5. Computer Program for Control Rod Programming of BWR, *Hiroshi Motoda, Takashi Kiguchi, Toshio Kawai (AERL-Japan)*

In the BWR in-core fuel management, one of the most important tasks is to determine the control rod programming that maximizes the cycle length under the various operational constraints. Recently, many papers[1-5] have been published on the optimal control rod programming; however, their core models are too simple for practical use. Using complete core model, a control rod program has to be generated by trial-and-error method, which consumes long computing time and much manpower.

We have developed a computer program which generates the suboptimal control rod program using the realistic three-dimensional simulator FLARE.[6] To reduce the scale of the optimization problem, the problem was decomposed into two stages; i.e.,

1. Inner loop optimization: to determine the control rod positions, which minimize the mean square error of the power distribution from the target, at each burnup step
2. Outer loop optimization: to modify the target power distribution to minimize the residual control rods at the end of cycle.

The flow diagram of the program is illustrated in Fig. 1.

The inner loop optimization is formulated as

Control variable: rod positions R_i $(i = 1, \ldots I)$

Performance index:

$$J = \iiint [P(r) - P_{target}(r)]^2 \, dr \to \min \qquad (1)$$

Constraints: criticality $k_{eff} = k_{target}$
linear heat generation rate
$LHGR(r) \leq MLHGR$
critical heat flux ratio
$CHFR(r) \geq MCHFR$
stuck rod $R_j = R_j^{fixed}$.

The last constraint is used when some of rods are stuck or inserted for preventing fission product gas release.

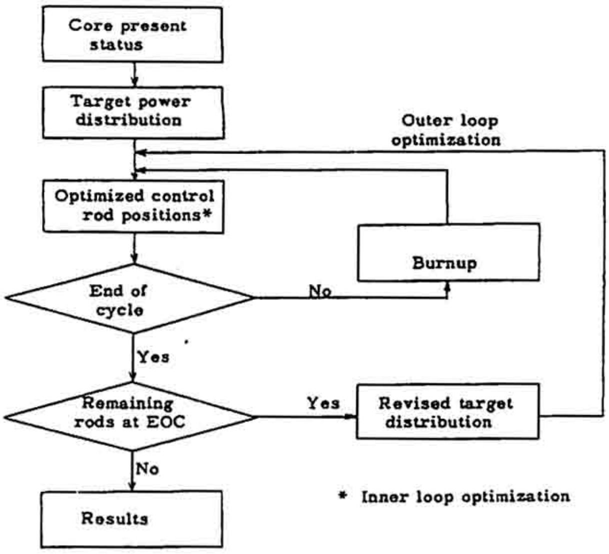

Fig. 1. Flow diagram of the program.

The above nonlinear programming problem is solved by the method of approximate programming[7]; that is, the performance index and constraints are linearized with respect to the control rod movements to use linear programming repeatedly. To reduce the scale of the linear programming problem, the control rods are ganged into five- or ten-rod groups. The grouping is prepared for four patterns, and the patterns are changed periodically to assure local uniformity of burnup. Constraints for LHGR and CHFR are considered at about 100 nodes, which scatter properly in the core.

In the outer loop optimization, the "bottom peaked skewed Haling's power distribution"[8] is used as the initial guess of the target distribution, and the target is revised as

$$P^{New}_{target}(r) = \left[1 + \alpha \frac{\Delta P(r)}{P(r)}\right] P^{Old}_{target} \quad , \qquad (2)$$

where $\Delta P(r)$ is the power increment, which compensates reactivity $\Delta k(r)$ of the control rod remaining at the end of cycle, and α is an input constant.

This program has been applied to a typical 460-MW(e) BWR. The computer running time for one case is 120 to 150 min by HITAC-5020F (equivalent to IBM 370/155). The cycle length is 2 weeks longer than that of the Haling's principle. At the end of cycle, all control rods are completely withdrawn under the operational restrictions of MCHFR and MLHGR, and the rod patterns are marked by the deep and shallow principle.

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