EBR-II DIGITAL DATA ACQUISITION SYSTEM STUDY

By

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EBR-II Project

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	4
I. SUMMARY DESCRIPTION	4
A. Introduction	4
B. Objectives	5
C. Justification	6
1. Analysis	6
2. Increased Power	6
3. Operational Aids	6
4. Data Logging and Reporting	7
5. Experimental Support	8
6. System Monitoring, Data Logging, and Operational Support.	8
II. REQUEST FOR PROPOSAL	12
A. Introduction	12
B. Program Requirements	12
1. Control-rod Calibration.	13
2. Power Coefficient.	13
3. Prediction of the Worth of Core Changes	14
4. Rod-drop or Reactivity-disturbance Analysis	16
5. Analysis of Thermodynamic Characteristic Behavior.	17
6. Rod Oscillator Experiments	18
7. Correlation of Various System Parameters	19
8. Determination of Characteristic Behavior of Reactor Support Systems	20
9. Reactivity Meter	20

Big

Table of Contents (cont)	<u>Page</u>
10. Subassembly-outlet-temperature Monitor	21
11. Heat-balance Monitor	22
12. Logging.	24
13. Secondary-flow Computer.	26
14. Alarm Functions	27
C. Equipment Location	27
1. Computer Room	27
2. Cable-routing Room	28
3. Reactor Building	28
4. Reactor Control Room	28
D. Equipment Description	28
1. Central Processor Unit (CPU)	28
2. Input-Output Processor	30
3. Peripheral Equipment.	30
4. Software Requirements.	31
5. Multiplexer Sample-and-hold Amplifier and Analog-to-Digital Converter.	32

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Block Diagram of Data-acquisition and -reduction System	29

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ABSTRACT

The Digital Data Acquisition System (DAS) described herein will be used as support of EBR-II. The objectives of the DAS will be to replace the outdated data-gathering equipment with a modern digital system that will be used as an operational aid, a data-reporting, and an analysis tool. As an operational aid, the system will display to the operators computed results for control and/or information. It will store the data for periodic reporting and automate the reporting process. The DAS will interface the experimenter to the reactor, allowing online, real-time analysis. This document describes the functional requirements and necessary equipment to perform the above tasks.

I. SUMMARY DESCRIPTION

A. Introduction

Assessment of the many problems that have arisen during the gradual conversion of EBR-II to an irradiation facility indicate a need for a modern digital online computation system. The need for a more efficient, faster, and more reliable system for data acquisition and processing is a direct consequence of the following factors: the unavoidable obsolescence in data-handling systems resulting from improvements in digital computational systems; the steadily increasing demands for plant-surveillance information; a concern for the stability and safety of the plant as the

reactor core becomes increasingly complex; and the increasing capability for processing, analyzing, and interpreting operation data with the acquisition of additional personnel. Underlying the concern for plant safety is the knowledge that, at the present time, EBR-II is the only operating fast reactor in the United States.

It is clear that a wide variety of problems were introduced with the gradual conversion of EBR-II from a demonstration plant to an irradiation facility. The need for a predictable, well-defined, and controllable environment is a direct result of the change to an irradiation facility. The existing data-acquisition, recording, and presentation system will be backed up and extended, but not directly replaced, by the Digital Data Acquisition System (DAS). A gradual phaseout of some of the existing equipment will be done as confidence in the DAS is established.

With the emphasis placed on EBR-II as an irradiation facility and with the increased availability of manpower for analytical effort, a modernized data-acquisition and -processing system will permit: a more rapid, comprehensive, and thorough surveillance of plant data; a better understanding of the steady-state and dynamic performances of the reactor; an increased assurance of plant safety; and a broader and more systematic input of information to the overall LMFBR program.

B. Objectives

The main objective of the DAS is the replacement of the existing data-logging system with a modern digital system that has a greater capability and flexibility for the acquisition and processing of routine and special plant-surveillance data. More specifically, the proposed system is expected to:

1. Improve the reactor plant factor by:
  - a. reducing the turnaround time currently needed for processing plant data with offline computers,
  - b. reducing the occasional need for repetitions of certain reactor experiments, and
  - c. decreasing the time needed for reactor physics experiments.
2. Facilitate the implementation of future power-increase programs.

3. Provide data processing for future instrumented subassemblies and in-core loops.
4. Decrease the probability of fuel meltdowns.
5. Increase the possibility that potential malfunctions may be indicated sufficiently in advance to permit corrective action or a minimization of downtime or damage to plant components.

C. Justification

1. Analysis

Digital computation for experimental results is made more useful if it is presented simultaneously with the running of the experiment. This, along with a graphics system, allows the experimenter to interface with the system. Thus, immediate rerun of the experiment is available along with comparison to system models, etc.

2. Increased Power

The plan to increase reactor power to the optimum power level places special emphasis on identifying the limiting system parameters and establishing the magnitude of safety margins. While the reactor demands primary consideration, the intermediate-heat-exchanger and steam-generator systems also must be considered. Obviously, the performances of these systems can be analyzed by an offline computer, but the results are only available after the fact. It is conceivable that during the time required for offline analysis, an impending malfunction, though indicated by the unprocessed data, would not be annunciated in time to prevent failure and possible damage to the system. The features of rapid surveillance and annunciation strongly recommend an online system. While this is true at all power levels, the higher the power level the greater the need for online analysis.

3. Operational Aids

A "post-incident recall system" is needed to separate causes and effects of nonroutine incidents. Most of the continuous monitoring at EBR-II is carried out with strip-chart recorders. Chart speeds are selected so that the consumption of chart paper is not excessive. For nonroutine events (such as a nonscheduled shutdown) the time base currently

afforded by the charts needs amplification. Furthermore, no suitable method exists for establishing reliable time reference between various strip-chart recorders. The determination of causes and effects, in many instances, has been very difficult. A more satisfactory system would anticipate that malfunctions which affect the parameters monitored will occur. The proposed system preserves the record prior to and during failure by high-speed logging on a continuous basis and erases the information when it becomes a few minutes old. The erasing procedure is automatically interrupted when off-normal conditions are indicated.

Another operational aid made possible by the DAS is an instrument-and-control-system monitor. The function of this monitor will be to rapidly test pertinent reactor instrumentation for substandard performance during reactor downtime and thereby provide faster reactor turnaround time.

4. Data Logging and Reporting

The present EBR-II plant includes an obsolescent automatic data-logging system. The system has the capability for scanning 250 points, logging digital information on punched cards, and printing selected points on four electric typewriters. This system has exceeded its life expectancy. Upgrading of the system would be expensive. The proposed Digital Data Acquisition System will perform all functions currently being performed, will perform them faster, and will additionally be able to perform a wide variety of other functions completely beyond the capabilities of the existing system. It will have the capacity to process the output signals from the instrumented subassemblies and will be expansible for future instrumented experiments.

The processing of raw plant data to finalized report form is severely restricted at present by the amount of manual effort required. Automation of the data-handling process will not only increase the quantity and accuracy of data, but will present them in a form suitable for reporting and publication. This feature will assume added significance when such projects as the instrumented subassembly, the loop experiments, and the nuclear instrument test facility materialize.

5. Experimental Support

The value of an online data-acquisition-and-reduction system has been clearly demonstrated during the past year with the successful application of digital techniques to measurements of the reactor transfer function. Inherent advantages are a significant increase in accuracy and the minimizing of the lag between data taking and obtaining of final results. Near-term advantages will accrue in the form of more information with a higher degree of accuracy and reliability.

The following experimental and data-reduction programs will be available:

- a. Control-rod calibration
- b. Calculation of power coefficient of reactivity
- c. Estimates of reactivity worths of reactor core changes
- d. Analysis of rod drops or other reactivity disturbances
- e. Analysis of thermodynamic-characteristic behavior
- f. Transfer functions by rod oscillator methods
- g. Correlation of various system parameters to determine system interrelationships
- h. Determination of characteristic behavior of reactor support systems

Other programs may be added to this list; however, the programs cited are intended to indicate the nature of experiments that fall within the capability of the proposed system. Experimental programs will be conducted sequentially in a manner optimizing memory and machine speed.

Programs related to control-rod calibration, power coefficient, and reactivity worth show promise of being developed into online operational aids for EBR-II and other future reactor systems. A description and an outline of each of the programs are given in Section II.B.

6. System Monitoring, Data Logging, and Operational Support

The system will provide the following programs and processes in support of reactor operation:

- a. Reactivity meter
- b. Subassembly-outlet-temperature monitor
- c. Heat-balance monitor
- d. Logging
- e. Secondary-flow computer

- f. Instrumentation-and-control-system monitor
- g. Alarm functions

The objectives of these programs follow.

a. Reactivity Meter

The FERMI incident pointed out the importance of a prompt flow of system information to operations personnel. The development and implementation of an online reactivity meter will aid in detection of any reactivity anomaly. The DAS will allow continuous computation and display of a parameter designated as "anomalous reactivity." Such a system is intended to eliminate the existing deficiencies in traditional period meters, which indicate an infinite period during steady-state operation and give erroneous information during and immediately following control-rod changes.

The reactivity meter will be the primary means of determining and annunciating anomalous reactivity behavior. The output of this device will be presented continuously to the reactor operator on an oscilloscope and will be retained in the recallable data for post-incident analysis.

b. Subassembly-outlet-temperature Monitor

The computation of setpoint limits that are normalized for actual power level and time response and the provision of an instant display of the subassembly-outlet-temperature profile will be significant improvements over the present system. These features would be helpful, under certain conditions, in annunciating the possibility of an impending fuel meltdown.

c. Heat-balance Monitor

There are several areas where operation of the reactor can be improved by an adequate flow of information to the reactor operator. Operation at a power level of 45 MWt has resulted in substantial safety margins for many auxiliary systems, but these margins will be narrowed for higher-power operation. A significant aid to the operational safety of the reactor will be the continuous monitoring of the heat balance across the intermediate heat exchanger and the steam generator. The heat balance of these systems should be in equilibrium with reactor power during steady-state operation. During transitional power periods of operation, the difference in heat balance defines the rate of change of system temperatures.

d. Logging

To check for performance changes in various components, daily logging and report logging will be performed. By utilizing about 100 input signals, the computer will perform the necessary operations to graph the various performance factors. The cognizant engineer for each system or component will receive every day a graph of the performance factors for the previous 24 hr. It is anticipated that a summary of these performance factors will be reported periodically as part of one of the EBR-II Project reports.

A special feature of the logging program will be the post-incident recall system. In the event of a scram or other abnormality, all data accumulated at the fastest scanning rate will be automatically retained for graphing. The parameters to be monitored will be identical with those used in the present logging program. After the 10-min interval following the event, information will be processed at the usual logging rates. At the present time it is difficult to establish time sequences of events in the operation of the reactor after the fact. Although the most significant parameters are recorded, many are displayed on single-pen recorders with chart speeds selected to minimize paper consumption. The sequence of events in periods of interest cannot be reliably reconstructed because of slow-moving charts and the lack of accurate time references. Running the charts at increased speeds is only a partial solution to this problem.

The anticipation feature is accomplished by continuous monitoring with a high scanning rate. When the data become 10 minutes old, they are automatically erased. When an abnormality occurs, the erasing process is automatically interrupted and the data stored.

e. Secondary-flow Computer

Another much-needed operational aid involves the control of the secondary EM pump. Manipulations of the flow rate of this pump require more skill on the part of the reactor operator than any other routine console operation. Skill is required because the operator must base adjustments of pump flow on extremely delayed temperature responses. There are no usable temperature sensors on the outlet side of the intermediate heat exchanger, and furthermore, none can be installed economically.

The reactor operator is required to wait more than a minute to observe the results of his actions as he makes adjustments in the secondary flow. It is highly desirable to provide the operator with more prompt information on the temperature responses. This information can be supplied through computational means with virtual elimination of the time delay. The computation involves pure time lags, which can be handled easily with digital equipment, but which would be impractical on analog equipment. The computation is made continuously by using an algorithm of the heat-exchanger and bulk-sodium-tank heat characteristics to predict the flow rates needed to adjust the temperatures. This information will enable the reactor operator to control the secondary flow more effectively.

f. Instrumentation-and-control-system Monitor

The present reactor instrumentation consists primarily of seven ion chambers, 75 thermocouples, three pressure transducers, and five flow meters. The techniques used for checkout prior to startup involve checklists with specific inputs selected at predetermined points in the systems, the visual interpretation of meters and analog charts, and "go"/"no-go" indication of interlocks. If an instrument fails to respond, then repair is obviously required. The typical time requirement for checkout prior to a reactor startup is now about 2 hr. Startup checks are made on about 5% of the total instrumentation.

Performance of the same checks on present instrumentation with a digital computer will require only a fraction of the time now required. The startup information now logged manually would be automatically recorded. Online monitoring can examine the characteristic behavior of any channel and instantaneously compare this with previous data from the same channel. A flag can be triggered whenever a significant change has occurred. This will reduce the probability of many incidents by providing an early warning of possible malfunctions. As a result of this monitoring system, an improved maintenance model can be formed based on statistical evidence.

New instrumentation could be designed with the computer interface in mind. (Digital-to-analog converters could be included, and wiring would provide for multiplexed inputs to the equipment.) The plant prestartup checkout procedure could then be completely automated.

Performance of these functions would require the use of many of the same information channels proposed in other portions of this document. Only changes in software and calibration of inputs are required. For new instrumentation, only software changes would be necessary.

To provide comparison data, each checkout event can be recorded on magnetic tape for subsequent comparisons. This would minimize the amount of computer core storage required, keeping it within the size dictated by other programs.

g. Alarm Functions

The present alarm systems will be supplemented to provide prescram alarm information. In addition, software will be developed for identifying the number of erroneous indications through the use of statistical filtering techniques and the computation of safety limits. This program may eventually lead to the development of a new online system for alarm and scram functions.

Other alarm functions will be provided by the monitoring systems that were described earlier in this document.

II. REQUEST FOR PROPOSAL

A. Introduction

The Digital Data Acquisition System (DAS) is to be used as a direct-support tool for EBR-II's present mission as an irradiation facility. The system will support the reactor-and-plant-analysis group, the reactor-and-plant-operations group, and the experimental program. To effectively perform these tasks, the system must provide flexible online (real-time) operation and be capable of batch-process operation. Input/output operations must be as independent of the central processor as possible. This is necessary to minimize interruptions to processing under alarm conditions and during experimental conditions that involve complex analytical programs.

B. Program Requirements

Several of the programs functionally described on the previous pages are outlined in detail below.

1. Control-rod Calibration

A control-rod-calibration program will be used during every startup to evaluate rod-worth curves. These curves will be plotted on the plotter and utilized by the operating personnel.

The rod-reactivity-worth curves will be generated by inverse kinetics calculations, and a recording will be made of the rod position for approximately 140 points in the 14.0 in. of rod travel. This will give a reactivity point for every 0.1 in. of rod travel. Additional calibrations will be made for specific control rods under banked rod conditions.

Once the rod-position-versus-reactivity data have been obtained, the data points will be fitted to a polynomial equation and stored for future use. This polynomial could be generated for each rod or for only those rods actually used in reactor operations or experiments. Such evaluations, in turn, will simplify and improve the reliability of power-coefficient, rod-drop, and transfer-function measurements.

Subroutines needed for online control-rod calibrations include:

- a. data acquisition,
- b. data smoothing,
- c. inverse kinetics,
- d. correction factors for various system deviations from normal operations, and
- e. polynomial curve fitting.

The data-sampling rate for power and rod position for this procedure would be approximately 700 samples per second, and storage of 6000 data points would be required.

2. Power Coefficient

The power coefficient of reactivity will be evaluated while the reactor is being brought to operating power. This program requires the use of the rod calibration previously discussed. The inputs to the calculation include the fitted polynomial, rod position, power, bulk-sodium inlet temperature, integrated power (MWd), rod bank worth, and reactor axial coolant differential temperature. Heat-balance data will be used to specify the power level.

The integrated power (MWd) will be used to determine the burnup correction factor. The bulk-sodium temperature and the reactor-coolant ΔT will be used to determine the power-coefficient correction factors, and the rod bank correction will be calculated from the rod bank position. These corrections will then be applied to the rod worth calculated by substituting the rod position into the polynomial predicted by the control-rod-calibration program. This program can be used each time the reactor power-reactivity decrement (PRD) is to be measured.

The programs necessary to compute the PRD are relatively simple calculations requiring a minimum of computer time, as shown by the equation

$$PRD = \sum_{i=0}^n a_i X_i + K_0 T_{BNa} + K_1 \Delta T_R + K_2 \int Pdt + K_3 X_{BR}, \quad (1)$$

where

a_i	= coefficients from rod calibration,
$K_0, K_1,$	
$K_2,$ and	
K_3	= predetermined reactivity coefficients,
T_{BNa}	= bulk-sodium temperature,
ΔT_R	= reactor-coolant ΔT
$\int Pdt$	= integrated power,
X_{BR}	= banked rod position, and
X_i	= control-rod position.

The data-sampling rate will be less than 10 samples per second with data smoothing applied to the samples.

3. Prediction of the Worth of Core Changes

The prediction of reactivity changes associated with reactor loading changes and burnup will be computerized. Information on the composition of replacement driver and experimental subassemblies will be put on punched cards. An inventory of all significant isotopes in all subassemblies will be kept in disc storage. This will be updated by burnup calculations during each run and by new loading information between runs. Differences in successive loadings, expressed as changes in composition at specific subassembly locations, will be used in conjunction with a perturbation code to predict the reactivity of each new core loading.

The inventory of pertinent isotopes will be recomputed daily, and the associated reactivity changes will be compared with those measured. Reactivity deviations beyond prescribed limits could be used as an alarm function.

a. Reactivity Worth of Loading Changes

The calculational procedures and approximate storage requirements for estimating loading changes are as follows:

(1) Call for inventory from disc storage to core, where the inventory consists of the masses of ^{235}U , ^{236}U , ^{238}U , ^{239}Pu , stainless steel, sodium, oxygen, carbon, fission products, and ten other miscellaneous materials in all core and inner-blanket subassemblies (169 locations).

(2) Call for burnup routine, which gives changes in the concentrations of fissile, fertile, and fission-product material at each location per megawatt-day of operation.

(3) Insert number of megawatt-days since last inventory. This can be inserted either from current reactor-console instrumentation or as a separate item on a card.

(4) Revise inventory in reactor core according to computed burnup changes.

(5) Call for loading-change information. This would be made available as a set of manually punched cards for the subassemblies involved in the loading.

(6) Compute differences in subassembly compositions between calculated burnup composition and new loading.

(7) Call for perturbation routine, which provides estimates of specific worth for each material at each subassembly position (ten materials at 20 radial locations). These estimates have been previously derived from a multigroup, multiregion reactor-core calculation.

(8) Apply perturbation routine to composition changes to obtain reactivity change.

(9) Call for control rod-reactivity worth curve to translate the reactivity change in rod position.

(10) Print output in terms of reactivity change, core changes, and critical position, and store new inventory on disc.

The information stored on the computer disc must contain a reference core inventory and must have space for a second (updated) inventory. Either the reference or the most recent updating may be used as the basis for burnup and loading-change calculations.

The burnup subroutine will consist of calculated reaction rates for ^{235}U , ^{236}U , ^{238}U , ^{239}Pu , and Pu production in 20 radial locations in core and inner-blanket elements. The perturbation routine will involve worths of 10 materials at 20 locations. The rod calibration will be given in terms of a few hundred positional points. Although core-storage requirements for these calculations are not large, convenient access between the computer core and the magnetic-disc-stored inventories and subroutines is necessary.

b. Daily Reactivity Check

For the routine check (daily estimate) of reactivity changes due to burnup, a similar calculation with no computer-core change will be used. Only the burnup changes through step (4) will be used in the calculation of the new reactivity. This will be converted into change in control-rod position and compared with control-rod changes observed at the console. Significant differences in the comparison would indicate the existence of a reactivity anomaly.

4. Rod-drop or Reactivity-disturbance Analysis

The rod-drop technique is now used for establishing the magnitudes and time dependencies of feedback components. The method consists of dropping a modified stainless steel control rod from the core and following the power decay with magnetic-tape recording equipment. At the power level of essentially zero (500 kW or less), the worth of the control rod is established by the inverse kinetics code. Several drops are conducted; corresponding worths are then evaluated and smoothed, and are stored for later use in evaluating the reactivity feedback to the system when rod drops are conducted at higher power levels. Vital to the accuracy of the feedback separation is a relatively precise evaluation of the time-dependent reactivity withdrawal rate associated with the drop rod. To assure the necessary precision, the rod positional-worth relationship is called from the bulk storage system and used in the final separation of reactivity feedback.

The rod drops at power will be performed in the same manner as those at zero power, using inverse kinetics to determine system reactivity. By subtracting the rod worth from the calculated system reactivity, the feedback reactivity in the system is generated as a function of time. The machine will then store the calculated system reactivity and feedback, and plot these for the experimenter. The computer will aid in establishing the proper reactivity coefficients for developed system models, using the computed feedback. It will then compare the results indicated by the best-fit model with the actual experimental results. Finally, a list of deviations from the model will be noted and a more suitable model generated.

The insertion of other reactivity functions will require similar treatment, providing the insertions are on approximately the same time base. If, however, methods for extremely short withdrawal rates can be developed and implemented, the calibration at 500 kW may not be necessary and the last half of the program may be modified accordingly. For reactivity-insertion schedules of a more complex nature, more sophisticated analytical procedures will be necessary; but, as discussed below, these too are within the capabilities of the proposed system.

The program to evaluate the time-dependent reactivity feedback from a rod drop involves the following:

- a. Inverse kinetics calculations
- b. Data smoothing
- c. Exponential curve fitting
- d. Plotting and display
- e. Data acquisition

The memory requirements are somewhat variable, depending on the nature of the disturbance function and the type of analysis.

5. Analysis of Thermodynamic-Characteristic Behavior

The thermodynamic effects in the individual subsystems determine the characteristic behavior of the entire EBR-II system. Areas where these effects are most pronounced are listed below:

- a. Reactor feedback
- b. Primary-to-secondary heat exchanger
- c. Steam generator, condenser, superheater, and turbogenerator
- d. Cooling tower
- e. Primary-tank flow (streaming due in part to thermal gradients)

This list is incomplete, but indicates some of the areas of importance. All these subsystems are interdependent and consequently are in a continual dynamic state.

The problem of determining static response for these subsystems requires a large amount of data acquisition. In order to perform a system analysis, the static and dynamic characteristics must be separated.

The subsystems do not lend themselves to transient analysis by the preferred method of introduction of a disturbance. However, this problem may be resolved by online accumulation of data and offline analysis. The data will be obtained by long-term accumulation and the static characteristics determined by relatively simple data reduction. The dynamic analysis will require the use of a large-scale offline computer utilizing correlation codes. The results of these experiments are vital to increasing system power and will determine limits of operation and guidelines for system improvements.

The program necessary to fulfill these requirements will be dependent on the available instrumentation; however, the use of special experimental subassemblies containing in-core instrumentation will allow further investigation of the fundamental characteristics. If flow modulation in any channel within the reactor can be developed, then basic fuel and sodium measurements can be obtained. The program list shown below will be considered sufficient for performance of most of the experiments:

- a. Data accumulation
- b. Correlation codes
- c. Fourier analysis
- d. Curve fitting
- e. Steady-state heat-transfer codes
- f. Transient heat-transfer codes

The computer core requirement will depend on the amount of online reduction that is performed. Of the programs listed above, the correlation program is the most demanding on computer core storage.

6. Rod Oscillator Experiments

Rod oscillator measurements of the reactor transfer function will continue to be performed, if possible, whenever major changes are made in the material composition of the configuration of the core. Such

experiments are also regarded as desirable in future power-increase programs.

The current technique used for evaluating the reactor transfer function utilizes the IBM-1620 computer to compute the Fourier coefficient of the fundamental frequency. Through the performance of a large number of measurements, it has been shown that this technique has the capability for reproducing the calculated zero-power data with precision limits of $\pm 0.3\%$ in amplitude and $\pm 0.25^\circ$ in phase. As demonstrated at EBR-II, such precision and reliability are desirable for definitive kinetics analyses.

The programs necessary to conduct the rod oscillator experiment will include:

- a. data acquisition,
- b. Fourier analysis,
- c. kinetics code in frequency domain,
- d. calibration,
- e. plotting, and
- f. data smoothing.

7. Correlation of Various System Parameters

The determination of reactor and plant system characteristics has been discussed above. Variations in major parameters will have effects on other system components. The measurements of these effects and the subsequent data reductions are based on power-spectral and cross-spectral density measurements. Since the systems being investigated are mainly of low band width (less than 1 cycle per second), and the sampling rates are correspondingly low, these experiments may be run on line.

The basic equations would be

$$\psi_{11} = \int_0^t f(t) f(t - \tau) dt \quad (2)$$

$$\psi_{12} = \int_0^t H(t) G(t - \tau) dt \quad (3)$$

and a Fourier analysis of the correlation function, where $H(t)$, $G(t)$, and $f(t)$ are arbitrary functions of time, and τ is the lag time.

8. Determination of Characteristic Behavior of Reactor Support Systems

The development of new reactor support or safety devices for the LMFBFR program makes the testing of these devices a necessary and continuing program at EBR-II.

The type of information to be gained by these tests will be

- a. sensitivity of the measurement,
- b. time response,
- c. characteristic behavior,
- d. reliability, and
- e. models to aid in improvement of the device.

There are many areas to be covered in these evaluations. Many of the devices may measure secondary effects where extensive analyses must be applied to determine the meaning of the indications. The aim of testing these devices is to improve the usefulness of the measurements so that real-time measurements coupled with analysis can improve speed of response. This is basically a data-gathering and -smoothing problem, with the development of the analytical techniques an offline problem until the techniques are developed.

9. Reactivity Meter

Input requirements for the reactivity calculation include the following variables:

- a. Power
  - flux (ion chamber)
  - power measured by heat balance
  - integrated power
- b. Control-rod positions
- c. Control-rod bank positions
- d. Bulk-sodium temperatures

and the following fixed inputs:

- a. Burnup coefficient of reactivity as a function of megawatt-days of operation
- b. Coefficients for determining control-rod worth as a function of position
- c. Zero-power control-rod worths

These inputs are used to evaluate the amount of excess reactivity. At steady state, this will be compared with the power-reactivity decrement to determine the vital information needed by the operator. He will receive information at the maximum rate of 1.0 point/second. If the magnitude of the indicated discrepancy falls outside predetermined limits, an audible alarm will alert the operator to the anomalous behavior.

The steady-state value will also be computed by an alternative method. Using the flux (ion chamber) input, an inverse kinetics calculation will be performed and used to correct the steady-state value. Any discrepancy will be calculated and utilized as an alarm function. Since the two calculations are based on separate power measurements, these values will be compared and alarms initiated if the deviation exceeds expected values.

10. Subassembly-outlet-temperature Monitor

The temperature rise across a given subassembly is a function of the following parameters:

- a. Reactor loading (fissionable material and flow orificing effects)
- b. Reactor power
- c. Primary-sodium flow
- d. Integrated power

The reactor loading changes cannot be predicted far enough in advance to be efficiently programmed. Therefore, prior to each run the expected subassembly outlet temperature at 45 MWt will be estimated for each thermocouple, and these 25 values will be constants supplied to the computer in a manner similar to that used on the present monitoring system.

Within the limits of present measuring accuracy, the temperature rise through the subassemblies has been shown in general to vary linearly with power level, but the temperature change lags behind the power-level change. Therefore, another input will be computed using neutron flux and a time constant, and this value will be used in computing the expected subassembly outlet temperature as it varies with reactor power level.

Radial heat transfer, particularly from Row-6 to Row-7 subassemblies and from power-producing subassemblies to adjacent experimental

subassemblies, causes the temperature rise in some subassemblies to vary with total flow. This function will be established either by calculation or through the application of empirical methods. A total reactor-flow input signal will thus be required.

The total number of input signals for these analyses is therefore 27.

With present sampling rates, analysis has shown that alarms can be set to give protection for deviations greater than $\pm 10^{\circ}\text{F}$ from the expected temperature. With data smoothing or correlations, the alarm can probably be set for smaller deviations from expected values than are presently possible.

Correlations may be possible with the reactor inlet temperature or other parameters of the control systems or inherent system characteristics. To make these correlations, the relative variations with time of a number of measured values will be studied.

Data will be presented in two forms: (a) Off-normal values will be reported by indicating the reactor grid location of the thermocouple and the deviation from expected value of temperature rise in percent. (b) The operator can select any of the 25 subassembly outlet temperatures and read the value directly (e.g., position 6C4, 875°F).

11. Heat-balance Monitor

In the performance of a heat-balance calculation, the EBR-II plant can be separated into three components: the primary and secondary sodium systems and the steam system. The heat sources and sinks in the primary system are:

- a. Reactor
- b. Electric heaters
- c. Pumps
- d. Shutdown coolers
- e. Shield and thimble cooling
- f. Intermediate heat exchanger
- g. Primary purification system

The steam system has a number of components. The major ones are the turbine-generator, four feedwater heaters, the condenser, and the pumps. For the

purpose of this calculation, the steam system will be considered as a single heat sink.

The following equations will be evaluated by the computer to determine the losses to atmosphere:

Reactor Power + Electric Heat + Pump Power - Shutdown-cooler Power - Primary-purification Power - Thimble Cooling - Intermediate Heat Exchanger = Losses.

Intermediate-heat-exchanger Power - Superheater Power - Evaporator Power - Secondary-purification Power + Secondary-pump Power = Losses.

If the losses calculated from these equations exceed 1 MW (or some other specified value), an alarm will sound. When the alarm sounds, each of the parameters below will be listed in engineering units. The reactor operator can select any of the following values to be read out on the oscilloscopes.

Reactor power--heat input to primary sodium by reactor

Electric-heater power--heat input to primary sodium by electric heaters

Primary pump 1--heat input to primary sodium

Primary pump 2--heat input to primary sodium

Primary auxiliary pump--heat input to primary sodium

Shutdown cooler 1--heat removed from primary sodium

Shutdown cooler 2--heat removed from primary sodium

Shield-cooling exhaust--heat removed from primary sodium

Shield-cooling refrigeration--heat removed from primary sodium

Intermediate heat exchanger

Superheaters--heat removed from secondary sodium

Evaporators--heat removed from secondary sodium

Primary purification--heat removed from primary sodium

Secondary purification--heat removed from secondary sodium

Included above are a total of 24 input signals, 6 constants, and 2 nonlinear functions that describe the relationship of steam and feedwater enthalpy as they change with change in temperature (pressure is assumed constant).

To perform this heat balance continuously will require a knowledge of the interaction of the systems. As transfer-function studies of the systems are performed, the response-time characteristics of each system will be determined. These response-time characteristics will be used to monitor the system performance during transient as well as level-power operation.

12. Logging

Sampling rates for accumulation of logged data will be as follows:

Daily Logging: one set of data every 10 minutes while at steady power levels

one set of data every minute during power-level changes or alarm conditions

Report Logging: one set of data every 30 minutes while at steady power levels

one set of data every 10 minutes during power-level changes or alarm conditions

The following are parameters to be logged:

a. Reactor Core and Blanket Performance Points (87)

- (1) Neutron-flux level (2)
- (2) Reactor power (flow x ΔT x K) (1)
- (3) Reactor inlet and outlet temperature (2)
- (4) Reactor ΔP and upper-plenum pressure (2)
- (5) Subassembly-outlet-coolant temperature (25)
- (6) Cover-gas radioactivity (^{133}Xe , ^{135}Xe , ^{41}Ar) (3)
- (7) Reactivity (1)
- (8) Fuel element rupture detector channels 1, 2, and 3 (3)
- (9) Cover-gas temperature and pressure (2)
- (10) Control-rod positions (14)
- (11) Primary-tank temperature (30)
- (12) Fission gas monitor channels 1 and 2 (2)

b. Primary Pumps (15 points)

- (1) Core flow and blanket flow (pumps 1 and 2) (4)
- (2) Pump discharge pressure (pumps 1 and 2) (2)
- (3) Input power (pumps 1 and 2) (2)
- (4) Clutch current (pumps 1 and 2) (2)

- (5) Pump rpm (pumps 1 and 2) (2)
- (6) Total coolant flow (1)
- (7) Amperes and volts to auxiliary EM pump (2)
- c. Primary Purification System (5 points)
  - (1) Flow (1)
  - (2) Pump current (1)
  - (3) Pump discharge pressure (1)
  - (4) Coldest-point temperature (1)
  - (5) Crystallizer ΔP (1)
- d. Primary Tank (3 points)
  - (1) Sodium level (1)
  - (2) Bulk-sodium temperature (1)
  - (3) Electric-heating kW (1)
- e. Shield Cooling (6 points)
  - (1) Exhaust flow 1 and 2 (2)
  - (2) Operating-flow temperature (1)
  - (3) Exhaust temperature (1)
  - (4) Refrigeration-system flow (1)
  - (5) Refrigeration-system inlet temperature (1)
- f. Shutdown Coolers (6 points)
  - (1) Flow 1 and 2 (2)
  - (2) NaK-inlet-temperature 1 and 2 (2)
  - (3) NaK-outlet-temperature 1 and 2 (2)
- g. Secondary Sodium Pump (4 points)
  - (1) Flow (1)
  - (2) Discharge pressure (1)
  - (3) Inlet pressure (1)
  - (4) Pump current (1)
- h. Intermediate Heat Exchanger and Steam Generator (19 points)
  - (1) Secondary power (flow $\times \Delta T \times K$) (1)
  - (2) Temperature of sodium entering superheater (1)
  - (3) Temperature of sodium leaving superheaters (2)
  - (4) Temperature of sodium leaving evaporators (8)
  - (5) Steam-drum temperature (1)
  - (6) Steam-superheater-outlet temperature (1)

- (7) Feedwater temperature (1)
- (8) Blowdown temperature (1)
- (9) Total steam flow (1)
- (10) Feedwater flow (1)
- (11) Blowdown flow (1)

i. Turbine-generator System (5 points)

- (1) Flow of steam to turbine (1)
- (2) Temperature of steam to turbine (1)
- (3) Electric-power output (1)
- (4) Plant steam rate (1)
- (5) Turbine steam rate (1)

13. Secondary-flow Computer

The parameter that must be predicted by the program is the reactor inlet temperature. The computer calculates what the steady-state reactor inlet temperature will be when all transient effects have vanished. During steady-state operation, the actual and predicted reactor inlet temperatures are the same. During non-steady-state operation, the reactor inlet temperature is a function of five parameters and of the dynamic characteristics of two systems. The five parameters are heat-exchanger primary inlet temperature (T_{pi}), heat-exchanger secondary inlet and outlet temperatures (T_{si} and T_{so}), and the primary and secondary flow rates (M_p and M_s). The two dynamic systems are the intermediate heat exchanger and the primary bulk-sodium tank.

The distribution of the heat-exchanger system is complex. Accurate models of the system are also complex. Fortunately, a good model of the system is not required. A first approximation of the model, based on a step input function, will be of the form

$$T_{po} = T_o + T_{pi} (1 - e^{-t/\alpha_1}) - M_s/M_p (T_{so} - T_{si}) \quad (4)$$

where T_{po} is the intermediate-heat-exchanger primary outlet temperature and α_1 is a composite approximating time constant of the heat exchanger. While a time-lag term could be included in the above expression, the time dependency can be conveniently treated as part of the dynamics of the primary bulk-sodium tank. The sodium-tank dynamics are determined by primary

flow rate, the intermediate-heat-exchanger outlet temperature, a time constant generated by partial mixing of the coolant, a transport lag generated by the coolant flow, and a heat-loss function of the primary tank. A first approximation of this model will be of the form

$$T_{ri} = C_0 [T_{po} (t - \tau_1) + T_{po}] - C_1 [T_{ri} (t - \tau_2) - T_{ri}] + C_2 [T_{ro} (t - \tau_3) + T_{pi}] \quad (5)$$

where T_{ri} = the reactor inlet temperature,

C_0 , C_1 , and C_2 = constants to be determined empirically,

and τ_1 , τ_2 , and τ_3 = the appropriate time lags of the system.

The equation will be manipulated to provide an acceptable empirical model of the combined system. The model may be a simplification of the models described since prediction is obtained by assumed elimination of time constants and time-lag coefficients.

The demands made on the computer by this system are relatively modest except that the time lags in the model set a requirement for clocks on the computer.

14. Alarm Functions

The program for computing alarm functions includes online limit prediction, data smoothing, and limits for comparison. The program must be stored in the memory during reactor operations. At alarm, the priority system must identify the source of the interrupt and the time sequence of all subsequent alarm signals. The program will also call all necessary codes and modify data-acquisition rates.

C. Equipment Location

The computer is restricted to a location that is within 40 ft of both the cable-routing room and the reactor control room. The remaining source of inputs is the reactor building, which is approximately 300 ft from the cable-routing room.

Proposed locations for the equipment are listed below:

1. Computer Room
  - a. Computer mainframe
  - b. Rapid-access memory

- c. Card reader
- d. Card punch
- e. Magnetic tape recorder
- f. Printer
- g. Plotter
- h. Graphics
- 2. Cable-routing Room
  - a. Multiplexer^{*}
  - b. A/D converter^{*}
- 3. Reactor Building
  - a. Multiplexer^{**}
  - b. A/D converter^{**}
- 4. Reactor Control Room
  - a. Oscilloscope and keyboard input units (2)

D. Equipment Description

A block diagram of the system is given in Fig. 1. The description of the components is as follows:

1. Central Processor Unit (CPU)

The objectives of this unit are complex and require both online and batch processing routines. To fulfill these requirements, the unit will contain the following specific features or provide the following functions:

- a. Minimum word length of 24 bits plus sign and parity bits
- b. Parity checking at each data transfer
- c. Sufficient memory (32k) for the batch-process monitor and real-time requirements, with expansion capabilities
- d. Direct and indirect addressing of entire core
- e. General-purpose registers with capability of multilevel program operation with context saving (expansion must be possible)
- f. Real-time clocks
- g. Sufficient real-time priority interrupts to do time-sequence-of-events analyses for 200 different interrupts either by hardware or software

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* For all instruments now installed.

** Necessary for new instrumentation.

Fig. 1. Block Diagram of Data-acquisition and -reduction System

- h. Floating-point hardware
- i. Memory protection
- j. Fail-safe power and watchdog timer
- k. Adequate control console for operating, interrupting, and trouble-shooting the system

2. Input-Output Processor

This component is discussed separately from the CPU because data acquisition and control of peripheral equipment must be carried out with a minimum of CPU interruption. Data transmission from memory to external equipment or external equipment to memory must not pass directly through the CPU. The input-output processor must be capable of handling the following equipment, at the rate specified by the vendor, with minimal CPU interruption:

- a. Rapid data-storage system
- b. Magnetic tape recorder
- c. Card punch
- d. Card reader
- e. Line printer
- f. A/D converter

3. Peripheral Equipment

a. Card Reader

The card reader to be included in the proposal must be adequate to support the system needs, assuming a minimum of data being supplied to the system from cards. The major use of the card reader will be for programming support.

b. Card Punch

The card punch will be used to obtain a limited amount of output from the computer for experimental data that cannot be reduced by the computer and must be transmitted to the NRTS computer center. The punch will also be used to support the system operation.

c. Magnetic-tape Transport

The magnetic-tape transport will be IBM-compatible for seven-track 556 BPI. This unit will be used for storage of data for reporting purposes, for permanent records, and for transmittal of data to experimenters, etc.

d. Online Printer

The online printer will be used to print out data for shift reports, daily reports, etc. and to provide results of experiments and all hard copy to be recorded. This will be the main data output from the system; its speed of operation must reflect this fact.

e. Oscilloscope Output

Two oscilloscopes are required for reactor operational support. These units will be placed in the control room to supply the information necessary for system control and to indicate alarm conditions, scrams, etc. They will also provide the visual indication of information requested by the operator. The oscilloscopes should be of sufficient size to allow easy interpretation of the information presented. Updating of data shall be fast enough to allow system control, and the screen area should include sufficient reserve area to allow scram and alarm indications when they occur.

f. Rapid-acquisition Bulk Storage

The bulk storage has two major functions:

(1) It should be the buffer between computer core and output and should serve as the storage location for the various codes needed during experiments and for alarm and scram analyses.

(2) It should also provide the storage area for post-incident recall. The system should be directly addressable from the I/O controller to reduce the CPU interrupts. Total program and data storage in the device should be greater than 3 million bytes.

4. Software Requirements

The software necessarily includes assemblers, compilers, loader, debug codes, and text editors. It must include a FORTRAN IV language that meets the standards and specifications of the ASA. The symbolic or mnemonic-oriented language must have an instruction repertoire large enough and fast enough to effectively utilize the processor and its peripherals.

The monitor must have the capability of intermixing the symbolic language and FORTRAN in a source program. This includes the capability of calling machine language subroutines with a FORTRAN statement. The monitor

also must provide a background/foreground capability and be able to preserve a routine environment (registers, working storage, indicators) when interrupted, and restore this environment when the routine is resumed.

The vendor must be able to supply a routine in the resident monitor that will enable the operation of online I/O processes (line printer, tape drives, reader, punch, etc.) concurrently with a user's job in a multi-programming system.

The software package must contain maintenance and checkout programs for the central processor unit and for all peripheral equipment.

5. Multiplexer Sample-and-hold Amplifier and Analog-to-Digital Converter

A functional description of these items is as follows:

a. Multiplexer

(1) Total number of channels will be 400 with the possibility of expanding to 600.

(2) Normal scanning rate will be 600 samples per second.

(3) Ten channels should have a scanning rate of 700 samples per second per channel.

(4) Multiplexer should be capable of random selection of any channel. Channel selection will be on computer command.

(5) Parameter ranges are 0-10 mV, 0-50 mV, and 0-100 mV analog. The ten channels that are used for a scanning rate of 700 samples per second will be high-level channels.

(6) To conserve the analog-to-digital converters, multiplexing of multiplexers should be considered.

(7) All inputs and outputs must be differential (three-wire) systems.

b. Sample-and-hold Amplifiers

(1) The amplifiers shall meet the requirements for overall system accuracy, scanning rate as specified above, and gain to meet input requirements of the A/D converter.

(2) Amplifier aperture width must be less than 5 μ sec.

(3) Inputs must be compatible with the multiplexer outputs.

c. Analog-to-Digital Converter

(1) Conversion rate should be compatible with the above-mentioned scanning rates.

(2) Output of the A/D converter should be 15-bit binary plus polarity bit with an accuracy of $\pm 1/2$ bit.