U.S. DEPARTMENT OF ENERGY
NUCLEAR ENERGY RESEARCH INITIATIVE
ABSTRACT

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Title: **Feasibility Study of Supercritical Light Water Cooled Fast Reactors for Actinide Burning and Electric Power**

The use of supercritical pressure light water as the coolant in a direct-cycle nuclear reactor offers potential for considerable plant simplification and consequent capital and O&M cost reduction compared with current light water reactor (LWR) designs. Also, given the thermodynamic conditions of the coolant at the core outlet (i.e. temperature and pressure beyond the water critical point), very high thermal efficiencies of the power conversion cycle are possible (i.e. up to 46%). Because no change of phase occurs in the core, the need for steam separators and dryers as well as for BWR-type recirculation pumps is eliminated, which, for a given reactor power, results in a substantially shorter reactor vessel than the current BWRs. Furthermore, in a direct cycle the steam generators are not needed.

If a tight fuel rod lattice is adopted, it is possible to significantly reduce neutron moderation and to attain conditions for which the reactor core operates with a fast neutron energy spectrum. A supercritical water fast breeder reactor that makes use of oxide fuels was studied in Japan at the University of Tokyo. Their core employs long fuel rods (i.e. 3.5m) and it is rather complicated as it comprises of one outer and two inner radial blankets, an axial blanket, two seed regions and several layers of zirconium hydride to attain a negative void reactivity coefficient. Because breeding is not currently of interest, we propose to explore an alternative supercritical water reactor concept with a simple, blanket-free, pancake-shaped core. This type of core can make use of either fertile or fertile-free fuel and retain the hard spectrum to effectively burn plutonium and minor actinides from LWR spent fuel while efficiently generating electricity.

This reactor concept presents several technical challenges. The most important are listed below.

1) **Fuel and Reactor Core Designs:**
   - Local or total coolant voiding increases leakage, but hardens the neutron energy spectrum and decreases parasitic absorption. The net effect can be a reactivity increase. The core must be designed to ensure that the overall reactivity coefficient is negative.
   - A low conversion ratio fuel rapidly loses reactivity with burnup, thus requiring a large excess reactivity at BOL to operate continuously for an acceptably long time. Therefore, a control system must be designed that safely compensates for reactivity changes throughout the irradiation cycle, or the spectrum must be hardened to increase the conversion ratio.
   - Because of the hard spectrum, the doppler feedback will be much smaller than that found in typical LWRs.

2) **Fuel Cladding and Structural Material Corrosion and Stress Corrosion Cracking:**
   - Because of the oxidizing nature of high temperature water, corrosion and stress corrosion cracking of the fuel cladding and core internals materials are expected to be major concerns for this reactor concept.
   - Because of the hard neutron spectrum, radiolysis of the water coolant may take place at a higher rate than in traditional LWRs. In addition, the radicals formed by the radiolytic decomposition of the water are highly soluble in supercritical water and may not recombine as well as in an LWR.

- The hard neutron spectrum makes the irradiation damage of the fuel cladding and core structural materials more pronounced than in traditional LWRs. Also, high-energy neutrons work as catalysts for the oxidation and stress corrosion cracking of the structural materials (irradiation assisted stress corrosion cracking).

3) **Plant Engineering and Reactor Safety Analysis:**
   - Depending on its mission (e.g. electricity generation, co-generation of steam and electricity, desalinization), the plant will exhibit different optimal configurations and operating conditions.
   - Because no change of phase occurs in the reactor vessel, the need for a pressurizer to maintain the operating pressure has to be assessed.
   - The implications of utilizing supercritical water on the design of the reactor containment need to be evaluated.
   - Because of the significant coolant density variation along the core, the supercritical water reactor might be susceptible to coupled neutronic/thermal-hydraulic instabilities.
   - The response of the plant to design and anticipated accidents and transients might differ significantly from that of LWRs and needs to be evaluated.

Proposed Work

Fuel-cycle Neutronic Analysis and Reactor Core Design (INEEL). Metallic, oxide, and nitride fertile fuels will be investigated to evaluate the void and doppler reactivity coefficients, actinide burn rate, and reactivity swing throughout the irradiation cycle. Although metallic alloy fuels are incompatible with the water coolant, we envision the use of a dispersion type of metallic fuel which will be compatible with water. Included in the fertile options will be the use of thorium. The main variables are the core geometry (e.g. fuel rod length, pitch-to-diameter ratio, assembly configuration) and the fuel composition. The MCNP code will be utilized for instantaneous reactivity calculations and the MOCUP code for burnup calculations and isotopic content.

Fuel Cladding and Structural Material Corrosion and Stress Corrosion Cracking (University of Michigan). Supercritical water presents unique challenges to the long-term operation of engineering materials. The generation of oxygen and hydrogen gas by radiolysis and the high solubility of these gases in supercritical water will result in higher corrosion and stress corrosion rates than experienced with other reactor designs. In addition, radiation may accelerate or assist the stress corrosion cracking in the reactor region, and stress corrosion cracking and accelerated corrosion may occur in the preheat and cool-down sections of the circuit. The existing data base on the corrosion and stress corrosion cracking of austenitic stainless steel and nickel based alloys in supercritical water is very sparse. Therefore, the focus of this work will be corrosion and stress corrosion cracking testing of candidate fuel cladding and structural materials. A high temperature autoclave containing a constant rate mechanical test device will be built and operated at the University of Michigan. The resulting data will be used to identify promising materials and develop appropriate corrosion and stress corrosion cracking correlations.

Plant Engineering and Reactor Safety Analysis (Westinghouse and INEEL). The optimal configuration of the power conversion cycle will be identified as a function of the plant mission (e.g. pure electricity generator, co-generation plant, desalinization plant). Particular emphasis will be given to the applicability of current supercritical fossil-fired plant technology and experience to a direct-cycle nuclear system. A steady-state sub-channel analysis of the reactor core will be undertaken with the goal of establishing power limits and safety margins under normal operating conditions. Also, the reactor susceptibility to coupled neutronic/thermal-hydraulic oscillations will be evaluated. The response of the plant to accident situations and anticipated transients without scram will be assessed. In particular the following transients and accidents will be analyzed: start-up, shut-down, load change and load rejection; LOCAs and LOFAs. As part of this analysis, a suitable containment design will be explored to mitigate the consequences of LOCA accidents.