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Simulation of Operational and Safety Transients in
LMFBR Systems*

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The operational and safety transients (either anticipated, unlikely or extremely unlikely) that may originate anywhere in a liquid-metal fast breeder reactor (LMFBR) system have to be simulated to assist in plant design, fabrication and licensing efforts. Depending upon the extent of involvement of the pertinent components of the plant, these transients may be classified as whole-core or plant-wide events. In the former case, because of relatively short time scale phenomena, only in-reactor core parts are considered. Typically, hypothesized core-disruptive accidents fall under this category. The plant-wide events, on the other hand, can, and do, extend over a period of hours and days. It is for these events that the details of the primary, intermediate and tertiary circuit designs, in addition to the reactor itself, must be considered.

A general purpose plant simulation code is required by the designers in assessing the impact of often conflicting requirements that may result from operational and safety transients. For example, a slower pump coastdown may be desirable by certain safety-related events and yet a slower pump coastdown will result in more severe thermal shocks to the key structural elements. An assessment on the plant duty cycle and component operating temperatures due

to various transients, therefore, must be made, particularly since the plant is designed for a thirty to forty year life. A general thermohydraulics code for the system is also needed in designing the plant protection and control systems.

This paper is concentrated on describing a new, advanced thermohydraulic simulation code for LMFBRs. This code, designated as the Super System Code (SSC), simulates operational and safety transients that may be initiated anywhere in the system. The SSC code provides for the simulation of all essential components in the primary and intermediate heat transport systems. The steam generating circuit along with the turbine and condenser are also included. The usefulness of this code in future LMFBR plant designs will be demonstrated by its application to the Clinch River Breeder Reactor-type plant. Several design and operational transients such as normal scram, control rod withdrawal, after-heat removal by natural convection and load follow-up will be analyzed. A pipe rupture accident in the primary heat transport system will also be discussed.

The SSC code is being developed at Brookhaven National Laboratory in such a way that a designer or user can control modeling details without having to undertake programming effort. For example, for the detailed thermal analysis of in-core, a user may lump all heat transport circuits into a single circuit. Conversely, for details in the heat transport circuit, all in-core simulation may be achieved by a single heating rod. These cases, and others like them, can be run simply by controlling input numbers.

The following list is prepared to illustrate the scope and details that are incorporated into the SSC code:

- (1) The reactor vessel is represented by inlet and outlet plena, heat-producing and nonheat-producing portions.
- (2) The heat-producing region is represented by a number of parallel channels.
- (3) The heat production rate is allowed to vary from one channel to another. The source of heat production (fission or decay) is explicitly considered.
- (4) Interassembly flow redistribution during transient is modeled.
- (5) Fuel restructuring, prior to transient, is computed.
- (6) Coolant mixing in the outlet plenum allows for flow stratification.
- (7) Sodium boiling in the reactor core. For some transient events boiling in parts of the core is feasible.
- (8) Detailed thermohydraulics in the primary, intermediate and tertiary circuits. Actual conservation equations are solved.
- (9) The centrifugal pump is modeled for all phases of operation including the normal mode.
- (10) Pipe breaks of any size are considered. Both free-flow and confined-flow models are used.
- (11) The intermediate heat exchanger model allows for detailed thermal and hydraulic balances.
- (12) The steam generator is represented in a generalized way so that both the recirculating and once-through designs can be accommodated.
- (13) Other components such as the check valve and surge tank are also accounted for.

The entire code is organized in a modular form. This permits modeling improvements or modifications without excessive burden. In order to permit plant simulation with minimum computational time, a multi-step scheme for numerical integration was developed. This scheme, for a simplified test problem, has been found to be more efficient by a factor of two to three than the commonly used single-step or common time step methods.

The SSC series of codes consist of versions specifically applicable to major design options for LMFBRs. For example, the SSC-L code is directed towards the loop designs while SSC-P will analyze both "hot" or "cold" pool designs. A version of SSC for the thermohydraulic analysis of gas-cooled fast reactors can be readily developed by appropriate modifications in the heat transport circuit.

Experience gained from the current generation of breeder reactors and other support facilities is being incorporated into the SSC code so that it can be applied to future breeder reactor plants with an increased level of confidence. Simplified versions of the SSC code are also being compared with plant-oriented system codes (e.g., IANUS, DEMO). Some comparison with experimental data will also be made.

In summary, this paper will discuss the scope and limitations of a general purpose, thermohydraulic simulation code (SSC) for LMFBR systems. Code verification based on experience with operating plants and existing experimental data enables application of the SSC code with an increased level of confidence. Special versions for the short-term or long-term heat removal from loop or pool designs are either developed or being developed. This series of codes can be used in (1) design of plant, (2) changes in plant

design, (3) load following operation, (4) predicting thermohydraulic transients for structural analyses, (5) designing plant protection and control systems and (6) safety events such as after-heat removal by natural convection or through auxiliary heat removal circuits. This paper will also present detailed results computed for many of these events.