho National Engineering and Environmental Laboratory

Primary Investigator (France): Philippe Martin, DEN/DEC/SESC CEA

Collaborators: Massachusetts Institute of Technology

Project Number: 2001-003-F

Project Start Date: September 29, 2001

Project End Date: September 30, 2004

High-temperature gas-reactor technology is achieving a renaissance around the world. Preliminary research has concluded that this technology has an excellent opportunity to satisfy the safety, economic, proliferation, and waste disposal concerns that face nuclear electric generating technologies. The potential economics of gas reactors are attractive enough that development continues in a number of countries. Small gas research reactors have been built in Germany, Japan and China. Russia and the United States have a project to develop a Modular High Temperature Gas Reactor (prismatic type) to burn excess plutonium. An ambitious project in this area is being pursued by a large utility in South Africa (ESKOM), which is proposing to build a 110 MWe pebble-bed gas reactor for commercial electric generation within the next five years. Fast reactors with gas coolant and a self-sufficient fuel cycle may also be needed in the future.

Many technical issues must, however, be addressed before construction of gas-cooled reactors becomes commercially viable. One of the most important issues is the behavior of coated particle gas reactor fuels during normal, off-normal, and accident conditions. The experience with coated-particle gas reactor fuels over the last 30 years is that some have performed well while others have performed poorly. No consensus has been reached in explaining the observed differences in fuel behavior.

The classical gas reactor coated-particle fuel is a spherical layered composite of microscopic dimensions. It has a fissile fuel kernel, generally made of UO_2 or UC_2, or UCO, that is surrounded by a porous graphite buffer layer that absorbs radiation damage, allows space for fission gases produced during irradiation, and resists kernel migration at high temperature. Surrounding the buffer layer is a layer of dense pyrolytic carbon, an SiC layer, and one or two dense outer pyrolytic carbon layers. The pyrolytic carbon layers act to protect the SiC layer, which is the primary pressure boundary for the micro-sphere. The inner pyrolytic carbon layer also protects the kernel from corrosive gases that are present during the deposition of the SiC layer. This layer arrangement is known as the TRISO coating system. Each micro-sphere acts as a mini pressure vessel, a feature that is intended to impart robustness to the gas reactor fuel system.

Compared to light water reactor and liquid metal reactor fuel forms, the behavior of coated-particle fuel is inherently more multi-dimensional. This is due to such anomalies as potential shrinkage cracking in the Inner Pyrocarbon (IPyC) layer, potential de-bonding between coating layers, and some degree of particle asphericity. Fuel behavior is

2001-003-F (continued)

further complicated by statistical variations in fuel physical dimensions and material properties from particle to particle due to the nature of the fabrication process. Previous models of coated fuel have typically been simplified one-dimensional models designed to perform simulations on large populations of particles at a reasonable speed.

The challenge addressed in this project is to produce an integrated mechanistic model for coated-particle fuel that accurately accounts for the multi-dimensional behavior of the coating layers, chemical changes of the fuel kernel during irradiation, and statistical variations in the dimensions and properties of the coating layers. The advent of powerful personal computers and the advancements in fundamental modeling of materials science processes should make this possible. Results from the model will facilitate the design of coated particle fuel for the gas reactor or other particle fuel applications.