Computer Code Abstract

BEAGL-01

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1. Program Identification: BEAGL-01 calculates the neutronic and thermal-hydraulic conditions in a light water reactor (LWR) core at steady state and while undergoing a transient. It is Brookhaven's and EPRI's adaptation of the TWIGL program.

2. Function: BEAGL-01 solves the two- (energy-)group neutron kinetics equations on an r, z (radial, axial) mesh. It solves the thermal-hydraulic equations for the coolant in multiple parallel, i.e., one-dimensional, channels and the 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 initially steady state. The boundary conditions are the inlet flow rate and temperature and a single system pressure. Control rod movement may be the center rod by itself, all banks of control rods, or some combination of these. This modeling makes BEAGL-01 suitable for analyzing many transients of safety significance. It is particularly useful for (a) the rod drop accident in a boiling water reactor (BWR), (b) the rod ejection accident in a pressurized water reactor (PWR), (c) anticipated and abnormal overpressurization events in a BWR, (d) overcooling events (such as a steamline break) in a PWR, and (e) transients with failure to scram in both BWRs and PWRs.

3. Method of Solution: The neutron kinetics model consists of the two-group diffusion equations and the balance equations for up to six groups of delayed neutron precursors. They are solved in (r, z) geometry using a standard five-point finite difference approximation. The inner iteration process uses a one-line optimum successive overrelaxation technique. The outer iterations are accelerated by a cyclic Chebyshev technique (noncyclic in the steady-state problem).

   The thermal-hydraulic model consists of a fluid dynamics model and a heat conduction model, which are coupled to one another via the heat flux at the fuel rod outer surface. The fluid dynamics is described by an inhomogeneous, nonequilibrium (i.e., subcooled boiling is allowed), two-phase flow model based on energy splitting between liquid and vapor phases. One-dimensional conservation equations of mass and energy are solved by means of a marching technique for multiple parallel flow channels, taking into account six different flow regimes. The average inlet mass flux is specified by the user as a function of time. The user also specifies the relative flow distribution to each channel, which is invariant in time.

   The fuel rod heat conduction model is based on spatially averaged, time-dependent heat conduction equations for the average pellet temperature and the cladding inner and outer surface temperatures. The average cladding and gap temperatures are linear combinations of these temperatures. A semi-implicit time-differencing scheme is used to solve the heat conduction equations.

   The thermal-hydraulic equations are solved for coarse regions that may include many neutronic mesh volumes. The coupling of the fluid dynamics and heat conduction is semi-implicit in time in that some quantities are new at each time step and others are based on values from the previous time step. The scheme works well since the thermal hydraulics is solved using a relatively small time step, the result of the fact that the time step size is determined by the neutron kinetics.

   The thermal-hydraulics equations are solved successively with the neutron kinetics at every time step (rather than simultaneously). In the steady-state algorithm, the coupling is done by iterating between the neutron kinetics and thermal hydraulics.

4. Related Material: BEAGL-01 uses the PAD program for graphics postprocessing.

5. Restrictions: The use of (r, z) geometry requires regions of the core to be homogenized so that they can be represented as annuli. This homogenization is generally 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. For many PWR transients of interest with BEAGL-01, however, there is little time for any significant cross flow to develop. The use of an equilibrium correlation for the heat transfer between the two phases 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; 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.

6. Computers: The program has been successfully executed on a CDC 7600 and an IBM 370.

7. Running Time: For a sample problem with 36 radial neutronic mesh points and 61 axial neutronic mesh points, the program took 120 s to converge the steady-state solution on a CDC computer. For the transient solution of this sample problem with a 0.01-s time step size run out to a 4.0-s transient time, the CDC running time was 1725 s.

8. Programming Languages: For the CDC computer, the programming languages are FORTRAN (>99%) and COMPASS (<1%). The COMPASS consists of one subroutine. For the IBM computer, the only language is FORTRAN (a FORTRAN dummy subroutine has been substituted for the COMPASS subroutine).

9. Operating System: The CDC version uses the SCOPE 2.1 operating system and the FORTRAN EXTENDED Version 4 compiler. The IBM version uses the OS/VS2 MVS operating system and the FORTRAN H EXTENDED compiler. On either computer, the compiler option should be chosen for the highest degree of safe optimization that is available.

10. Machine Requirements: The CDC version requires $160K_8$ SCM and $400K_8$ LCM. The IBM version requires 1600K.

11. Material Available: The material available is a two-volume reference report and a magnetic tape. The CDC tape consists of 15 files containing the BEAGL-01 program source card images, segmented loader directives, input data for four sample problems, output data for the sample problems, and 5 intermixed files of control cards to UPDATE, compile, load, and catalog the program and to execute the sample problems. The IBM tape consists of 9 files containing the BEAGL-01 program source card images, input data for the four sample problems, and output data for the sample problems as executed on the CDC computer. (The CDC and IBM results for the steady-state problems are identical, but there are small differences for the transient problems, probably due to word-size differences.)

    The BEAGL-01 program is available from the Electric Power Research Institute (EPRI). A license is required and EPRI classifies the program as a research code.

12. Acknowledgments: BEAGL-01 is based on the transient solution to the neutron kinetics equations as programmed originally for the TWIGL code of Bettis Atomic Power Laboratory. The remainder of the code is the product of many workers at Brookhaven National Laboratory. In particular, the two-phase coolant thermal-hydraulic model and the fuel rod heat conduction model was developed by G. S. Lellouche, and the steady-state neutronics algorithm was developed by L. D. Eisenhart. Overall responsibility for coding went to A. L. Aronson. Other special aspects of BEAGL-01 include models for control rod and bank movement (H. S. Cheng), for cross-section parameterization (H. S. Cheng), for decay heat (D. J. Diamond) and for time step control (D. J. Diamond and A. L. Aronson), and many additions to the editing features (A. L. Aronson and W. Bornstein), including reactivity edits (D. J. Diamond and H. S. Cheng). Also involved in the development of the current version of the code were M. M. Levine and M. S. Lu.

13. References:

[1]D. J. DIAMOND, H. S. CHENG, and L. D. EISENHART, "BEAGL-01, A Computer Code for Calculating Rapid LWR Core Transients, Volume 1: Mathematical Modeling," EPRI NP-3243-CCM, Vol. 1, Electric Power Research Institute (1984).

[2]A. L. ARONSON and D. J. DIAMOND, "BEAGL-01, A Computer Code for Calculating Rapid LWR Core Transients, Volume 2: User's Manual," EPRI NP-3243-CCM, Vol. 2, Electric Power Research Institute (1984).