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BEAGL-01, A Computer Code for Calculating Rapid LWR Core Transients

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BEAGL-01 (Brookhaven's and EPRI's Adaptation of the TWIGL code (1)) is a computer program for calculating the conditions in a light water reactor (LWR) core at steady state and during transients. It solves the finite-difference neutron kinetics equations on an r,z (radial, axial) mesh, the thermal-hydraulic equations for the coolant in multiple parallel, i.e., one-dimensional, channels and the one-dimensional radial fuel rod heat conduction equations for pellet, gap and clad. The analyst provides time dependent boundary conditions and/or specifications for control rod movement in order to perturb the system from an initial steady state. The boundary conditions are the inlet flow rate and temperature and a single system pressure. The analyst also supplies a normalized inlet flow distribution across the core which does not vary with time. Control rod movement includes the center rod by itself, all banks of control rods, or some combination of these. BEAGL-01 has just been made available outside of BNL (2, 3) where it had been in use for many years. The objective of this summary is to give its capabilities and limitations.

Capabilities

The modeling within the code makes it suitable for analyzing many transients of safety significance, as well as transients expected during operation. In particular, it is useful for: 1) the rod drop accident (RDA) in a

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events in a BWR; and 4) generic studies on the effect of thermal-hydraulic feedback and control rod movement. These applications are further discussed below.

In the two reactivity insertion accidents, the RDA and REA, the power in the core is non-separable in the axial and radial directions and hence (r,z) geometry (as in BEAGL-01) or (x,y,z) geometry is necessary. BEAGL-01 has a two-phase coolant model and a cross section formulation which allows for feedback as a function of thermal-hydraulic variables; both of which are necessary for a proper calculation of these accidents. Although the modelling in the code is suitable for both reactivity insertion accidents, extensive experience exists (with the predecessor of BEAGL-01, BNL-TWIGL) only for the rod drop accident (4).

In most PWR transients initiated by perturbations in the thermal-hydraulics, the changes in the core power distribution are relatively slow and spatially dependent neutron kinetics is not necessary. Although exceptions to this rule can be found, it is the application of BEAGL-01 to thermal-hydraulic transients in BWRs that is more important. In a BWR the strong coupling between steam voids and power necessitates the use of a code like BEAGL-01, i.e., a code with spatial neutron kinetics coupled to thermal-hydraulics.

This is particularly true for overpressurization events such as those initiated by a turbine trip, load rejection or closure of the main steam isolation valves. In these events reactor trip is usually not effective until after the core has experienced a power surge. A detailed core model is also important for anticipated transients where there is no (or partial) insertion of control rods (an "ATWS" event).

In transients initiated by a thermal-hydraulic perturbation it is usually changes in the axial power shape that are significant since frequently the radial shape does not change much. In such a case a one-dimensional neutron kinetics solution (which can be obtained with BEAGL-01) may be adequate. Documented experience with BEAGL-01 includes the application to turbine trip events,(5) including transients without turbine bypass capacity (6) and without scram.(7)

The fourth application referred to above is the use of the code for generic studies on the effect of thermal-hydraulic feedback and control rod movement. Two documented examples of this are a study of steam void feedback (8) and scram reactivity, (9) both for a BWR. These studies showed the effect of space-time coupling and hence the importance of applying a code like BEAGL-01 to determine the effect of void feedback and scram.

Limitations

As with all computer models there are certain limitations that the analyst should be aware of when using BEAGL-01. In general these limitations are not so severe that they seriously constrain the user for the applications discussed above.

Basic limitations of the neutron kinetics model are the result of using (r,z) geometry and the diffusion approximation. The use of (r,z) geometry requires regions of the core to be homogenized so that they can be represented as annuli. This homogenization in general is no more limiting than that required to represent a fuel assembly as a single composition. However, it does preclude consideration of an individual control blade or cluster except at the center of the core.

A basic limitation of the diffusion approximation is that it is not valid near a strong absorber. In practice a BEAGL-01 input model is usually set up with compositions homogenized over regions at least as large in cross section area (perpendicular to the direction of flow) as a fuel assembly. These homogenized regions should not be so strongly absorbing that this limitation becomes a problem with applications of BEAGL-01.

Four basic limitations of the thermal-hydraulics modeling are the one-dimensional solution, the interphase energy transfer, the absence of a bypass channel, and the inability to calculate flow reversal. The one dimensional solution for the coolant thermal-hydraulics implies that there can be no cross flow between assemblies. This condition - no cross flow - is satisfied in BWRs but does not apply in general to PWRs. The PWR transient of most interest is the rod ejection accident. Since the power surge in the REA is terminated rapidly due to the Doppler effect, there is little time for any cross flow to develop as a result of the power excursion. Therefore, this limitation should not be significant; indeed it is common practice to ignore cross flow in the REA.

The second problem in the thermal-hydraulic model is the use of an equilibrium correlation for the heat transfer between the two phases. This has the effect of overestimating the vapor generation rate during a power excursion. The effect of this inaccuracy has not been quantified.

The absence of a bypass channel for BWR analysis is not a serious limitation. Approximately 2% of the power is deposited directly in the bypass region and hence without this region the energy deposition in the coolant and fuel rod is slightly overestimated.

Flow reversal could occur in an LWR during a reactivity-initiated-accident. It is specifically disallowed in BEAGL-01 because the code uses a marching technique and a donor-cell formulation to solve the conservation equations and uses the concept of slip. This limitation is expected to be important in only a very limited number of cases.

In summary it is clear that BEAGL-01 is an important addition to the computational tools that are available to the nuclear industry.

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