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2. Development of a Time-Domain BWR Core Stability Analysis Program, *Osamu Yokomizo, Isao Sumida, Hiroshi Motoda (Hitachi/ERL-Japan)*

In the operation of a boiling water reactor (BWR) at partial power and lower core flow, the nuclear thermal-hydraulic stability of the core is an important constraint and it has to be assured prior to operation that certain stability criteria are satisfied in all operating conditions.

Widely adopted computer programs to predict the core stability are those in the frequency-domain with parallel channel capability or those in time-domain that treat the core as a single channel. The frequency-domain approach is very useful for the practical design purpose because of the short computation time to predict conditions for the inception of instability. However, for more realistic design, analyses of the transient behavior of the core with respect to the system nonlinearity are desirable. Parallel channel effect is also regarded to be important in core stability analysis. To satisfy these requirements, a time-domain program with parallel channel capability has been developed.

This program takes into account the following phenomena of the BWR core:

1. neutron kinetics with Doppler and void reactivity feedback
2. fuel heat transfer
3. thermal hydraulics of coolant in parallel fuel channels
4. recirculation flow hydrodynamics.

Because of the nonlinearity and the large number of the system variables it was anticipated the program would consume a long computation time. Therefore, several assumptions and approximations were introduced for each of the models.

1. *Neutron Kinetics:* The point neutron kinetics model with prompt jump approximation was used. Reactivity is obtained by averaging the infinite multiplication factor with weighting of squared power level and correcting it with initial condition leakage.

2. *Fuel Heat Transfer:* Axial heat conduction was ignored and radial one-dimensional (1-D) equations were implemented. Temperature dependence of thermal conductivity was accounted for.

3. *Channel Thermal Hydraulics:* The following assumptions were applied to the 1-D separated flow model:

a. System pressure is uniform and varying by time.
b. Vapor is always at saturated condition.
c. Fluids are incompressible.
d. Flow quality in the subcooled boiling region is a smooth function of mixed quality.

With these assumptions, a unified expression can be used for all of the single phase, subcooled, and bulk boiling regions.

4. *Recirculation Hydrodynamics:* Energy loss and deposition in the recirculating flow were neglected. A 1-D momentum equation was used for calculating the pressure difference between core inlet and exit.

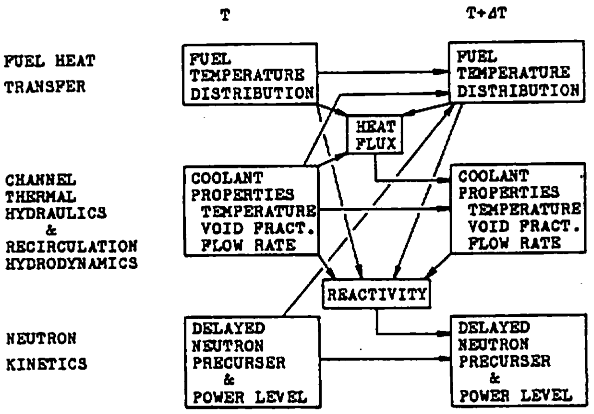

Fig. 1. Time integration scheme.

The implicit method was used to derive the finite difference equations for each model. The time-integrating scheme is illustrated in Fig. 1. First, fuel temperature distribution at time t + Δt is calculated from temperature distribution, coolant properties, and power level at t. Heat flux during time interval Δt is then calculated from coolant properties at t and t + Δt. Using this heat flux, coolant properties at t + Δt can be obtained. Next, average reactivity is calculated from fuel temperature and void fraction at t and t + Δt. Delayed-neutron precurser levels at t + Δt are calculated using the average reactivity, and power level is obtained using the reactivity at t + Δt.

This program has been applied to a BWR/4 core under a natural-circulation condition. Figure 2 shows an example of the analytical results. The curves are responses of core power to sinusoidal variations of core pressure with the amplitude of 0.2 MPa and two different periods. It should be noted that in the 1-Hz case the response is not sinusoidal. It has been found from detailed examination that in this case

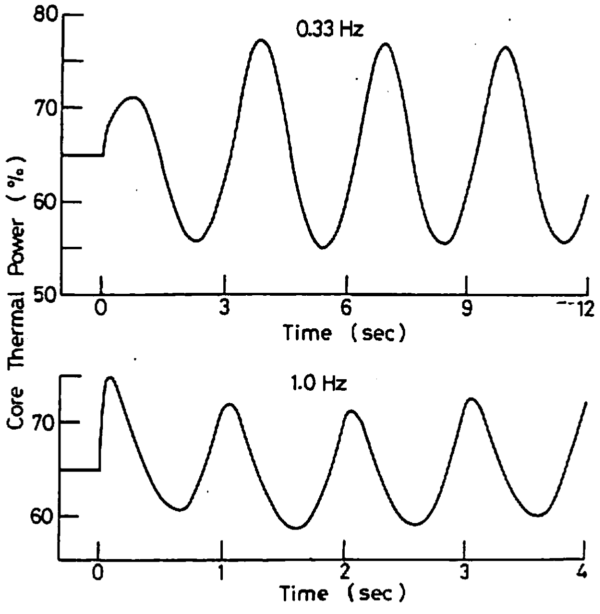

Fig. 2. Effect of nonlinearity and parallel channel geometry.

the central fuels and the peripheral fuels are behaving out of phase with each other, decreasing the change of the core reactivity, thus, the importance of nonlinearity and parallel channel effect has been demonstrated. This program is expected to be very useful in developing a new stability criterion.

3. An Advanced Absorber Assembly Design for Breeder Reactors, *A. L. Pitner, K. R. Birney (Westinghouse Hanford)*

An absorber assembly design has been developed that offers substantial improvements in performance characteristics and fabrication economics of breeder reactor control elements. The design represents a marked departure from conventional assembly configurations, including incorporation of large-diameter vented absorber pins, circular pin arrays and duct tubes, and advanced alloy structural components. Benefits achievable from application of this advanced design include faster scram time, longer assembly lifetime, and reduced fabrication cost.

The principal design changes adopted in evolving from the Fast Flux Test Facility (FFTF) reference absorber assembly design to the advanced design are depicted in Fig. 1. Whereas the reference design is comprised of 61 sealed boron carbide pins arranged in a hexagonal configuration, the advanced design incorporates 19 vented pins arrayed in a circular pattern inside round duct tubes. Also, in lieu of AISI Type 316 stainless-steel reference duct and cladding material, the advanced design makes use of the advanced alloy D9 in the fabrication of these structural components. These design changes lead to a number of improvements in both performance and economics.

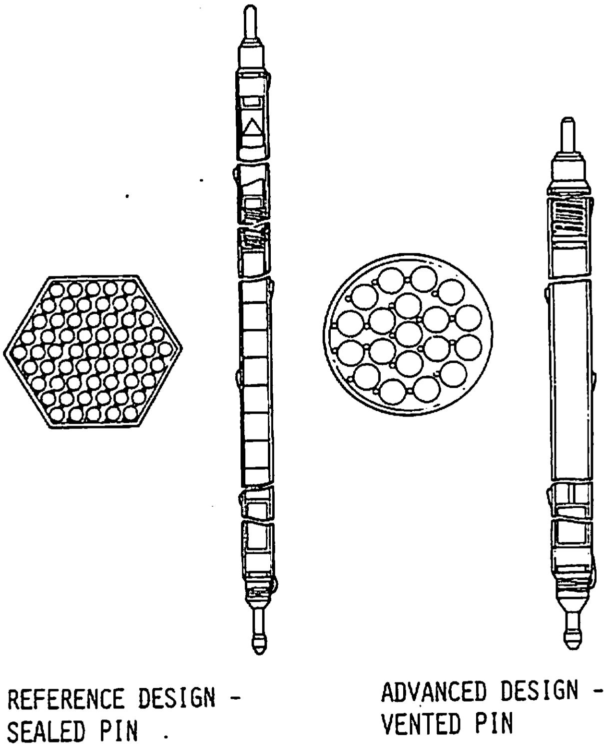

Fig. 1. Comparison of FFTF reference and advanced absorber assembly designs.

The boron carbide absorber material in breeder reactor control rods produces helium gas under irradiation service conditions. In sealed pins, the associated gas pressure buildup and high cladding stresses that develop can ultimately limit the absorber assembly lifetime. These problems are circumvented by venting the helium to the reactor coolant. In the present design, this is accomplished using a vent assembly comprised of a porous plug flow restrictor device located above a diving bell chamber at the bottom of the absorber pin. The porous plug is fabricated from sintered stainless-steel powder, and allows venting to occur only above some threshold pressure differential. The diving bell chamber serves to prevent sodium wetting of the porous plug. This vent assembly design was selected on the basis of suppressing sodium ingress to the absorber pin.

The transition from a 61-pin bundle design to a 19-pin bundle design offers substantial savings in fabrication costs. The pin diameter has been increased from 0.474 in. (1.204 cm) for the reference design to 0.784 in. (1.991 cm) for the advanced design. Since little gas pressure buildup occurs, the cladding wall thickness has been reduced from 0.051 in. (0.130 cm) to 0.025 in. (0.064 cm). The overall reduction in cladding volume makes additional space available for absorber material, and the ^{10}B content for the advanced design is 12.5% greater than for the reference assembly.

The advanced design employs round duct tubes, with hexagonal load pads affixed where the assembly mates with surrounding core assemblies. Whereas the torque imparted by the control rod drive mechanism during rod withdrawal can cause contact between the inner and outer ducts in a hexagonal design, round duct tubes will not interact under these circumstances. Thus, potential wear problems are avoided by employing a round assembly design. Another benefit gained with the round design is increased coolant flow through the pin bundle. The pin bundle/bypass annulus flow ratio for the hexagonal reference design is 60%/40%, while for the advanced design it is improved to 75%/25%.

The primary benefit gained in application of the advanced alloy D9 for structural components is related to assembly bowing behavior. With Type 316 SS, thermal and flux gradients across absorber assemblies result in significant bowing, which can lead to vertical travel interference and shortened lifetimes. D9 exhibits very low in-reactor swelling, which effectively eliminates problems related to duct bowing.

Scram performance of the advanced assembly is substantially improved relative to the reference design. The advanced assembly weighs less and exhibits reduced hydraulic resistance when compared to the reference design. Consequently, it responds faster to accelerating scram forces. Based on calculations performed using the SCRAM code,[1] which was developed for FFTF control rod scram analysis, the advanced absorber assembly scrams 30 to 40% faster than the reference assembly.

The FFTF reference absorber assembly design has been modified to increase its lifetime from 300 to 600 full power days (FPD). Lifetime analyses performed for the advanced design using the CONROD code[2] indicate that this assembly is capable of a 900-FPD lifetime in the FFTF. The 50% increase in design lifetime combined with reduced fabrication costs provide for substantial economic gains when the advanced absorber assembly is implemented in FFTF. Two of the absorber assemblies in FFTF will be replaced with advanced prototypes in the future to verify performance capabilities.

It is expected that the general benefits derived from the advanced absorber design developed for FFTF can be