NUCLEAR ENERGY RESEARCH INITIATIVE

Coupling of High Temperature, Lead-Cooled, Closed Fuel Cycle Fast Reactors to Advanced Energy Converters

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The three-year program of research and development aims to develop high-temperature modular nuclear plant concepts that take advantage of the sustainability benefits of a fast neutron spectrum core; the safety benefits of molten lead primary coolant; and the cost advantages of modular construction, factory fabrication, and simplification with natural circulation heat transport. At the same time these plant concepts would achieve sufficiently high coolant temperatures to drive an advanced power conversion system-for example, a gas turbine Brayton cycle using supercritical carbon dioxide-providing efficiencies competitive with those claimed for high temperature gas reactor (HTGR) concepts. Unlike HTGRs, the concepts provide the sustainability and economic fuel cycle benefits of a liquid metal-cooled fast reactor. Unlike conventional fast reactors, utilization of a gas turbine, compressors, recuperator, precooler, intercoolers, and supporting components offers radical plant simplification, reduced staffing levels, and cost savings, as well as greater efficiency relative to a Rankine cycle water-steam system, but at traditional liquid metal reactor (LMR) temperatures of approximately 550°C.

Lead (T_{mp} = 327°C) is selected as the primary coolant based upon its high boiling temperature (1,740°C) and inertness; lead does not burn when exposed to air. When operating at higher-temperature, Brayton-cycle conditions, the high melting point (327ºC) ceases to be as large a problem as under Rankine cycle conditions. Lead is less corrosive than bismuth, especially at elevated temperatures. Small module power (e.g., approximately 400 MWth) enables 100+ percent natural circulation of the primary coolant, enhancing plant simplification, reliability, cost savings, and passive safety. The fast spectrum core with negative reactivity feedbacks facilitates nearly autonomous operation whereby the core power automatically adjusts itself to load changes as a result of inherent physical processes. Heat rejection to a gas also favors autonomous load following over a wider range of power levels. The reactivity feedback coefficients together with a passive reactor exterior cooling system utilizing air driven by natural circulation also effect passive core power shutdown in the event of accidents such as a loss-of-heat sink.

The utilization of supercritical carbon dioxide as the Brayton cycle working fluid could provide cycle efficiencies of about 45 percent at core outlet temperatures as low as 550°C. Increases in efficiency to well over 50 percent could be achieved with supercritical carbon dioxide by increasing the lead temperature. The achievement of such high efficiencies, even at traditional fast reactor temperatures, is a result of the low amount of work required to compress carbon dioxide immediately above the critical pressure as compared to the case of nonsupercritical He or CO_2. The supercritical CO_2 approach is particularly attractive because it works at temperatures traditionally reached in LMR systems, whereas if gaseous (i.e., nonsupercritical) helium or carbon dioxide were utilized as the Brayton cycle working fluid, cycle efficiencies of 45 to 50 percent would be achieved only by heating the gas to a core outlet temperature of nearly 900°C. In that case, a main challenge would be the identification of cladding, fuel, and structural materials for use with molten lead at elevated temperatures as well as innovative techniques for the manufacture of components from these materials. The need for experiemental data to undertake further development will be evaluated.

The goal to move away from the Rankine steam cycle to modern energy converters will not stop at the Brayton cycle. As an alternate to a gas-turbine energy converter, magnetohydrodynamic (MHD) generators for direct power conversion can potentially take advantage of the high electrical conductivity of liquid metals such as molten lead. A MHD generator converts fluid kinetic energy to electrical energy.

Argonne National Laboratory, as well as the Forschungszentrum Karlsruhe in Karlsruhe, Germany, will partner with Oregon State University (OSU) on various aspects of the project.