FEASIBILITY STUDY OF CORE MANAGEMENT SYSTEM BY DATA COMMUNICATION FOR BOILING WATER REACTORS

FUEL CYCLES

KEYWORDS: *BWR-type reactors, fuel management, optimization, burnup, feasibility, on-line control systems*

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A core management system by data communication has been designed and proposed for more efficient operation of boiling water reactor (BWR) plants by faster transmission and centralized management of information. The system comprises three kinds of computers: a process computer for monitoring purposes at the reactor site, a center computer for administration purposes at the head office, and a large scientific computer for planning and evaluation purposes. The process and the large computers are connected to the center computer by a data transmission line.

To demonstrate the feasibility of such a system, the operating history evaluation system, which is one of the subsystems of the core management system, has been developed along the above concept. Application to the evaluation of the operating history of a commercial BWR shows a great deal of merit. Quick response and a significant manpower reduction can be expected by data communication and minimized intervention of human labor. Visual display is also found to be very useful in understanding the core characteristics.

I. INTRODUCTION

Strong incentives exist for economic and safe operation of a nuclear power station. The complexity of reactor core characteristics, however, involves many difficult problems. The area that is mostly related to the operation in a broad sense is called core management. The optimization of core management is a tremendous task due to a large amount of information and the many interrelated problems involved.

Figure 1 shows typical programs required for core management of boiling water reactors (BWRs). An on-line core performance evaluation program runs periodically on a process computer at the reactor site; the input data to this program are the actual operating data of a nuclear reactor. Control rod programming codes receive the updated core data and determine the rod strategy for the rest of the cycle. These are normally classified in four categories: long term, intermediate term (shim), pattern change, and startup. The results of these calculations are confirmed, upon modification if necessary, by a more detailed three-dimensional BWR simulator (design code). Output of the simulator is fed into a refueling schedule code to determine the reloading pattern for the next cycle. The results are again subject to confirmation by a more detailed three-dimensional simulator, after which the control rod withdrawal sequence is calculated for the next cycle. The accuracy of the three-dimensional simulator is occasionally evaluated by the measured operating data.

As can be seen in the above example, the output of one program is used as the input to another program that deals with the problem of different time scale. The on-line core performance calculation requires a quick response for monitoring purposes even if accuracy is to be sacrificed. On the other hand, the detailed evaluation of operating history can only be performed occasionally (about once a month) but requires high accuracy.

With regard to the above situation, it was felt necessary to develop a core management system under which all the information is well organized

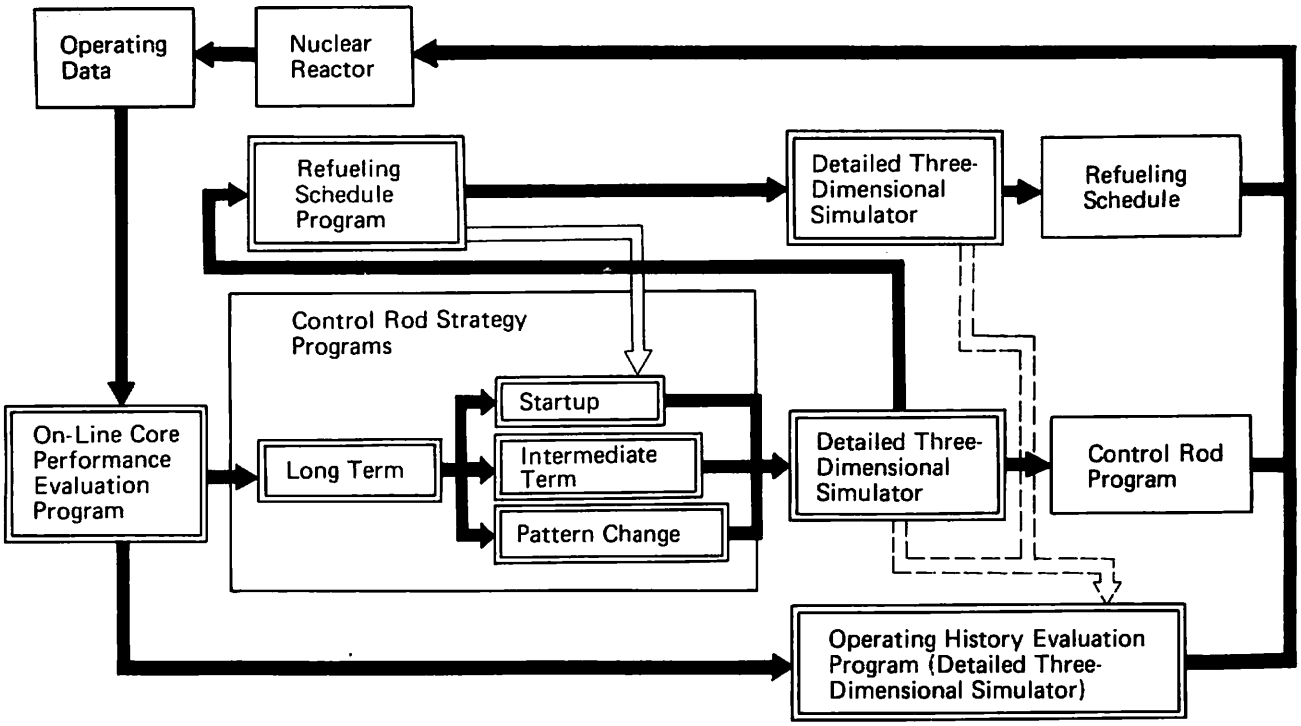

Fig. 1. BWR core management programs.

and controlled and each of the management tasks is well administered. This is particularly important for the station having several nuclear power plants. One possible approach to this problem is to use a computer network. Each task is allocated to a computer that is most suitable, and the computers are connected with each other by data communication.

This paper discusses such a system for BWR core management, and the results applied for an operating history evaluation system are described to show the feasibility and merits of such a system.

II. OVERVIEW OF A CORE MANAGEMENT SYSTEM FOR BWRs

Figure 2 shows the overview of a core management system for BWRs now under development. This system comprises three major subsystems: planning, monitoring, and evaluation.

The planning system develops short- and long-term operating strategy. This includes control rod programming and a refueling scheduling and is often called in-core fuel management. The basic tools for this system have already been developed.[1-4]

The monitoring system is for on-line use. This includes core performance evaluation, core performance prediction, and operating sequence modification. The first monitors the core state periodically and/or on demand. All commercial BWRs are equipped with this monitoring function. The other two are new functions. A core performance prediction program is used to predict how much the power distribution changes before the actual operation takes place for control rod withdrawal or flow rate change. An operational sequence modification program is used to modify, for example, the startup sequence if the actual reactor state is found to be different from what has been predicted by the planning system. These programs are now under development. Some of the results appear in Ref. 5. An operating history evaluation system analyzes the reactor operating history in detail and provides back data for the other two systems. Three-dimensional nuclear thermal hydraulic codes are used in this system to calculate gross[6,7] and local[8] power distributions of fuel assemblies.

The tasks concerned with the planning and evaulation systems normally require a large-scale scientific computer because of the large amount of computation involved. On the other hand, the tasks concerned with the monitoring system use plant data and require quick response. Therefore, these must be subject to an on-line process computer at the reactor site.

A concept of data base is essential for efficient information control of several nuclear power

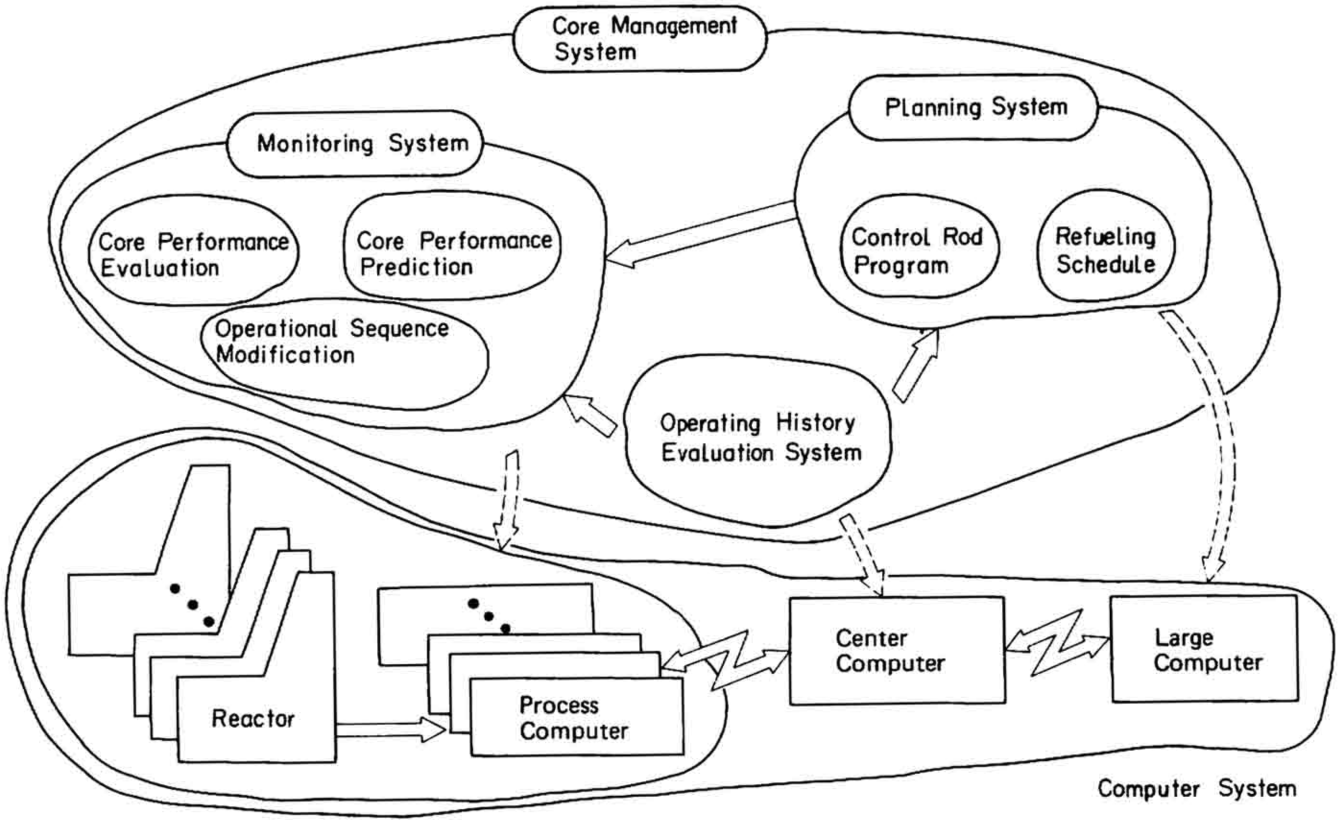

Fig. 2. Overview of core management system for BWRs.

plants. For this purpose, a medium-sized computer, denoted as the center computer in Fig. 2, is introduced between the process and the large computers. This center computer has a large disk file to store all the information necessary for the core management and is connected with each of the process computer(s) at the reactor site(s) and with the large computer by data transmission line.

A possible location for the center computer would be the head office of a utility, while that for the large computer would be a computing center. The desirable form of linkage between the process and the center computers is an on-line real time connection, and that between the large and the center computer is an on-line time sharing connection.

III. OPERATING HISTORY EVALUATION SYSTEM BY DATA COMMUNICATION

III.A. System Configuration

To demonstrate the feasibility of the core management system described in the previous section, the operating history evaluation (OHE) system was selected, and the minimum required software for data communication was developed. The three computers used are the HIDIC-500 (process computer), the HITAC-8250 (center computer), and the IBM-370/158 (large computer). These three are located at different places in Hitachi, Ltd. [HIDIC-500 at Atomic Energy Research Laboratory (AERL), HITAC-8250 at Hitachi Research Laboratory (~200 km north of AERL), and IBM-370/158 at Hitachi Works (~30 km further north)].

For the program to evaluate the operating history, a simple three-dimensional simulator STROD [which is equivalent to FLARE (Ref. 7)] coupled with the parameter adjustment program[9] PAD is used. PAD functions to optimize parameters used in STROD such that the calculated traversing in-core probe (TIP) readings best fit the measured readings. Newly developed programs are line programs for on-line data communication between the process and the center computers, a cathode ray tube (CRT) control program to control the data transmission and the display format, and a few programs for data management at the center computer.

Figure 3 shows the hardware configuration of the operating history evaluation system. The process and the center computers are on-line real time connected, and the data stored in the OHE

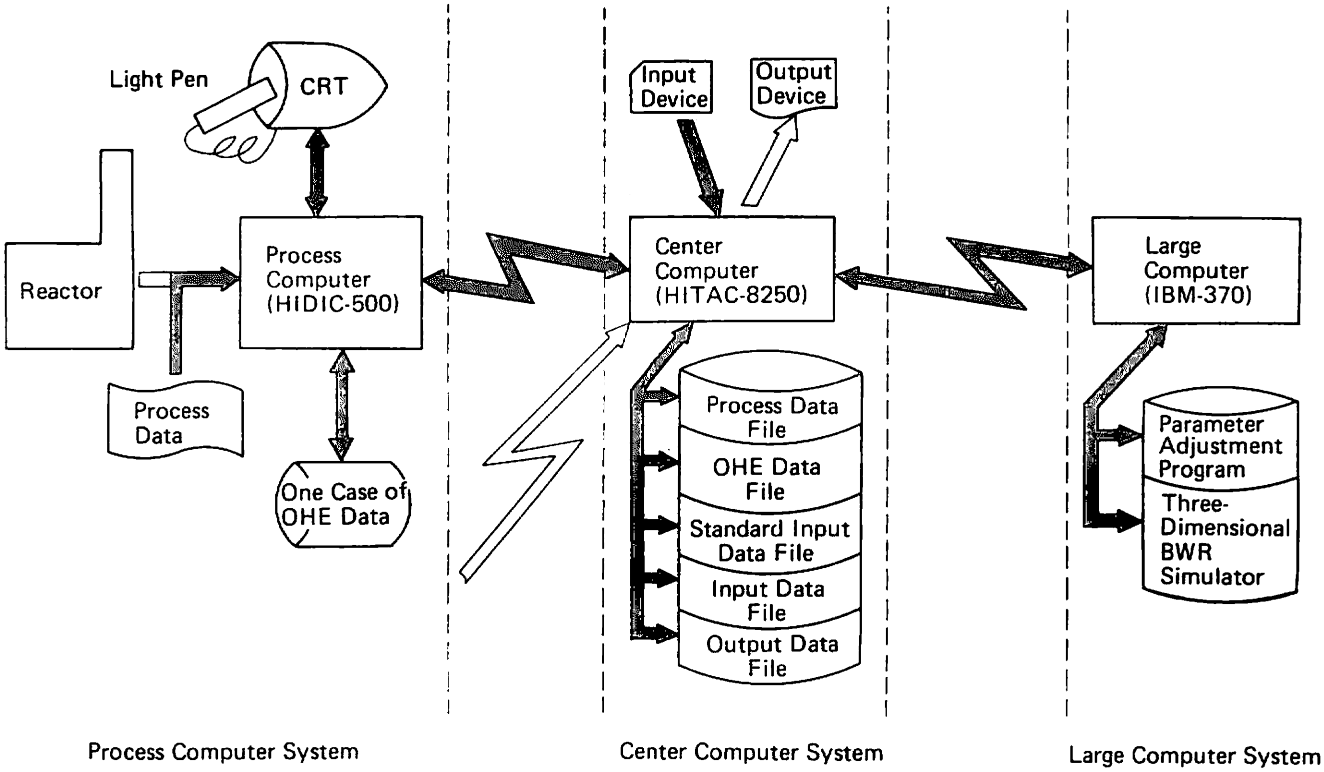

Fig. 3. Hardware configuration.

data file at the center computer can be accessed from the process computer on request through the light pen, and the results are displayed on the color CRT. The center and the large computers are connected on remote batch base. A special system program, the REmote batch Station Program[10] (RESP), is provided for this purpose. As mentioned in Sec. I, the time sharing system is more efficient but is not available for the moment under the present system.

III.B. Information Flow

Figure 4 shows the information flow of the OHE system. Plant data (heat balance data, control rod pattern, TIP readings, etc.) are simulated on a paper tape. These process data are read into the process computer, transmitted to the center computer, and stored in the process data file by the line programs. The stored process data and the standard input data (core geometry, nuclear constants, etc.) that have been stored in the standard input data file in advance are put together to generate the input data in a format acceptable to the OHE programs (PAD and STROD). The generated data are stored in the input data file. These data are directly transmitted to the large computer together with a few control parameters. The job is registered once it is transmitted in the input queue file and processed. After the job is completed, the results are automatically transmitted back to the center computer and stored in the output data file. The stored data are rearranged by an editing program and are finally stored in the OHE data file.

Once the final data are stored in the file, it is possible to have access to any part of them from the process computer. The data are displayed on the screen in various forms of figures and tables.

III.C. Data Communication

III.C.1. Data Communication Between the Center and the Large Computers

No major technical problems exist for the data communication between the center and the large computers under the RESP system, except that a part of the editing program has to be written by assembler language because of the difference of block sizes between the two computers. The only problem here is that the turnaround time of the submitted job is not necessarily short enough under the remote job entry system. A time sharing system that allows a large amount of core memory is felt to be strongly desirable.

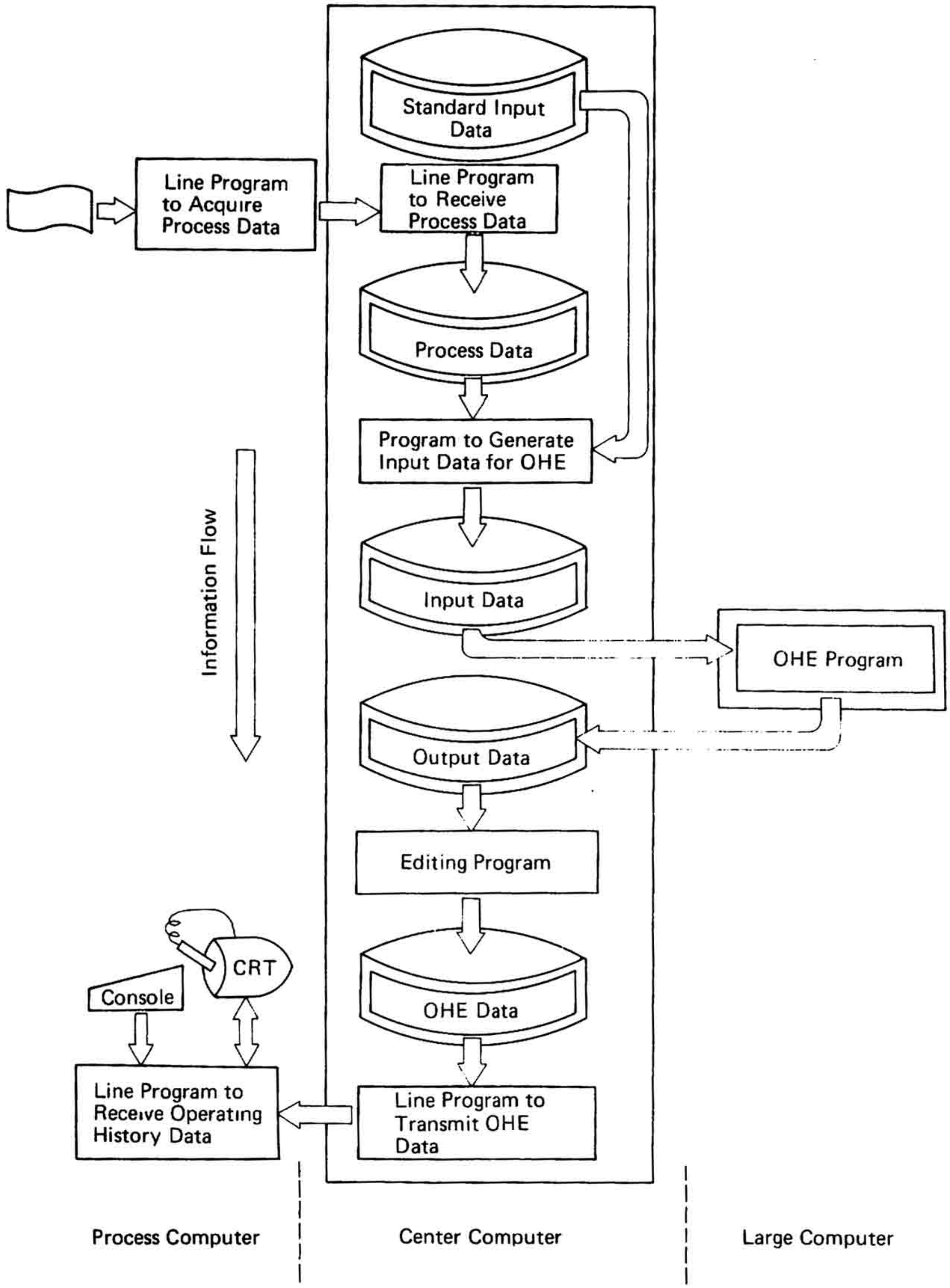

Fig. 4. Information flow of OHE system.

III.C 2. Data Communication Between the Center and the Process Computers

All the line programs and the CRT control program have to be written by assembler language. Transformation of data is necessary because of the differences in bit size and architecture between the two computers.

Figure 5 shows the procedure to transmit process data from the process computer to the center computer. The CRT control program starts upon system initiation, whereupon the line program runs by the instruction given through the light pen. Transmission request of the process data is given through the console. Upon request, the block names of the process data for which the transmission is requested are stored in the file name data file, and, at the same time, the process data are read in and stored in the process data file. The transmission data are generated by an editing program from these two sets of data in the two files. The data are then transmitted block

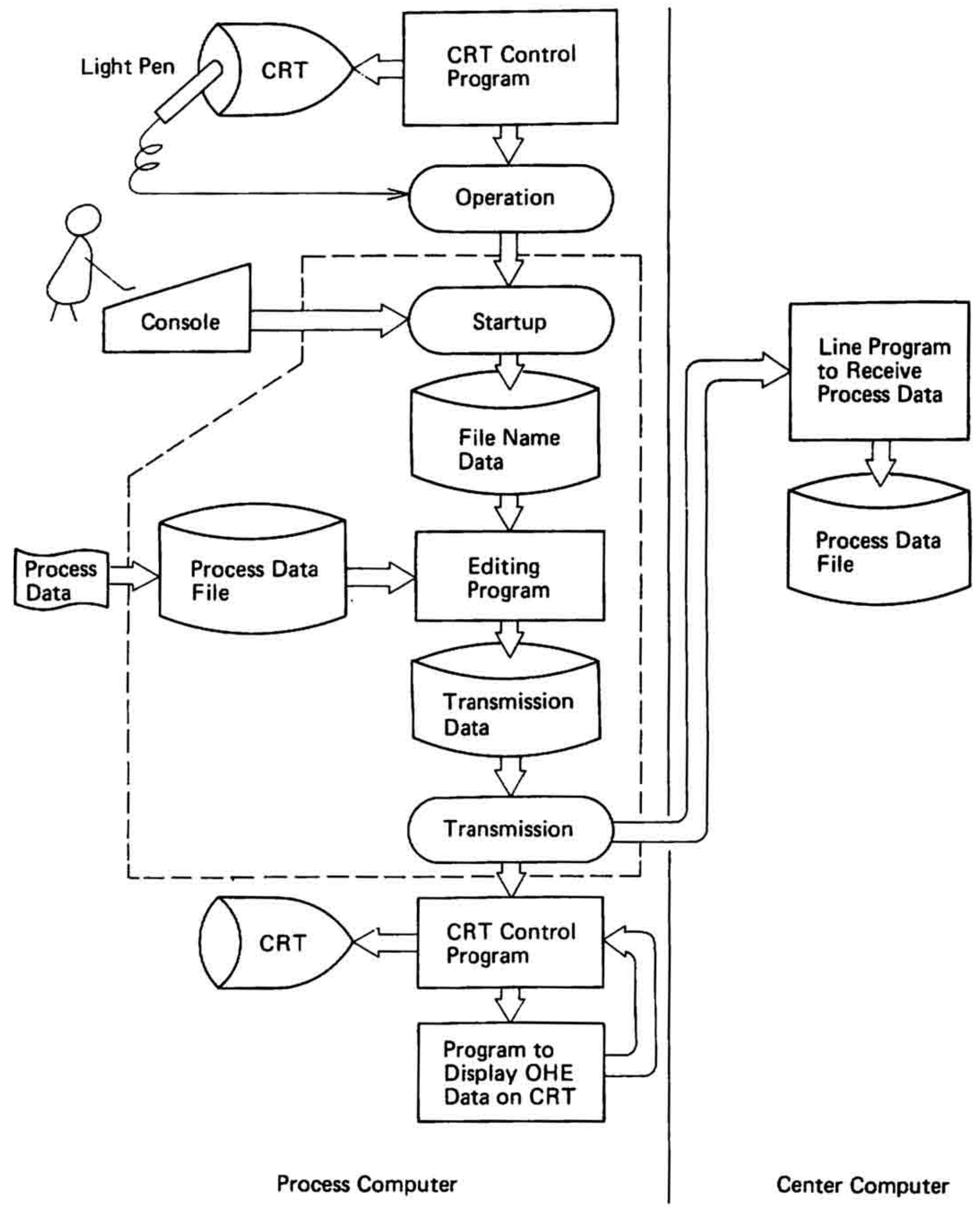

Fig. 5. Process data transmission procedure from the process computer to the center computer.

by block to the center computer. The transmitted data are stored in the process data file in the center computer by the line program.

Figure 6 shows the procedure to transmit OHE data from the center computer to the process computer. The line program at the process computer generates the control information when the instruction for data aquisition is given through the console and transmits it to the center computer. The transmitted control information is then displayed on the CRT at the center computer, by which the nuclear engineer can recognize what is requested. The line program, after being given permission, starts searching the requested data in the OHE data file. The data are then transmitted block by block to the process computer. The line program of the process computer recieves the data and stores them in a temporary OHE data file. After the transmission is completed, the CRT control program starts, and the OHE data are ready to be displayed on the color screen.

III.D. Display of Results

The color CRT used is the character display HIDIC-7836. Graphic routines were newly developed to display some of the results in the form of figures.

Figure 7 shows the classification of the display data. The OHE data include main data (reactor power, core flow rate, inlet subcooling, margin from the rod block line, etc.) ①, control rod pattern ②, channel flow distribution ③, TIP data (readings ④, and string No. ⑤), and 13 kinds of three-dimensional data (power, linear heat rate, critical heat flux ratio, moderator density, xenon, iodine, exposure, etc.). These three-dimensional data are further classified into eight blocks: maximum, minimum, and core average ⑥, radial average ⑦, axial average ⑧, channel maximum ⑨ and axial location ⑩, channel minimum ⑪ and axial location ⑫, and channelwise three-dimensional distribution ⑬.

Particular emphasis was given such that these

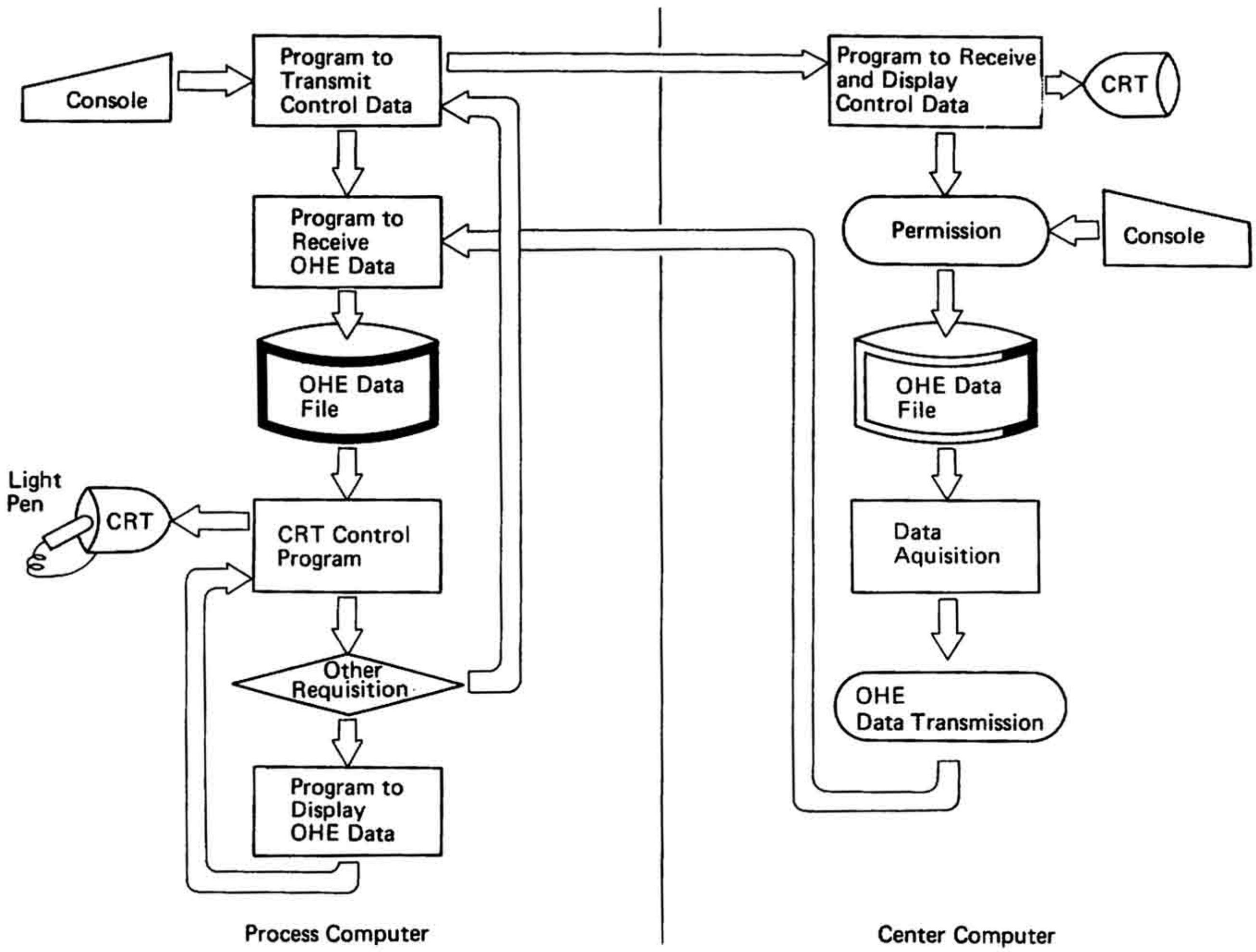

Fig. 6. OHE data transmission procedure from the center computer to the process computer.

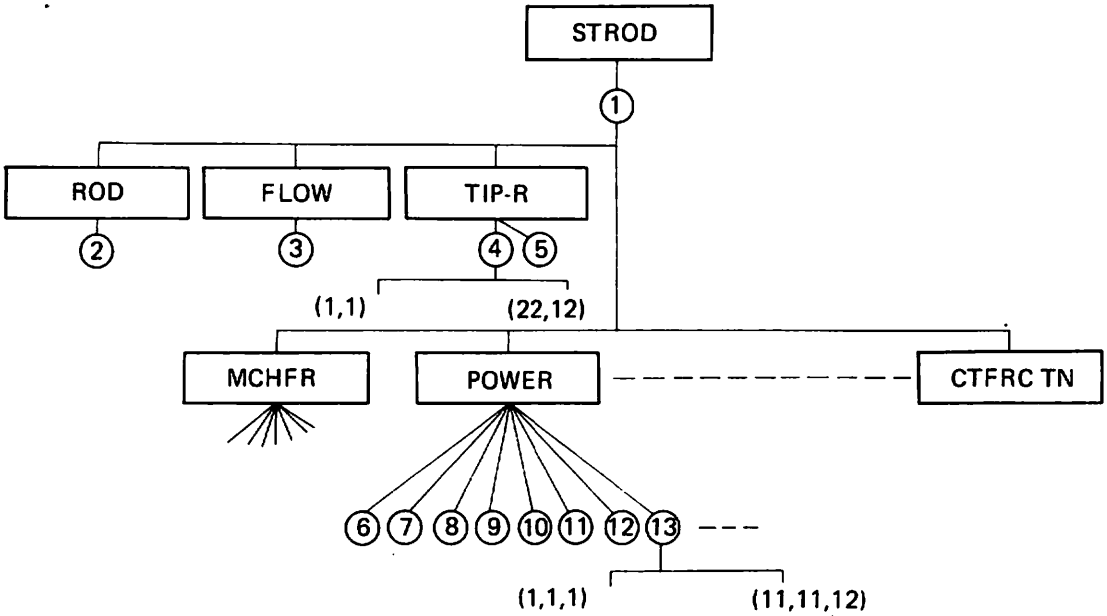

Fig. 7. Classification of display data.

data can be referred to in almost any order. Since the amount of information that can be displayed on a single format is limited, these data are grouped into a set of formats. Any set of data is referred to by selecting a keyword prepared in a menu for each display format. The relationship among keywords for display data is shown in Fig. 8. The arrows indicate the direction we can go from one set of data to another set. From the main menu, which is denoted as the basic diagram for display control in Fig. 8 and the format of which is essentially the same as Fig. 7, 17 sets of data can be accessed by selecting the keyword (ROD, TIP-R, POWER, etc.) through the light pen. For each of the data sets selected, the next keyword is prepared for selection in the submenu to go to the next data set, as indicated in Fig. 8.

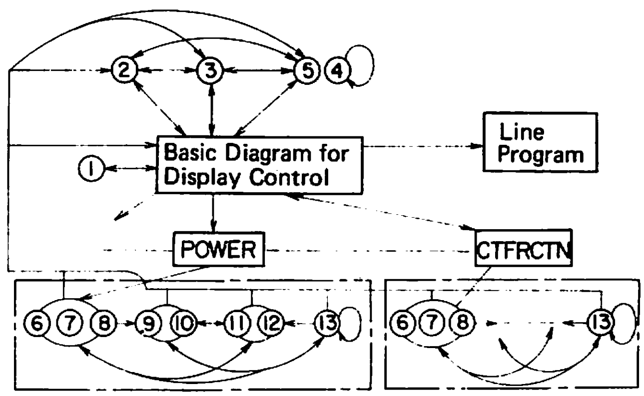

Fig. 8. Relationship among keywords for display data.

III.E. Demonstration

Using the aforementioned operating history evaluation system, the operation of a commercial BWR of 460 MW(e) has been traced for the first six months after its startup. A punched output paper tape of an on-demand program of the on-line core performance evaluation program was used to simulate the process data. The control rod pattern, TIP data, and the heat balance data were used to optimize the adjustable parameters (for example, radial and axial albedos, mixing factors of the transport kernel, and coefficients of void-quality relation) used in STROD by PAD. The procedure of optimization was similar to that described in Ref. 9. The optimized parameters were then stored in the standard input file. The optimization can be performed once a month because TIP data are normally taken every month. However, for the sake of simplicity, the parameters were optimized only once using the TIP data measured at the beginning of the cycle. The burnup step taken was one month.

Figures 9 and 10 show the control rod pattern and the TIP readings used to optimize the parameters. The depth of the rods is shown in numerals (24 indicating full insertion). The numerals on the right side of Fig. 10 are the string numbers of TIPs. The string at which the readings are to be viewed can be selected by pointing the number through the light pen. A maximum of three figures

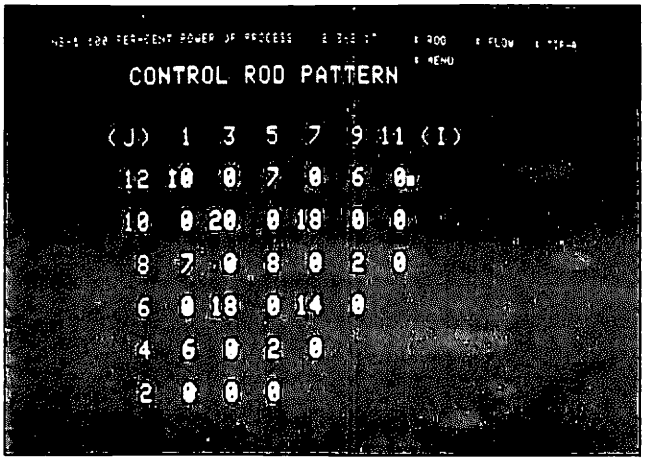

Fig. 9. Display format of control rod pattern.

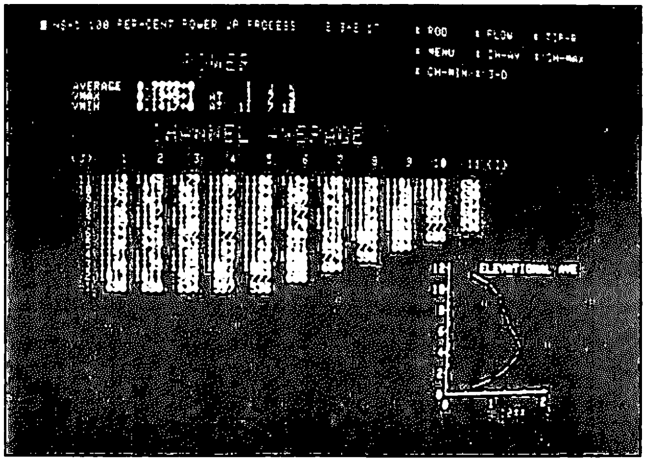

Fig. 11. Display format of maximum, minimum, core average, radial average, and axial average of power.

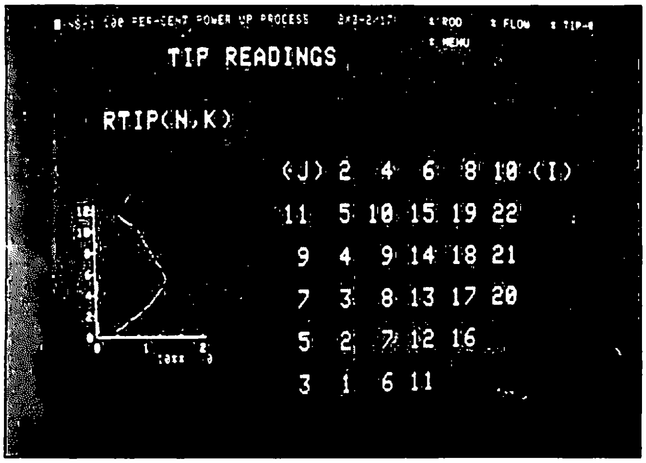

Fig. 10. Display format of TIP reading.

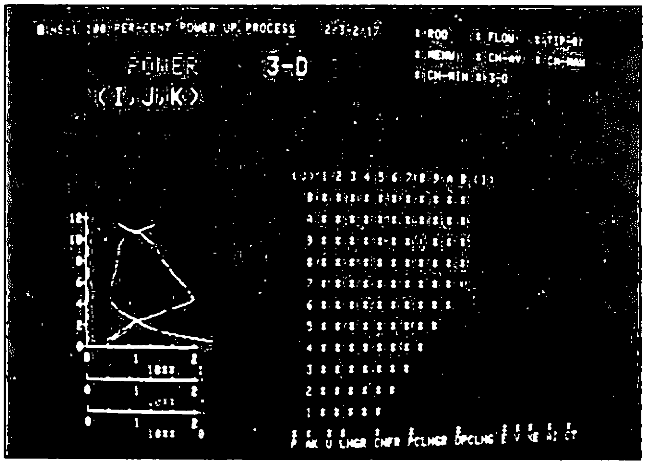

Fig. 12. Display format of channelwise three-dimensional distribution of power.

can be displayed on the format shown in the left side. When the fourth string is selected, the first one is erased. The readings and the string number are correlated with each other by the same color.

Figures 11 and 12 show the results of the calculated power distribution at the first burnup step. Core average, maximum, and minimum values are shown on the upper left together with their locations, with the radial average (channel) distribution shown in the middle and the axial average on the lower right in Fig. 11. The procedure used to display the channelwise power in Fig. 12 is exactly the same as that used in Fig. 10. The location of channel at which the axial power distribution is to be viewed can be selected by the light pen as many times as requested. One of the characteristics of this format is that the other quantities, such as MCHFR, exposure, etc., can be displayed while looking at the power distribution. For this purpose, the submenu shown at the right bottom can be used. In Fig. 12, MCHFR is displayed in addition to the power for a selected channel. The format of other three-dimensional quantities is exactly the same as those shown here for the power.

As explained in the above example, all the calculated results can be referred to at the reactor site by on-line data communication. The transmission speed of the line is now 4800 bits per second. It takes only a few minutes to send the process data from the process computer to the center computer and ~5 min to send the calculated results of one burnup step (one case) from the

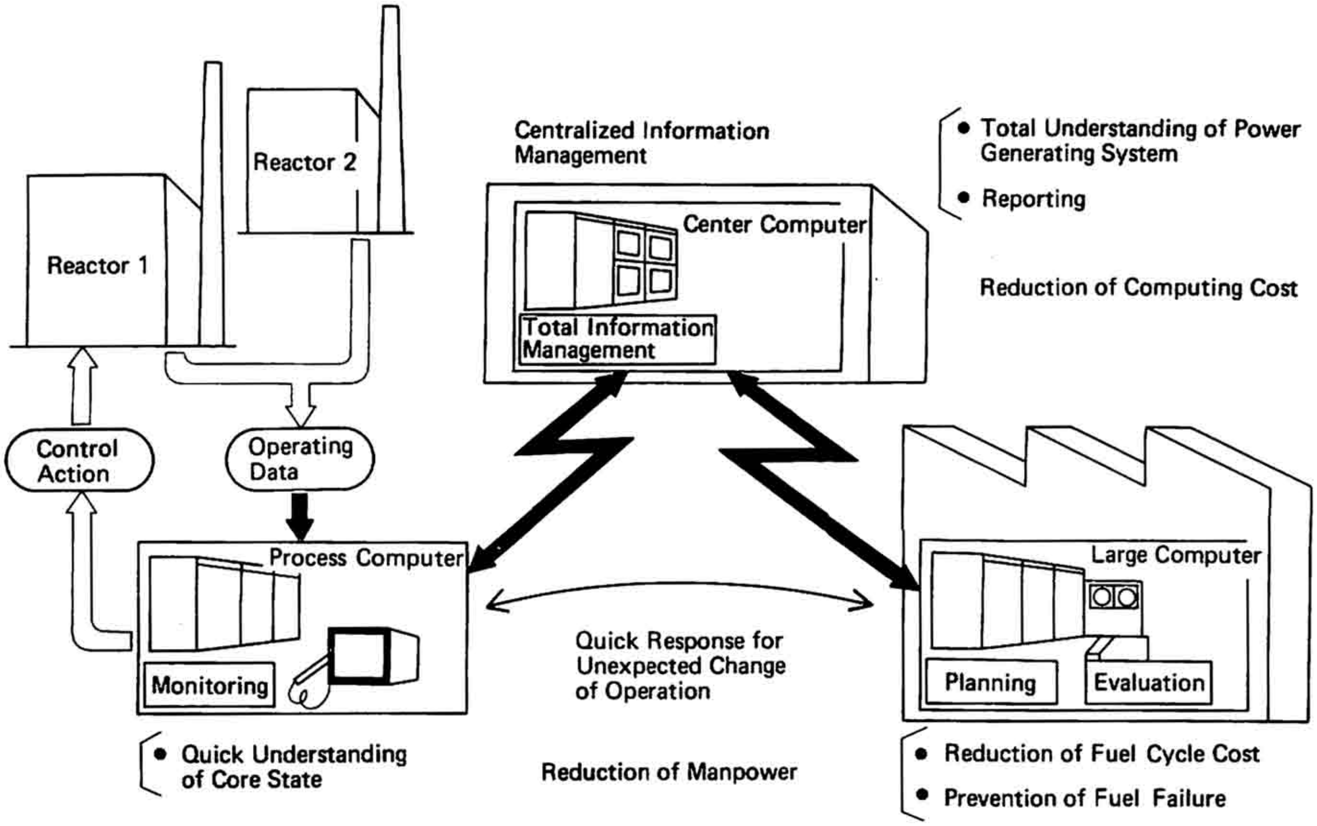

Fig. 13. BWR core management system by data communication.

center computer to the process computer. This includes the time required for retrial of transmission by noise on the line and for file access. The time required for the data transmission is felt to be acceptable for the purpose of operating history evaluation.

IV. CONCLUSION

A BWR core management system has been designed for more efficient and better organized management of several nuclear power plants. A schematic diagram of the proposed system is shown in Fig. 13. The basic idea is to establish a computer network by which to realize the faster transmission and the centralized management of information.

The system consists of three computers of different size and purpose: process computer(s) at reactor site(s), a center computer possibly at the head office of a utility, and a large scientific computer. Each of the core management tasks is allocated to a computer that is most suitable. The process computer is for monitoring, and the large computer is for planning and evaluation. The center computer is for centralized information management and is connected to each of the process computers and to the large computer by a data transmission line.

The expected merits of such a system are

1. quick response by data communication for unexpected change of operation, evaluation of operating history, and planning of operating strategy
2. reduction of manpower and computing cost by minimized intervention of human labor
3. quick understanding of core state by visual display
4. organized administration of the total power management system by centralized information management.

To demonstrate the feasibility and the merits of such a core management system, the operating history evaluation system has been chosen and materialized along the concept mentioned above. The feasibility study is successful, and the results obtained through the application of a commercial BWR confirm the merits of such a system. Various experiences encountered and techniques developed in this study will be very useful for future application to a more general system.

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REFERENCES

1. T. KAWAI, H. MOTODA, T. KIGUCHI, and M. OZAWA, "A Method for Generating a Control Rod Program for Boiling Water Reactors," *Nucl. Technol.*, **28**, 108 (1976).

2. H. MOTODA, J. HERCZEG, and A. SESONSKE, "Optimization of Refueling Schedule for Light-Water Reactors," *Nucl. Technol.*, **25**, 477 (1975).

3. H. MOTODA and O. YOKOMIZO, "Optimization of Fuel Assembly Allocation for Boiling Water Reactors," *J. Nucl. Sci. Technol.*, **13**, 230 (1976).

4. O. YOKOMIZO, H. MOTODA, T. KIGUCHI, and R. TAKEDA, "A Man-Machine Communication System for BWR Core Management Planning, *Nucl. Technol.*, **29**, 191 (1976).

5. Y. NISHIZAWA, T. KIGUCHI, and H. MOTODA, "On-Line Prediction of the Power Distribution Within Boiling Water Reactors," *Nucl. Sci. Eng.*, **60**, 189 (1976).

6. S. UCHIKAWA and R. TAKEDA, "A Few-Group Three-Dimensional BWR Burnup Code COSMO," *Trans. Am. Nucl. Soc.*, **18**, 178 (1974).

7. D. L. DELP, D. L. FISHER, J. M. HARRIMAN, and M. J. STEDWELL, "FLARE-A, Three Dimensional Boiling Water Reactor Simulator," GEAP-4598, General Electric Company (1964).

8. K. DOI, T. KIGUCHI, S. UCHIKAWA, and R. TAKEDA, "Nuclear-Thermal-Hydraulic Characteristics of BWR Fuel Bundles," *J. Nucl. Sci. Eng.*, **12**, 526 (1975).

9. T. KIGUCHI and T. KAWAI, "A Method for Optimum Determination of Adjustable Parameters in the Boiling Water Reactor Core Simulator Using Operating Data on Flux Distribution," *Nucl. Technol.*, **27**, 315 (1975).

10. "Program Manual HITAC-8250 NDOS RESP," (in Japanese), Hitachi Ltd. (1970).