STUDY FOR HFEF DATA-ACQUISITION
AND PROCESS-CONTROL SYSTEM

by

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ABSTRACT

The HFEF data-acquisition and process-control system described herein will use a programmed digital controller (PDC) and a standardized modular dataway to control remote-examination processes and data-gathering functions in the two HFEF hot-cell facilities. The digital data highways will employ the CAMAC modular instrumentation system for data handling and control. The process-control system will be based on a pre-planned control strategy that will be valid over the approved range of conditions.

The objectives of the system will be to establish a control room where the PDC, with the help of its peripherals, can command and service the data highways that extend to the hot-cell processes. The system will also be used as a proving ground for the development and standardization of modular systems for the control of remote hot-cell processes.

I. SUMMARY DESCRIPTION

A. Introduction

Argonne National Laboratory operates the Hot Fuel Examination Facility (HFEF) at the EBR-II site on the National Reactor Testing Station (NRTS). The HFEF is being used in support of the Liquid Metal Fast Breeder Reactor Program.

The HFEF provides capabilities for assembling and disassembling irradiated experiments and for making interim or terminal examinations for experiment sponsors. A large share of the work load consists of interim examinations, which do not destroy the cladding or the experiment. After the capsules or elements are examined, they are reassembled into a sub-assembly for continued irradiation in experimental reactors (i.e., EBR-II, PBF).

The HFEF complex now has available neutron radiography, a visual stereo-inspection station, photography, equipment for measuring bow and length of capsules or elements weighing equipment, reencapsulation equipment, precision gamma scanner, profilometers (contact and optical), temperature-measuring devices, visual-examination equipment (i.e., periscope, electron microscope), and eddy-current cladding testers.

In the area of gamma scanning alone, the HFEF will take 60,000 pieces of irradiation data per second after three gamma scanners are installed. The HFEF will record 1×10^8 pieces of data per 24-hr day and will still have to delete some proposed examinations because of lack of time to record the data. This will be particularly true in the areas of capsule or element failure detection (see Ref. 1), precision gamma scanning, and profilometry. The HFEF staff proposes to record this data and increase throughput, wherever possible, by the following means:

- (1) Computer-oriented data acquisition
- (2) Computer-oriented process control
- (3) Preplanned software procedures
- (4) Improved mechanical remote handling
- (5) Computer-controlled element/capsule transfer and storage systems

The purpose of this system study is to point out which devices are suitable for computer control in HFEF, and to propose an economical control system that can be used as a standard for future additions. Items 4 and 5

above will require separate consideration and are not part of this proposal. Alternative systems other than computers are also evaluated. We do not propose to establish a data-processing center. Data processing will be left to the EBR-II digital data acquisition system (DAS) and NRTS Computer Center. The computing system in HFEF will be called the HFEF data-acquisition and process-control system. Its primary objectives will be to collect data from hot-cell examinations, control hot-cell examination processes, and test proposed hot-cell instrumentation and control equipment. It is not planned for this system to do any batch processing or scientific problem solving except where required for process control. Data will be sent to the DAS, the NRTS IBM-360, or the ANL-East IBM-360 on magnetic tape for reduction.

B. Project Organization and Scope

A work project has been established for the design, procurement, and installation of the HFEF data-acquisition and process-control system. Figure 1 gives an arrow diagram for the project, which is now in the second phase. A number of ANL departments will be involved in the design, procurement, installation, operation, and maintenance of the system. However, primary responsibility for preparing feasibility and system studies falls to the Experiment Coordination Group of HFEF. This group has a general responsibility for maintaining awareness of present and future needs for automatic data-processing equipment in HFEF.

The scope of the project will be the production of a basic computer-control system, based on an existing Datacraft 6024/3 computer and the CAMAC modular instrumentation system for data handling. The CAMAC standard of digital-data-handling equipment, which was originally formulated to meet the requirements of nucleonic instrumentation, provides an internationally adopted solution to the problem of connecting various data and control points to a computer. European research centers, under the auspices of the European Standards Organization for Nuclear Electronics (ESONE), began work on what has become the CAMAC standard of modular instrumentation for data handling. Their results are detailed in the two definitive specifications EUR 4100e and EUR 4600e (see Refs. 2 and 3). These specifications have been endorsed by the AEC Committee on Nuclear Instrument Modules, and they will be used in the design of the HFEF data-handling system. The

Fig. 1. Arrow Diagram for Work Project for HFEF Data-acquisition and Process-control system

specific goals of the project are

- o To establish an access floor in room 201, HFEF/N.
- o To establish a motor generator and power-distribution system for computing systems in room 201.
- o To establish an extended branch data highway between room 201 and the HFEF/S hot-cell area.
- o To establish an extended branch data highway between room 201 and the HFEF/N hot-cell area.
- o To establish an engineering display terminal, hard-copy unit, and chart digitizer in room 201 of HFEF/N.
- o To add new peripheral devices (card reader, line printer, additional core, etc.) to existing HFEF computer (Datacraft 6024/3).

C. Justifications

The following paragraphs describe how the HFEF data-acquisition and process-control system will benefit operations at the HFEF:

1. Automation of Examinations

Some hot-cell examinations like gamma scanning and profilometry produce vast amounts of data, and only so much data can be taken in an 8-hr shift. Automation of the examination device can improve the situation in two ways:

- o By making it possible to operate the device 24 hr a day without operator attention.
- o By improving the efficiency of the machine through automation.

A preplanned procedure (software program) is used to control the examination. The efficient execution of this procedure by the computer increases efficiency and integrity of the examination, thus increasing throughput. This philosophy of control has been successfully proven with the Mark-I precision gamma scanner.¹

2. Hot-cell Incidents

A hot-cell incident in HFEF is any undesirable situation that causes damage to equipment or experiments. Incidents usually result from

lack of proper procedures and/or human error. The use of computers to control examinations reduces the possibility of incidents in the hot cells by the following:

- Preplanned procedures are necessary to begin operation of the system. Fixed or predetermined control actions can be carried out by the computer. To be successful, the preplanned operation requires prior development of a control strategy that is valid over the anticipated range of conditions.
- Computer control virtually eliminates human error. Computer and equipment malfunctions can be handled safely by proper development of the control strategy.

3. Integrity of Data

The integrity of data can be jeopardized by transposing numbers, misplacing decimal points, reading numbers wrongly, and poorly interpreting meters or charts. Direct acquisition of the data by the computer eliminates these conditions.

4. Data Logging and Reporting

The processing of hot-cell examination data to finalized report form is severely restricted at present by the amount of manual effort required. Automation of the HFEF data handling (where feasible) will not only increase the quantity and accuracy of data, but will present them in a form suitable for reporting and publication. In many cases, a quick look at the data will facilitate logical decisions about the interim-examination plan. The quick look is possible only with automatic data acquisition and reduction.

5. Experimental and Operational Support

Certain types of examination data, like gamma spectra and profilometry diameters, are of interest to experiment sponsors and HFEF examiners. Some of these data are generated by the experiment sponsor prior to the experimental irradiation and are transmitted to the HFEF examiner for comparison with the postirradiation data. The only way to

make any practical comparison between the data points in the short time available is by automatic reduction on the computer. Many experiments now performed on the Mark-I precision gamma scanner would not be possible if it were not computer-controlled, owing to tight schedules and the need to obtain data before the decay of short-lived isotopes.

Decisions on how to examine an experiment are made according to a preliminary analysis, which may include, for example, a quick gamma scan. Because of tight schedules and isotopic decay, the preliminary analysis must be made as quickly as possible to determine the final analysis plan. This is feasible only with automatic data processing.

Operations personnel will also use the HFEF data-acquisition and process-control system in their scheduling and nuclear-material accountability.

D. Prototype Studies

Several prototype studies have been made during the past year to aid the selection of the proper system to satisfy HFEF needs. The results are given below.

1. CAMAC and NIM^{*} Standards

Both the CAMAC and NIM standard instrument modules were used in the design of the Mark-I precision gamma scanner. Both standards have performed well and will be used in the HFEF data-acquisition and process-control system. Easy maintenance, modular instrument construction, commercial availability, and flexibility are the primary advantages of the CAMAC and NIM systems.

2. Mark-I Precision Gamma Scanner (PGS)

The PGS was the first fully computer-controlled examination device in HFEF. Its performance has surpassed the design expectations. A full description and evaluation is given in Ref. 1. The results show that computer control of certain examination devices is both safe and efficient.

*NIM is the abbreviation for the AEC Committee on Nuclear Instrument Modules.

3. CAMAC Digital Storage Module

It is planned to operate at least three and possibly more gamma-ray detectors in HFEF at the same time. These gamma data will make up 90% of the HFEF data being collected. However, if these data are collected directly by the computer, 100% of the computer time will be dedicated to this service and other devices will be shut out. Therefore, it is planned to close the loop on these high-data-rate devices in their respective CAMAC crates. A CAMAC standard digital storage module is being prototyped to collect the gamma data in the CAMAC crate. This technique is feasible and economical. Since the module is being designed to the CAMAC standard, it will find uses in other systems without modification.

4. Digital 24-bit Computer

As our experience with the Datacraft 6024/3 computer has shown, a computer with 24-bit word length has many advantages over a 16-bit or lesser. We recommend that the 24-bit computer be used as the standard for the CAMAC system when employed to control hot-cell examinations. Our recommendation is based on the following:

- The 24-bit computer word is compatible with the 24-bit CAMAC command words.
- The 24-bit word gives sufficient computing power at an economical price for control of hot-cell examination devices.
- Programming of the machine is simplified by using a 24-bit word.

II. SYSTEM STUDY

This section gives further details of the study for the HFEF data-acquisition and process-control system, first from a technical and then from an economic standpoint.

A. Technical Study

1. Projected Work Load

The purpose of the technical study was to determine clearly which subjects in what condition come from which sources, what courses they follow

through the process, how they are measured and controlled, and what equipment is involved.

The subjects being examined in HFEF are irradiated experiments from various test reactors. Each experiment is different in shape and size; therefore, it is not possible to standardize on the subject. The condition of the subject varies with each experiment, as the effects of irradiation often cannot be determined beforehand. However, it can be determined how the subjects are to be measured and what equipment is involved.

By January 1974, the following equipment will be under full control of the HFEF data-acquisition and process-control system:

- Mark-I precision gamma scanner, HFEF/S air cell (data rate, 20 kHz).
- Mark-II precision gamma scanner, HFEF/N main cell (data rate, 20 kHz).
- Loop gamma scanner, HFEF/N loop-insertion cell (data rate, 20 kHz).

Although these are the only pieces of equipment scheduled for full automatic control by January 1974, plans are being made to later add the fission-gas-measuring devices and optical profilometers (low-data-rate devices) when the design and funding are established. In addition to the design uncertainties for these later devices, many of the design characteristics for the three gamma scanners have not been worked out to completion. Therefore, for these systems to interface simply in the future, a standard interface will be used. This interface is CAMAC, which is already available and proven.

Figure 2 is a block diagram of the HFEF data-acquisition and process-control system. This system ensures data acquisition in both HFEF/N and HFEF/S by August 1973, at minimum cost. Figure 3 shows how the system can be expanded to cover future data-acquisition and process-control applications.

2. Features of CAMAC Standard

a. Overall Advantages

The CAMAC standard will be used in the HFEF data-acquisition

Fig. 2. HFEF Data-acquisition and Process-control System
 as Proposed in This System Study

Fig. 3. Possibilities of the formation of the α -phase in the β -phase.

Possible Future Expansion of the HFEF Data-acquisition and Process-control System

and process-control system for the following reasons:

- CAMAC is a U. S. Government-approved, international standard for data acquisition and control.
- CAMAC is a universal, modularized interface that is already in use in well over one hundred digital systems in the U. S., Canada, and Western Europe.
- CAMAC prevents getting locked into a single computer vendor. Expanding and upgrading are economical and easy.
- CAMAC simplifies software.
- CAMAC functions with all types of controllers -- from computers to pushbuttons.
- CAMAC gives manual backup.
- CAMAC greatly increases the number of devices that can be added to a computer.
- CAMAC modules are becoming readily available from U. S. vendors.
- CAMAC modules are flexible and are reusable in other systems.
- CAMAC systems are easy to troubleshoot.

The specifications for the CAMAC standard are given in EUR 4100e and EUR 4600e (Refs. 2 and 3). These specifications will be followed by ANL design engineers in designing the CAMAC interface modules for HFEP. If the device being interfaced to the CAMAC system exceeds the data rates given in the specifications, the data-collection loop will be closed and the data stored within a CAMAC digital storage module, as mentioned above in Section I.D.3.

The following subsections explain the various levels of the CAMAC standard, beginning with the mechanical arrangement.

b. Mechanical Arrangement

The CAMAC standard provides a packaging concept, the basic element being termed a crate (Fig. 4), which mounts in a standard 19-in.-wide rack and measures 8-3/4 in. vertically. The crate has a maximum of 25 slots for mounting plug-in units, and these units communicate with the system via printed-circuit-board edge connectors mounted at the rear of the crate. The printed-circuit board normally used as the method of construction of a plug-in unit measures approximately 7-1/4 by 12 in. The

Fig. 4. Front View of CAMAC Crate and Module

mechanical dimensions of the plug-in units and the crates are defined in EUR 4100e in sufficient detail to ensure compatibility between equipment from any source.

This choice of mechanical packaging permits efficient use of integrated circuits and thus provides adequate complexity in a single station width for the majority of device controllers or interfaces. It is, therefore, a valid arrangement for the foreseeable future, while integrated circuits predominate as the standard circuit for digital devices.

The standardized mechanical characteristics of the CAMAC module enable ANL design engineers to interface or design their control modules on CAMAC boards so that they fit into the system correctly. Thus, it is not necessary to consider the compatibility of the control equipment in front of the CAMAC crate. This greatly simplifies the technical study.

c. Logic Structure

Within a crate, all the plug-in units communicate with and are controlled by a "controller." The two right-hand positions of the crate (viewed from the front) have features used by the controller, and these positions constitute the "control station." All the others are called "normal" stations and have identical connections to the dataway. The electrical, logical, and time-related characteristics of this dataway are given in EUR 4100e in sufficient detail to ensure compatibility of controllers and modules from any source, without unnecessarily restricting their internal design.

Information is transferred via the dataway in a series of discrete operations. During each operation, the controller generates a CAMAC instruction, normally termed a "command." The command consists of both an address section and an operational section. The address section is in two parts: one (termed the "station line," N) specifies the line connecting the controller to the selected normal module; the other (termed the "subaddress," A) specifies the selected subsection of the normal module. Each normal module is served by four subaddress lines that cater to up to 16 subaddresses.

The type of operation is defined by a five-bit "function" code (F) which allows for a set of 32 types of operation. Of these, 16 are fully defined by EUR 4100e, 8 are available for special use, and 8 are reserved for possible future use.

Each command (mnemonically termed NAF) determines a specific transfer between the controller and a selected subaddress of a module. In the transfer of data from a module to the controller, termed a "read" operation, the module outputs its data onto a 24-line "read" section of the dataway -- the "read" lines. Transfers from controller to module are by 24 "write" lines. Some commands do not involve any data transfers.

Irrespective of the direction of data transfer, the controller, after allowing a specified time for the establishment of the data on the dataway, generates two timing signals onto the dataway. The first is used to accept data and is designated "strobe 1" (or S1); the second is used to activate any internal changes that might change the presented data and is designated S2. After a further specified time, the command is removed. In addition to S1 and S2, a timing line "busy" (B) is generated by the controller for the duration of a dataway operation.

Besides transferring data by the "read" lines, a module can transfer status information to the controller by a separate bus line termed "response" (Q). This may be used for a variety of purposes: for example, to indicate the presence of data, or to indicate that a valid command (i.e., understood by that module) has been used.

In addition to these normal commands, three nonaddressed commands, which are presented to every module, may be generated by the controller. These are an "initialize" (Z) command, which sets every unit to a ground state, "clear" (C), which clears designer-selected features of a module (normally data registers), and "inhibit" (I), which inhibits designer-selected features while present.

So far, only actions initiated by the controller have been covered. To cover transfers initiated by measuring devices, the dataway incorporates an individual call-line termed "look-at-me" or LAM or just L, star-connected between each normal (station) and the control station. A device (acting through its module) uses the L line to inform the controller, at any time, that it requires attention.

Returning to the 16 function codes specified by EUR 4100e, four are associated with the reading of data, four with the writing of data,

and eight with the transfer of control and/or status information only -- in particular, status information on the LAM of the module.

Power busses for ± 6 V dc, ± 24 V dc, and power return (mandatory supplies), along with ± 12 V dc, $+200$ V dc (for neons, etc.), 115 V ac, and two spare busses, are incorporated into the dataway structure available at every station.

The logical conventions used throughout the dataway, as described above, are the wired-OR, active-low type, which are compatible with standard teletype integrated circuits. These logic levels, coupled with the use of the "guard signals" S1 and S2, and careful design of the dataway, reduce crosstalk and noise to very low levels.

In summary, the CAMAC logic structure constitutes the second and principal level of standardization. This logic structure is defined in EUR 4100e, which fully specifies the manner in which a controller and a module for a measuring device may communicate via CAMAC. An engineer, faced with a difficult problem of coupling a device into a computer, can, by designing the interface as a CAMAC module, follow a simple set of design rules that ensure compatibility with the CAMAC system, leaving the complications of the whole interface to be handled by standard CAMAC units. He is, thus, freed to concentrate on the problem associated with the specific device.⁴

Put another way, a dataway socket can be viewed as a standardized computer input/output socket, where the connection requirements have been simplified as much as possible and the complexity transferred to a unit common to all the CAMAC normal modules, i.e., the controller. All too often, valuable time is consumed in solving computer-dependent problems rather than concentrating on the key, device-dependent problems. CAMAC overcomes this problem.

d. Multicrate Organization

The additional stages of standardization and compatibility have virtually no effect on the service received by a particular module. The description of CAMAC given in the previous subsection was limited to a single crate. The function of the controller is at the heart of the operation of the CAMAC system, since the controller is the source of every command, and of all data transferred to the CAMAC crate, as well as that transferred from the crate. The sequence of commands generated by the controller forms the system program.

In the very simplest of systems, the controller may contain internally the list of instructions that form the required program. (Test units that generate one or two commands are a typical example of such controllers.) In HFEF, however, the concern is with the use of a digital computer as the ultimate controlling device. The crate controller, therefore, may become an interface between the computer's input/output channel and the CAMAC dataway. Although this solution may be applicable in a limited number of cases, it does not suffice for more complicated systems. For a controller to act as the interface between a particular computer and CAMAC system, the controller must have certain fixed features. These features may be too complex for the requirements (not a serious fault) or not complex enough (a very serious fault); but in any event, one controller can control only a limited number of normal modules. Thus, the designers of the CAMAC standard (the ESONE Committee) found that there was much to gain by specifying a standardized method of communication between several crate controllers and an overall system controller or computer.

e. Branch Highway

EUR 4600e defines a CAMAC "branch highway" (a 66-twisted-pair cable) to achieve the purpose described above for up to seven crates. It is basically an extension of the dataway with some important modifications. To link to the branch highway, each crate has a crate controller whose primary function is to transfer information between signal lines at the branch highway port and corresponding or related lines in the crate dataway. As far as the branch highway is concerned, the source of command is a "branch driver" (which forms part of the link to the computer).

As with transfers within a crate, information is transferred in discrete branch operations of two types. The first is an extension of the crate operation, except that the command word has necessarily changed. Function code (F) and subaddress (A) remain identical to those in the crate. The station code (N), however, is transmitted via the branch highway not in ordinal but in 5-bit binary code. In a manner analogous to the individual N lines in the crate, the branch highway contains seven crate-address lines (C), one for each of the total permitted number of crates. The command, therefore, becomes CNAF on the branch highway.

Transfer of data in either direction is by 24 bidirectional data lines (read/write lines). Response (Q) is extended directly from a crate dataway to a corresponding branch line. Since the branch highway can be of unspecified length, the sequence of a command operation is controlled and interlocked to the sequence of any associated dataway operation by a "handshake" dialogue of timing signals between the crate controller and the branch driver. This dialogue automatically adjusts the timing to suit the actual signal delays that are encountered in the particular route through the highway.

The second type of branch operation is associated with the "demand" handling capabilities of the CAMAC system, i.e., the ability to detect the service look-at-me (LAM) requests from modules. Each crate has potentially 24 LAM sources, which are wired to the crate controller. This second type of operation causes all crate controllers to output, on the branch read/write lines, the pattern of LAMs in their crate. So that priority allocation is not necessarily linked to geographical position, it is normal for crate controllers to have the facility to output LAM signals to a unit that will rearrange, mask, or carry out any other desirable operation on the LAMs and pass back so-called "graded-L" signals.

It is these graded-L signals (GLs) that are transmitted in this second type of operation. To inform the branch driver (ANL design) that a LAM is present in the system, a "branch demand line" (BD) is included in the highway. A graded-L signal is established on BD by any unmasked source of LAM becoming active.

The branch highway, fully defined for multicrate CAMAC systems by EUR 4600e, provides a third level of standardization. This level has been crucial to the satisfactory development of virtually all CAMAC systems currently implemented.

f. Crate Controller

One additional and highly significant step was made in EUR 4600e, however, and that was the complete functional specification of a standard controller known as the "crate controller Type A" as the interface between a crate dataway and the branch highway. Without defining how to achieve the detailed functional specification, EUR 4600e's definition of the crate controller Type A is sufficient to ensure complete operational compatibility. In other words, all units meeting this specification

will look identical in a software sense, as well as being logically compatible with the branch highway.

All these levels of compatibility are already a reality in CAMAC standard equipment, and the current efforts of the ESONE Committee are largely directed toward software compatibility for CAMAC-computer systems. The difficulties are obviously considerable; but the worldwide use of CAMAC with a great variety of computers has already resulted in the generation of a substantial body of software experience, which is continuing to expand rapidly. There are obvious advantages from such concentration on providing software for what is effectively a single peripheral, the branch driver-computer interface.

8. Branch Driver

The branch driver for the HFEF system will be housed in a free-standing cabinet, where only the functional details will be determined by the CAMAC specifications. The branch driver will be designed to interface to the Datacraft 6024/3 computer so that block transfer of data can be effected through the CAMAC dataway without the attention of the computer's central processing unit.

3. Datacraft Computer

The Datacraft 6024/3 is a medium-scale general-purpose digital computer featuring a cycle time of 1 μ sec. The computer has a fixed word length of 24 bits. These and other features provide rapid access to memory, ease of programming, and a real-time control capability approaching that of a multiprocessor or large-scale computing system. A stripped-down pre-wired version of the Datacraft 6024/3 was purchased under the work project for the Mark-I precision gamma scanner and is presently dedicated to this examination device. The plans are to make field additions (core, stall alarm, software interrupts, etc.) to the Datacraft 6024/3 under the funding for the present work project. The proposed field additions will bring the machine up to full power, which will make it capable of servicing all the future data-acquisition and process-control needs in HFEF. The additions to the computer mainframe will be

- 24K of 24-bit computer core

- 12 additional priority interrupts
- 120-Hz clock
- Stall alarm
- Program restrict and instruction trap
- Disc-bootstrap hardware
- Software interrupt
- Automatic clock controllers
- Input/output channels

4. Peripheral Equipment

The proposed system is not intended to do batch processing; therefore, the peripheral equipment for input and output is minimized. Since the computer already exists at HFEF and the monitor will be supplied by Datacraft, all standard peripherals will be purchased from Datacraft. Datacraft does not have a lease agreement for their equipment. The following standard peripherals will be supplied by Datacraft:

- Line printer, 600 lines per minute
- Card reader, 300 cards per minute
- Disc and controller, 28 million bytes
- Magnetic tape unit, 7 track, 25 ips

A standard RS-232-C communications interface will be supplied by Datacraft for interfacing with a display terminal, hard-copy unit, and graphics tablet (chart digitizer). This display terminal will be the primary input/output device for graphic data from or to the system. It will also be used to input data from strip charts. All the data from HFEF's contact profilometers are produced on strip charts, which are not suitable for reproduction. The chart digitizer on the display terminal (named the engineering display terminal) will be used to input the data into the computer, edit the data, construct a reportable graph on the display terminal, and output the data through the hard-copy unit. The hard copy (consisting of either graphs or numerical data) will then be mass-reproduced for reporting.

5. Equipment Location

The computer additions and peripheral equipment discussed in Subsections 3 and 4 will be located in room 201 of HFEF/N. Room 201 will

be called the data-acquisition and process-control center. Figure 5 shows the equipment layout. The present work project will provide an access floor (square area in Fig. 5) for placement of the computer equipment and covering of the power-distribution and peripheral-equipment cables. The power-distribution system consists of a motor generator and conduit-wire system.

6. Cable Routing

Two data-highway cable paths will extend out of room 201. One cable will be called the digital link and will connect the room-201 computer center to the CAMAC crates in HFEF/S. The second path will extend out of room 201 to a cable tray mounted in the in-cell-utilities corridor of HFEF/N. The cable path is shown in Fig. 6 as a dotted line on the edge of the main-cell wall. This cable will service CAMAC crates in the north, east, and south portions of the in-cell-utilities corridor (HFEF/N).

B. Economic Study

The following subsections discuss the economic factors that justify the proposed HFEF data-acquisition and process-control system.

1. Equipment Cost and Staffing

Cost estimates for the equipment are shown in Table I. Staffing the HFEF data-acquisition and process-control system will require the equivalent of two and one-half persons. The cost for outside data-processing services from the EBR-II digital data acquisition system, the NRTS Computer Center, or the ANL Computer Center will probably not exceed \$10,000 per year.

2. Tangible Incentives

The tangible incentives of this system are quite clear. If automatic data acquisition and process control of the gamma scanners in HFEF is not employed, the work schedule cannot be met. Manual acquisition and process control of the three gamma scanners in HFEF would require 24-hr shifts for 365 days a year. Staffing would require six window technicians

Fig. 5. Floor Plan for Room 201 of HFEF/N, the Data Acquisition and Process Control Center

Fig. 6. Second-floor Plan of HFEF/N

TABLE I. Equipment Cost Including Engineering and Installation

<u>Item</u>	<u>Cost</u>
Computer additions and peripheral equipment	\$100,000
Engineering display terminal, hard-copy unit, and graphics tablet (chart digitizer)	20,000
Room modifications:	
Access floor	5,000
Motor generator	8,000
Power-distribution system	3,000
Digital link	5,000
CAMAC system:	
Branch-highway driver	15,000
CAMAC crates with power supplies	10,000
Type-A CAMAC crate controllers	8,000
Branch-highway termination units	250
Differential branch extenders	3,750
Branch-highway cable and connectors	10,000
Miscellaneous	<u>2,000</u>
Total	\$190,000

at \$50 per hour and two data clerks at \$35 per hour. The cost of manpower alone would exceed the cost of the system work project in less than one year. Assuming that the work load for HFEF is correctly estimated, the HFEF data-acquisition and process-control system will pay for itself within its first year of operation.

3. Intangible Incentives

A number of intangible benefits are also involved. Better equipment control and supervision are possible under computer control, for it reduces the effort normally expended in logging data and maintaining routine supervision. Timely, automatic, and accurate preprocessed information frees personnel to devote more time to the creative aspects of their jobs. By providing a better picture of daily operations in HFEF, computer control permits better interprocess coordination in the hot cell and better scheduling of facilities and examinations. Furthermore, computer control may constitute a major step toward total system control of an examination line, where the entire interim examination of a subject is efficiently treated as an economic entity.

Experimental results of high quality are to be expected from computer-controlled tests, whether performed on single examination devices or a full-scale interim-examination line.

Safety during the examination is improved through the predetermined procedure called a software program.

4. Alternatives to Computer Control

The following alternatives to direct on-line digital-computer control were evaluated:

a. Computer-oriented Alternatives

The technological inadequacy of off-line computer control, the manpower requirements, the limited ability to deal with process disturbances, and the limited computer availability would inhibit the success of the following approaches:

- (1) Use of an off-line computer.

- (2) Installation of relatively simple digital card-reading and automatic controlling devices.
- (3) Use of an analog computer.

b. Other Alternatives

The second set of possible alternatives to computer control does not involve computers. More and better instruments were considered as one means to recover a portion of the incentive associated with computer control. This would involve better location of indicators, graphic panels, and controls, and more use of automatic control loops and cascade controls. With this approach, however, equipment costs are in competition with the computer system, and the equipment is dedicated. This approach is hardware-fixed to one system and is not flexible to meet programmatic changes. Therefore, conventional controls were ruled out.

5. Results of Economic Study

The results of the economic study are quite clear. Based on the projected workload for HFEF gamma scanning and profilometry, it would cost the AEC more money in lost time and manpower to operate the equipment manually than it would to procure and operate an automatic computer-control system. Besides, without automation, it would be impossible to complete the work in the allotted time.

6. Operational Evaluation of Incentives

The HFEF data-acquisition and process-control system is both economically and technologically justified. The system, however, must be installed regardless of economic returns in order to meet the experimental requirements of the LMFBR Program. It is, therefore, proposed that the economics of the system be studied for a one-year period of operation and then be reported in the final report on the system.

C. Summary of System Study

The results of the system study are summarized in Table II.

TABLE II. Summary of System Study

<u>Item</u>	<u>Type</u>	<u>Justification or Comment</u>
1. Computer	Datcraft 6024/3	Already being used at HFEF; functions satisfactorily.
2. Computer addition	24K computer core	Needed to handle additional programming and gamma-spectrum storage.
	12 priority interrupts	Needed to handle additional process real-time interrupts and service new peripheral devices.
	120-Hz clock	Needed for operation of disc-monitoring system (DMS).
	Stall alarm	Needed to detect software traps.
	Software interrupt	Needed for DMS operation.
	Disc-monitor system	Needed for dynamic operation of real-time control system.
	Automatic block controller and input/output channels	Needed to input/output data from hot-cell processes and computer peripherals.
	Program restrict and instruction trap	Needed for dynamic operation with DMS and for program protection.
	Disc-bootstrap hardware	Needed for rapid loading of DMS monitor.
3. Computer peripherals	Disc	Needed for rapid loading and storage of programs and real-time data.
	Magnetic tape unit	Needed for storage of HFEF/N gamma-scanner data.
	Card reader	Needed for the input of small amounts of data and programs on cards.
	Line printer	Needed for program debugging, listing of profilometer data, and listing of gamma-scanner data.
	RS-232-C interface	Standard interface for communications devices like displays and telephone connections. Needed for engineering display terminal.

TABLE II (continued)

<u>Item</u>	<u>Type</u>	<u>Justification and Comment</u>
4. Process interface	CAMAC	Standardized, economical, flexible, nondedicated, and technically feasible.
5. Engineering display terminal	Graphic terminal with inter-active graphics unit (joy stick) Hard-copy unit Graphics tablet (chart digitizer)	Needed for the rapid production of graphical data at HFEF. Needed for hard copy of graphical data produced on the display terminal. Needed for the input of strip-chart data to the computer system (i.e., strip charts from contact profilometer).
6. Motor generator and power distributor system	208 V ac 110 V ac	Needed to isolate building power noise from data-acquisition equipment.
7. Floor (room 201)	Access	Needed for the location of computer equipment and peripheral devices.
8. HFEF/S data highway (digital link)	CAMAC extended branch highway and cable tray	Needed to connect CAMAC crates in HFEF/S to room 201.
9. HFEF/N data highway	CAMAC extended branch highway and cable tray	Needed to connect CAMAC crates in HFEF/N to room 201.

III. SYSTEM PROPOSAL

With the control computer (Datacraft 6024/3) and data-highway system (CAMAC standard) already specified, the system configuration can readily be proposed.

A. System Configuration

The HFEF data-acquisition and process-control system will use the existing Datacraft 6024/3 medium-scale general-purpose digital computer featuring a cycle time of 1 μ sec with a fixed word length of 24 bits. The computer is presently being used as the control computer for the HFEF/S Mark-I precision gamma scanner. This machine has been named the programmed digital controller (PDC). The PDC will be moved to room 201, where Datacraft engineers will make field additions to the computer to bring it up to full power. The machine has already been prewired for all field additions. Table III describes the present equipment contained in the PDC and the proposed field additions. Table IV lists the proposed additions to the PDC peripheral support. Table V gives the final computer configuration for the HFEF data-acquisition and process-control system.

The CAMAC data-highway system will consist of two multicrate hookups. One will be a three-crate hookup, with one crate in room 201 and two crates in HFEF/S. The other will also be a three-crate hookup, with one crate in room 201 and the two other crates stationed around the HFEF/N main cell on the second floor (in-cell-utilities area). The two data-highway hookups are specified in Table VI. The entire CAMAC system will conform to EUR 4100e and EUR 4600e (Refs. 2 and 3).

B. Software Requirements

All data-acquisition and process-control software programs will operate under the control of a real-time operating system that provides foreground multiprogramming, concurrently with sequential batch processing in the background. The foreground is designed for the programs related to process control that will control the gamma scanners, optical profilometer, etc. The batch processing is never time-critical, so the background is serviced when processing time and memory are available. The operating system will be purchased from Datacraft as a package.

TABLE III. Field Additions to the HFEF Programmed Digital Controller

<u>Present Equipment</u>	<u>Proposed Additions</u>
1. Central processing unit	1. 24K of 24-bit memory core
2. 8K of 24-bit memory core	2. Software interrupt
3. Interval timer	3. Disc-bootstrap hardware
4. One automatic block controller	4. Stall alarm
5. One 8-bit input/output channel	5. 120-Hz clock
	6. Twelve priority interrupts
	7. Program restrict and instruction trap
	8. Three automatic block controllers
	9. One 24-bit input/output channel

TABLE IV. Field Additions to the Peripheral Support for the Programmed Digital Controller

<u>Present Equipment</u>	<u>Proposed Additions</u>
1. Peripheral cabinet	1. 28-million-byte disc and extra disc pack
2. Nine-track magnetic-tape transport and formatter	2. Disc controller
3. ASR-33 teletype	3. Nine-track magnetic-tape transport
	4. Peripheral cabinet
	5. Card reader
	6. Line printer
	7. RS-232-C communication interface
	8. Engineering display terminal
	9. EDT hard-copy unit
	10. EDT graphics tablet
	11. Interactive graphics unit

TABLE V. Final Configuration of HFEF Programmed Digital Controller

Group-1 Priority Interrupts				
No.	Device	Channel	Unit	Function
0	Not used			
1	Not used			
2	Not used			
3	Not used			
4	Buyer's use			
5	Buyer's use			
6	Buyer's use			
7	Buyer's use			
8	Card reader	4	0	Input
9	Teletype	0	0	Input
10	Teletype	0	0	Output
11	Line printer	4	2	Output
12	Communications interface	4	2	Input
13	Communications interface	4	2	Output
14	Disc	5	0	Input
15	Magnetic tape	7	0	
16	Buyer's use			
17	Buyer's use			
18	Buyer's use			
19	Buyer's use			
20	Buyer's use			
21	Buyer's use			
22	Clock	-	-	Not on a channel
23	Software priority interrupt	0	1	Input

Channel Assignment			
No.	Type	Device	Unit Designation
0	8-bit I/O channel	Teletype, software priority interrupt	0, 1
1	Not used		
2	Not used		
3	Not used		
4	24-bit I/O channel	Card reader, communications interface, line printer	0, 1, 2
5	Automatic block controller (ABC)	Disc	0
6	Not used		
7	ABC	Magnetic tape, 9-track	0, 1
8	Not used		
9	Not used		

TABLE V. (continued)

No.	Type	Device	Unit Designation
10	ABC, differential output	CAMAC branch-highway driver (HFEF/N)	0
11	ABC, differential output	CAMAC branch-highway driver (HFEF/S)	
12	Not used		
13	Not used		
14	Not used		

Mounting of Peripherals and Controllers

Device	Mounting
120-Hz Clock	Buyer's central-processing-unit (CPU) cabinet
PGS control interrupt	Buyer's CPU cabinet
Card reader and controller	Free-standing cabinet
Line printer and controller	Free-standing cabinet
Disc drive unit	Free-standing cabinet
Disc controller	Peripheral cabinet
Communications interface	Free-standing cabinet
Disc bootstrap	Buyer's CPU cabinet
24K core	Buyer's CPU cabinet
Priority interrupts, stall, program restrict, I/O channels	Buyer's CPU cabinet

TABLE VI. CAMAC Data-highway System for HFEF/N and HFEF/S

Item	Description	Quantity		Specification	Supplier
		HFEF/N	HFEF/S		
1.	Branch-highway controller	1	1	ANL design	Lowest bidder
2.	Branch-highway cable with WSS0132 plugs (Hughes) at each end	5	4	EUR 4600e Cable: 66 twisted pairs; 7/0048 wire (EUR 4600e); 82 ohms nominal impedance; insulation PTFE, PVC-sheathed; diameter 0.491 in.	Lowest bidder
3.	Extended branch-highway cable	200 meters	200 meters	Cable: solid core, tele- phone grade; 75 twisted pairs; 63-mm solid core of polythene; PVC-sheathed; aluminum tape within sheath.	Lowest bidder
4.	CAMAC crate controller Type A	3	2	EUR 4600e	Lowest bidder
5.	CAMAC differential branch extender	4	2	EUR 4600e	GEC-Elliott ^a
6.	CAMAC crate with power supplies	3	2	EUR 4100e	Lowest bidder
7.	Hughes WSS0132 plug	4	4	EUR 4600e	Lowest bidder
8.	CAMAC look-at-me grader	3	3	EUR 4600e	GEC-Elliott ^a
9.	CAMAC branch-highway terminator unit	1	1	EUR 4600e	Lowest bidder

^aOnly known source

Process-control programs will be prepared by the HFEF Responsible Engineers and the HFEF Systems Engineer. Process-control programs will be written in either Assembly language or Fortran IV, or a combination of both.

C. System Checkout

The computer system specified in Section A will be checked out according to the recommendations in Ref. 5. A set of installation and test instructions will also be written as an internal document.

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