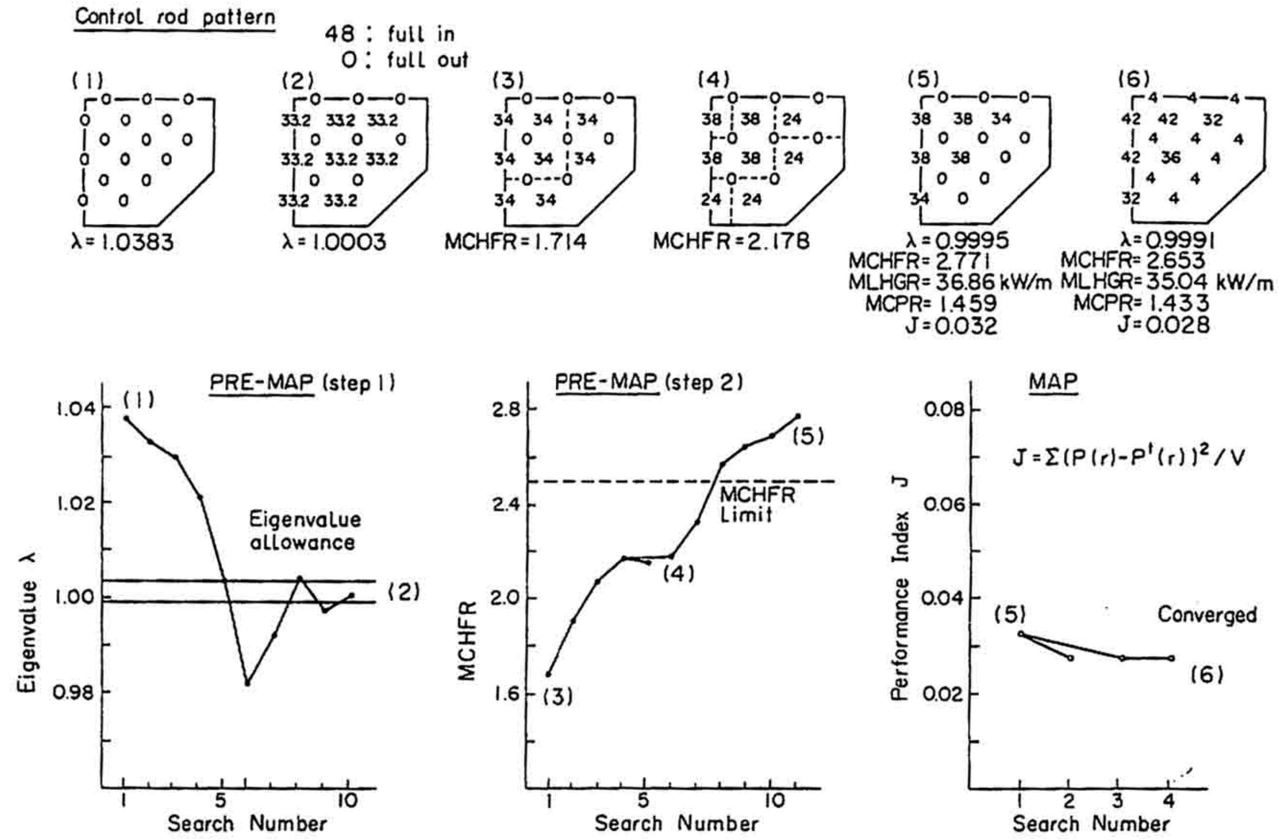

Fig. 1. An example of searching process during each step.

Step 2: Improvement of Core Characteristics by Deep Rods Search

The deep rods are divided into as many groups as necessary, out of which two subgroups are formed in the following manner:

1. Divide all the groups into two subgroups and search for a rod pattern that gives the best core characteristics.

2. Make ranking of the core characteristics throughout the regions associated with these groups, and form two new subgroups by selecting the highest and the lowest ranking groups. Then, search for the best rod pattern.

3. If the pattern obtained is an improvement over the starting pattern, go back to point 2. If not, form a new subgroup by combining the highest and the second highest ranking members and continue the search for the best pattern. If the best pattern obtained is an improvement, go back to step 2. If not, go to step 3.

Step 3: Fine Adjustment of Deep and Shallow Rods

If the last rod pattern obtained falls in the feasible region, go to MAP routine. If not, adjust the deep and shallow rods nearest to the location where the core characteristics are the worst.

The MAP routine was designed to find (starting from a feasible or near feasible solution) an optimal pattern that gives the power distribution which is the closest possible to the desired target power distribution. If the starting pattern is in the feasible region, the standard MAP is used. If not, unsatisfied constraints are temporarily relaxed and the flow goes into the MAP. These relaxed constraints are gradually tightened in the process of iteration.

This method was successfully applied to the first cycle of an 800-MW(e) BWR, having three different enriched fuel assemblies with axially distributed gadolinia. Figure 1 shows the search process during each of the previously mentioned steps. In this example, MCHFR is the severest constraint of all and the initial guess pattern selected was all-rods-out. A feasible rod pattern could be found during the course of step 2. In all other cases, the situation was about the same and so far no case has been experienced in which the search process failed in finding a feasible solution.

1. T. KAWAI, H. MOTODA, T. KIGUCHI, and M. OZAWA, *Nucl. Technol.*, 28, 108 (1976).

4. Evaluation of On-Line Power-Distribution Prediction Method by BWR Operating Data,

Takashi Kiguchi, Takaharu Fukuzaki, Yasuo Nishizawa (AERL-Japan), Hiroshi Motoda (Tokyo Elec Power)

It is highly desirable, for safer and more efficient operation of BWRs, to predict the change of power distribution in advance of control rod withdrawal, flow rate change, and xenon transient initiation. A method that meets such a requirement is proposed in our previous paper.[1]

The on-line test of this prediction system is planned at FUKUSHIMA-2 [784-MW(e) BWR] of Tokyo Electric

Power Company, and the accuracy of the predicted results has been evaluated by using the operating data of FUKUSHIMA-2 1A cycle, prior to its installation to the reactor site.

In Fig. 1 is shown the configuration of the on-line power distribution prediction program system.

The present TIP reading is used as the initial condition of prediction, and is estimated from LPRM readings by solving a one-dimensional (1-D) FLARE-type nuclear thermal-hydraulic equation[2] for the monitored channel, which consists of four fuel bundles surrounding the TIP string. The channel power and the horizontal albedo are adjusted iteratively so the calculated TIP reading hits the measured LPRM readings at their locations.

The change in power distribution after a control rod motion is localized and is limited to the fairly small region around the moved rod. This makes it possible to predict the change by solving 3-D FLARE [Eq. (1)] in four monitored channels adjacent to the control rod.

$$S_\ell(K) = k_{\infty\ell}(K)\left[\sum_{i=1}^{u} W_i^H(K)\, S_i(K) + W_\ell^V(K-1)\, S_\ell(K-1) + W_\ell^V(K+1)\, S_\ell(K+1) + W_\ell^S(K) S_\ell(K)\right] . \quad (1)$$

To reduce the prediction error arising from the inconsistency of the calculation model with actual TIP readings, $k_{\infty\ell}(K)$ in Eq. (1) is calculated as $k^0_{\infty\ell}(K) + \Delta k_{\infty\ell}(\Delta CR)$, where $k_{\infty\ell}(K)$ is the neutron multiplication factor which satisfies Eq. (1) for present power distribution and $\Delta k_{\infty\ell}(\Delta CR)$ is the change in k_∞ introduced by the control rod movement. The power change in the channels outside these four channels is approximated by the linearized nodal coupling equation that is valid for a small change of power distribution.

The power distribution change due to flow rate change and xenon transient is predicted by a whole core vertical 1-D FLARE model. The local power distribution change, such as the xenon transient after a control rod withdrawal, is predicted by the local 3-D FLARE equation similar to that used for control rod motion.

The method of allocating the TIP reading to the individual bundle power is similar to the conventional method for on-line core performance evaluation.

The power-flow trajectory is predicted by criticality search with the same whole core 1-D FLARE model. The critical eigenvalue depends on the operating condition due to the incompleteness of the core model. Therefore, the critical eigenvalue is expressed by a polynomial of power, flow rate, and core average xenon density. The coefficients are determined from the actual operating history by adaptive learning algorithm.

The accuracy of the results by this prediction program system has been evaluated extensively by using the operating data during startup operation of Fukushima-2 BWR. In Fig. 2 are shown the two sets of TIP readings, one estimated from measured LPRM readings, and the other predicted for control rod withdrawal and flow rate increase in comparison with the measured TIP readings.

The RMS (root mean square) error of each function is:

1. present TIP reading estimation (3%)
2. TIP reading prediction
   (a) control rod withdrawal (7%)
   (b) flow rate change and xenon transient (5%)
3. power-flow trajectory
   (a) power level (3%)
   (b) coolant flow rate (4%)

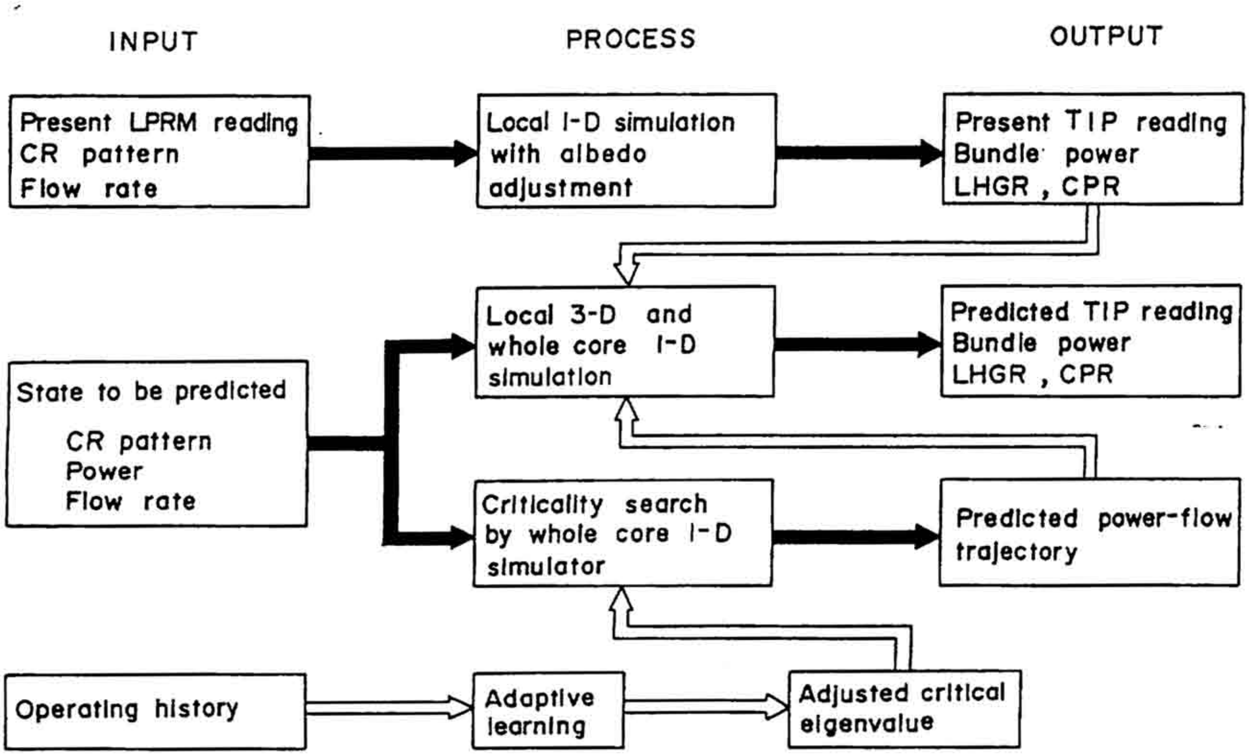

Fig. 1. Configuration of power distribution prediction program system.

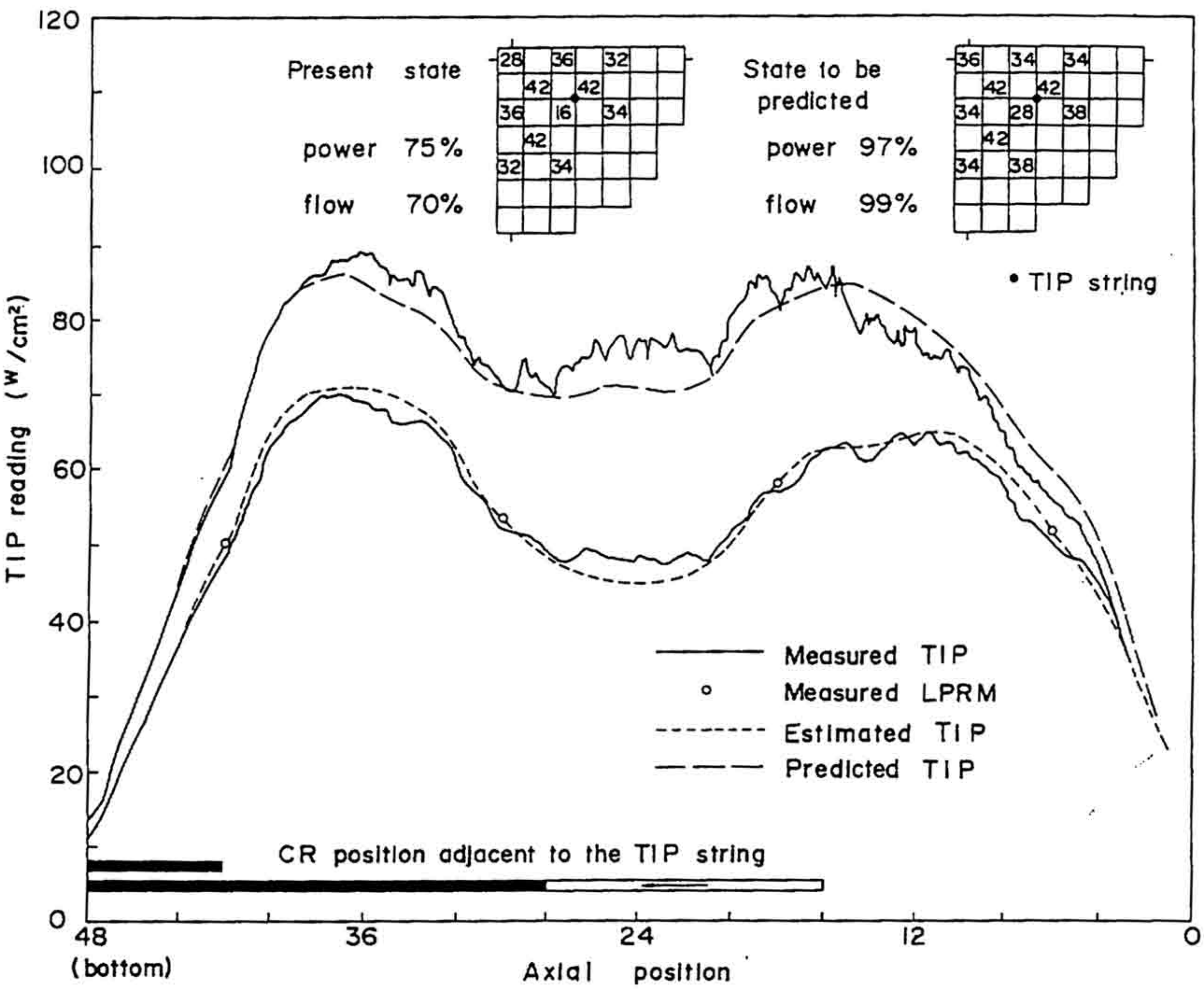

Fig. 2. Results of TIP reading estimation from LPRM readings and TIP reading prediction for control rod withdrawal.

The computing time of this prediction method is found to be short and the required core memory small enough for on-line use.

1. Y. NISHIZAWA et al., *Nucl. Sci. Eng.*, 60, 189 (1976).
2. D. L. DELP et al., "FLARE, A Three Dimensional Boiling Water Reactor Simulator," GEAP-4598 (1964).

5. Using Fuel Performance Prediction in Light-Water Reactor Fuel Management, *S. P. Schultz, A. L. Bement, J. E. Meyer (MIT)*

Current light-water reactor fuel management emphasizes strategies for fuel loading, fuel shuffling, burnable poison and control rod manipulation, and reactor operations which have been designed to meet the system operational requirements of the reactor and to provide energy output at a minimum production cost. The successful attainment of these goals requires that fuel rod integrity is maintained. This investigation proposes an analytical procedure which is designed for the incorporation of fuel integrity predictive methods into fuel management decision analysis.[1]

The aim is to evaluate and improve fuel management techniques with coupling to fuel integrity prediction for cycle-to-cycle fuel assembly shuffling decisions when fuel design parameters, enrichment, and batch size have been specified. Existing methodologies for this purpose utilize simplified fuel behavior modeling techniques which provide minimal account of the known power-time history effects in fuel rod performance. These effects are introduced into the present study by adopting a computer code with sophisticated fuel rod behavior modeling capabilities. A modified version of the GAPCON-THERMAL-2 fuel behavior modeling code[2] is employed as a prototype.

The procedure for coupling the fuel modeling code is developed through a unified analysis approach which employs a technique for mapping fuel performance parameters or integrity measures. This tool provides a format to generate the universal power-time/burnup operation-dependent behavior in an orderly fashion. Fuel performance or integrity prediction results are first obtained from the application of the modeling code to a set of possible three-cycle power-time/burnup management histories. Each member of the set has the same fuel burnup at the end of Cycle 3. A response map is then prepared from this set of problems. The procedure is repeated for sets giving other burnup levels. Finally, responses of fuel rods that experience operational histories specified by a proposed fuel shuffling management scheme are determined by interpolative methods.