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Argonne National Laboratory

A FEASIBILITY STUDY OF THE APPLICATION OF A DIGITAL DATA ACQUISITION AND PROCESS CONTROL SYSTEM TO A RESEARCH REACTOR

by

G. C. Vellender

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APPLICATION OF A DIGITAL DATA
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G. C. Vellender

Reactor Operations Division

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ABSTRACT

This report discusses the advantages of the digital data acquisition and control system. The report considers, in detail, the digital data system characteristics and the techniques of application. The discussion includes such topics as: accuracy, speed of data sampling, process-transducer characteristics, word length, equipment reliability, electrical noise susceptibility and emanation, input/output subsystems, programing, utility requirements, and service conditions.

A test-evaluation installation is proposed. A complete system specification and cost estimate are also included.

1. INTRODUCTION

During the past several years the state of the art of digital process control has advanced at an extremely rapid rate. Special instrumentation and high-speed data-processing equipment have been developed because of the needs of the aero space program, the business community, and complex automated high-efficiency processes. The combination of high-speed electronic transducers and digital data-processing techniques has resulted in a vast improvement in on-line systems for process-data gathering and reduction. The initial purpose of such systems was to obtain improved process design and operator guidance. In the last few years, the capability of these systems has been immensely increased by the development of computer output circuitry allowing direct process control. Simultaneously, major advances have been made in the theory of control optimization. Application efforts have mainly been concentrated in industries having high-volume processes which show promise of relatively short pay-off periods. Typical examples include paper mills, chemical plants, steel roll mills, and electric dispatch systems.

The study covered in this report was initiated by the Control Engineering and Instrumentation Group of the Reactor Operations Division of the

Argonne National Laboratory to obtain a comprehensive picture of the state of process computer development and its application to nuclear reactor control. It is to be used by the Operations Division to determine possible future needs. This report covers the work completed to date. It includes a discussion of the basic control concept, the salient features of the digital system, a proposed installation, a proposed test-evaluation program, proposed preliminary specifications, and a preliminary equipment training and programming cost estimate.

It is doubtful if the operating personnel and/or operating cost of any existing reactor could immediately be reduced with the proposed test-evaluation program. The justification of this project lies in the fact that the versatility of a digital computer appears to provide a means to improve the safety and to reduce the downtime of reactors. This is particularly true of the large machines for which reactor safety and downtime will rely upon a rapid evaluation of an extremely large number of variables. An additional justification is the advancement of the state of the art in the application of advanced instrumentation to reactor control and safety systems. The test-evaluation installation proposed in this report will provide the means for gaining the operating and engineering experience and general technical knowledge required for the future application of digital control systems in the nuclear industry and other process industries.

The study was implemented by a literature review, contacting and visiting equipment manufacturers, and contacting and visiting actual and proposed nuclear computer installations. System vendors which were contacted included International Business Machines Corporation, Control Data Corporation-Computer Control Division, Bunker-Ramo Corporation (T.R.W.), and Honeywell Incorporated. Users contacted included Phillips Petroleum Incorporated at the National Reactor Test site in Idaho; University of California at Los Alamos Scientific Laboratory in Los Alamos, Atomic Energy of Canada Limited in Chalk River Canada, and Oak Ridge National Laboratory in Oak Ridge.

A cursory review of the existing and proposed research reactors pointed out that it is relatively impossible to consider all phases and requirements of all types of research reactors for this study. Therefore, the decision to choose one specific nuclear reactor as "typical" and to perform the study based on the characteristics of that reactor was a fundamental premise of the study. The premise was made under the assumption that the results of the study could then be easily modified for other nuclear reactor applications. Since data are readily available for the Argonne Research Reactor (CP-5), it was chosen as the "typical" machine for the study.

1.1 BASIC CONCEPT

At the start of the study, three possible basic concepts were postulated. The first contemplated the use of a data and control system in conjunction

with all on-site reactors under the direction of the Reactor Operations Division. The second was based on a system which could be used jointly by a reactor and the experimenters using that reactor. The third assumed that the system would be used exclusively for data gathering and control of a single reactor. Computer systems are available which can provide the probable requirement for any of the three.

Near the beginning of the study it was resolved that the scope of this study would be limited to the third concept. This approach was chosen because the state of the art of the application of computer control systems to nuclear reactors has been very limited. It is imperative that certain basic concepts regarding computer-reactor compatibility be tested and evaluated on a limited basis rather than by other, more inclusive approaches.

As the study progressed, the literature review revealed recent investigations which have demonstrated the basic compatibility and some of the advantages of a central data-gathering facility at reactor sites. It is suggested that a separate study be started to determine the requirements for such a facility for the experiments associated with CP-5. If the system is warranted, the possibility of fulfilling the reactor control and experimental needs by utilizing a single computer-driven data-acquisition system can then be investigated.

After the basic concept was formulated, the following ideas were developed. The initial installation would consist of equipment suitable for guiding the operator in the operation of the reactor. The equipment would be installed and programed to:

- A. make the necessary calculations;
- B. provide a permanent log;
- C. scan for off normal or alarm points;
- D. provide a means for the operator to observe long-term process trends as well as a means for obtaining the specific value of any one of a large number of variables from past history;
- E. be suitable for gathering the required engineering data to evaluate the possibility of partial or complete reactor control;
- F. be suitable for simulating and evaluating reactor control problems;
- G. be expandable so that the necessary final control equipment can be added and the overall concept tested.

2. CONCLUSIONS

The following conclusions were reached as a result of this study and evaluation.

2.1 The safety and operating requirements of future large reactors will demand a control system which is capable of continuous process analysis, indication of automatic malfunction, and high-speed process control.

2.2 The requirements listed above will necessitate:

- A. more complete and accurate operating data;
- B. the ability to perform complex calculations at high speeds;
- C. a previously developed mathematical model of the process to determine, in advance, the effect of a change of any variable.

2.3 The flexibility, accuracy, and storage offered by the modern high-speed programable digital computer can be utilized in developing such a process control system.

2.4 The demonstrated reliability of computer-driven digital data-acquisition and process-control systems has reached the point at which these systems have a mean time to failure in excess of 1000 hr and an operational availability in excess of 99%.

2.5 Basic reactor-computer compatibility characteristics require further investigation and evaluation. These characteristics include the reactor-computer interface, operator-computer communications, dynamic engineering analysis, development of mathematical models, process-control and optimization techniques.

2.6 Mathematical programming techniques are available for the solution of a broad class of complex problems; however, they have found relatively little application in process control because of the lack of suitable installations and resultant lack of application experience.

2.7 It is preferable to use a nuclear reactor having time-proven stability for the initial investigation of computer control and test installation as opposed to using a new reactor with untested stability.

2.8 The Argonne Research Reactor, CP-5, has successfully demonstrated stability by operating for a period in excess of 10 yr and therefore is a suitable vehicle for use as a test installation.

2.9 The complexity, the capital investment, and the operating cost of the proposed Argonne Advanced Research Reactor (AARR) requires that all possible efforts be made to insure its safe and efficient operation. The application of proven digital-control techniques would greatly assist in accomplishing these objectives.

3. RECOMMENDATIONS

The recommendations reached in this study are given below.

3.1 A digital data-acquisition and process-control system should be installed in CP-5. The installation should be made as soon as possible to provide the equipment for a test-evaluation program. The test-evaluation program would initially consist of verification and improvement of the present concepts of the reactor-computer interface and operator-computer communications. In the future the test-evaluation program would involve dynamic engineering analysis, development of mathematical models, and process-control and optimization techniques.

3.2 The current rehabilitation program for CP-5 should be carried out under the assumption that the computer-driven digital data-acquisition and reactor-control system will be installed in the near future. The basic additional cost incurred by this assumption will be minor. Most of the additional cost will result from the installation of insulated, shielded, twisted-pair cable for transmission of low-level instrument signals. The cost of this cable is approximately 4 to 6¢/ft per pair of signal leads.

A second major consideration would be the utilization of process transducers having band-pass characteristics suitable for a dynamic analysis of the reactor and the process equipment. This report points out the advantages obtained from using high-level DC electrical current transmission signals. A review of costs of current instrument hardware shows that this type of signal transmission can be used with little or no cost penalty.

3.3 The basic control-system design study for AARR should evaluate the possibility of utilizing a digital control system. The CP-5 installation proposed in this report would provide basic information for this evaluation.

3.4 An engineering study should be initiated to determine the requirements for a central data-gathering facility. If such a system is warranted, the possibility of fulfilling the reactor control and the experimental needs by utilizing a single computer-driven data-acquisition and control system should be investigated.

3.5 The present engineering study should be continued. However, since the desirable equipment characteristics have been outlined in this report, the scope of the study should be limited to the investigation of advance control theory and the techniques of complex problem solving with digital computers.

3.6 This study illustrates the need for intensive engineering studies and test installations to evaluate and use the advanced control techniques

currently being developed by the control theoreticians. The continuation of the program proposed by this report is recommended because it will provide the tools and knowledge to advance the state of the art of the engineering application of these techniques. The results of this program will not only benefit the nuclear industry but will also provide basic engineering knowledge which has application in all process industries.

4. ADVANTAGES OF A DIGITAL DATA-ACQUISITION AND CONTROL SYSTEM

The following discussion considers the advantages of a digital data-acquisition and control system over existing conventional instrumentation and advanced analog techniques. These systems are briefly explained and the advantage in terms of the flexibility of the programmable digital computer are pointed out.

Fig. 1. Typical Analog Process Control Loop

4.1. TYPICAL ANALOG INSTALLATIONS

An example of a typical conventional analog instrumentation loop is given in Fig. 1.(1,2)*

It is possible to cascade several systems so that a perturbation in one loop will be evaluated and automatically readjust the control settings in other loops. An extension of this type of system results in the appli-

cation of the present-day analog computer and advanced analog programing concepts. These concepts revolve around the development of a mathematical process model.(2) The model normally consists of one or more differential equations which are solved by the analog computer. Process input data are fed directly into the control system from process transducers. Long process time constants or lags (milliseconds to minutes) allow the computer to operate "on line" in "real time." "Real time" has been defined as "the performance of a computation during the actual time that the related physical process transpires in order that results of the computations are useful in guiding the physical process."(3) These systems are considered nonprogrammable, since the analog equations are "wired" into the computer.

4.2 TYPICAL DIGITAL INSTALLATIONS

The control of processes by digital equipment can be divided into two basic categories. The first involves the operation of the digital system in parallel with conventional instrumentation, as illustrated in Fig. 2.

*(1,2) See list of references given beginning p. 66.

Fig. 2. Typical On-line Digital Computer Installation

This approach has several advantages for an initial installation. It allows the operating personnel the opportunity to observe the plant condition by means of familiar conventional instrumentation; it provides built-in backup in the event the computer fails; and it allows experimental installations in existing plants to evaluate equipment and techniques without appreciably affecting the future operation of the plant. This type of approach has been used in steel mills, paper mills, and chemical processing plants.

The second category, which is in reality the second generation of system design, virtually eliminates all plant analog equipment with the exception of the primary transducers and the equipment required for safety or for emergency plant operation. This approach is commonly known as direct digital control.

These categories can further be subdivided in many ways. As an example, we can consider machines that are programmable and nonprogrammable. This study only considers programmable machines because the flexibility of the nonprogrammable or "wired" machine is limited. Flexibility is one of the biggest assets of the digital computer. It is the characteristic which allows the computer to store instructions so that the mode

of control can automatically be changed under special conditions. It is this characteristic which allows the computer to be programed to provide process information in terms that can be understood by the operator, yet it can present the detailed information required for engineering evaluations. In addition, this flexibility when combined with the presently developing techniques of optimal programing and control theory should reduce the magnitude of process perturbations, thus increasing product production, quality, and plant safety.^(4,5) For a nuclear reactor installation, this means that a digital control system appears to provide a means to improve flexibility, reduce down time, and increase safety. As a final advantage, the digital data system can provide off-line data processing to make engineering evaluations and/or to reduce experimental data.

5. DIGITAL DATA-SYSTEM CHARACTERISTICS AND TECHNIQUES OF APPLICATION

To implement this study, a specification for a digital data system was written to provide a logical and orderly outline of the important parameters to be studied. In addition, it provided insight into special areas which required intensive investigation. In order to make this study economically realistic, a cost estimate was prepared in parallel with the specifications and the detailed examination of system parameters. The specification is contained in Appendix A and the cost estimate in Appendix B.

5.1 ACCURACY

Since the overall accuracy of the results of any calculation is a function of the input data, a review was made of the accuracies of commercial process transducers. A majority of the commercial process transducers currently available have accuracies in the range from 1/4 to 1% of span. The repeatability of these transducers is generally in the range of 0.1 to 1% of span. Special-purpose instrumentation has been constructed for particular parameters which have accuracies in the range from 0.001 to 0.1%; however, such equipment is generally built on a custom basis and is usually very expensive.

If we exclude the transducers, the accuracy of the computer-driven control system is limited by the analog-to-digital converter (ADC) and the computer word length or effective word length. The "standard" accuracy of the ADC is 0.1% of span. The resolution capability of the computer is a function of the effective word length.

The relationship between resolution capability and word length is expressed by the equation

$$R = 2^N,$$

where

R = resolution capability (one part in R);

N = the number of bits in the word.

As an example, a 14-bit word has a resolution capability of one part in 16,384. This equation is only one of the considerations in the determination of a minimum acceptable word length. Minimum word length involves many other considerations which will be discussed later. The equation can be used to determine the accuracy capabilities of the computer. An apparent economic choice appears to be an ADC accuracy of not less than 0.1% of span (one part in 1000) and a minimum effective word length of not less

than 10 bits. This is an economic "trade off," because it does not require a large capital investment for the development of a special ADC and it complies with the specifications of transducers which are generally commercially available. However, it does allow improvement of the system by an order of magnitude by the addition of a special purpose ADC at a later date.

5.2 DATA-SAMPLING SPEED

The selection of a suitable rate for scanning process conditions is far more complex than is generally appreciated. The problem can be divided into two basic areas: data reduction and process control. The major problem of data reduction is the determination of what has occurred between samples. The major consideration in process control is process stability.

5.2.1 Data Reduction - Data-scanning Speeds

In designing a digital data-processing system in which a number of continuous analog signals are being fed to the data system, it is necessary to choose a sampling rate such that fixed accuracy limits are known for data points between samples. The ability to reconstruct a process wave form from sampled data is effected by the dynamic characteristics of the process, the primary transducer, and the digital data system.

It is obvious that the transducer and digital data system must have an adequate frequency-response range or it will be impossible to reconstruct the actual process wave form. A second factor which influences the ability to reconstruct a process wave form is the interpolation technique used to convert the digital data to a continuous curve.

Interpolation is the process of approximating the curve between samples. There are several types of interpolation, including the following:⁽⁶⁾

- A. Step Interpolation, which involves the assumption that the data remain constant between samples and jump to a new value when a new sample is obtained;
- B. Linear Interpolation, which assumes that the original function was a straight line between adjacent sample values;
- C. Computer Interpolation, which utilizes a computer program to determine secondary points between samples (the determination is made by weighting neighboring and adjacent samples);
- D. Filter Interpolation, which utilizes one or more low-pass filters on the input to the analog-plotting device to smooth the data.

The Sampling Theorem widely attributed to Dr. Shannon of MIT states "if a time function contains only frequency components below F cycles per second, $2F$ samples per second will provide sufficient data to permit perfect wave form recovery."⁽⁶⁾ This theorem is probably one of the most misunderstood and misquoted theories in use. In practice, this theorem is severely limited because of the constraint imposed by the phrase "if the time function contains only frequency components below F cycles per second." Most natural and man-made phenomena do not have a sharp cutoff frequency, but usually have a slow "roll off." The roll-off slope is characterized by the order of the differential equation describing the phenomenon. The higher the order, the greater the slope of the "roll off."

Considerable theoretical work has been carried out to determine desirable sampling rates. Most of this work considers the use of low-pass filters to limit the bandwidth of the signal.⁽⁷⁾ A second approach commonly practiced among control engineers is to choose arbitrarily a sampling rate between three and thirty samples per cycle of the highest frequency of interest. This arbitrary approximation does not take into consideration the energy present at frequencies higher than those of interest. It can be shown mathematically that the energy spectrum effectively folds at a frequency equal to one-half the reciprocal of the sampling rate.

The energy contained in the spectrum above the folding frequency is vectorially added to the energy below the folding frequency. This effect produces a "spillover" error in the reduction of data at the frequencies of interest.⁽⁸⁾ Once the data has been digitalized it is impossible to determine the order of magnitude of the "spillover" error.

Recent work in the aero-space field has resulted in a technique for establishing the magnitude of the error if the data spectrum and the sampling rate are known.^(7,9,6) The results of this work can be reversed to determine the number of samples required to limit the maximum error to a particular level if the data spectrum is known. Table 1 contains four examples indicating the approximate number of samples per second required for a given maximum error.

As the maximum error requirements decrease, the order of the differential equation decreases, or the half-power point of the data increases, then the required number of samples per second increase. These examples indicate the need for high-speed sampling in a data-reduction system. As noted above, the choice of sampling rate requires knowledge of the limits of the energy spectrum of the data to be analyzed.

Table 1
SAMPLE RATE REQUIREMENTS

Example	1	2	3	4
Interpolation Error, %	3	3	1	0.1
Type of Interpolation	Linear	Linear	Linear	Linear
Order of the Differential Equation Which Describes the Data Frequency Characteristic	Second	First	Second	Second
Half Power Frequency of the Data in Cycles per Second	10	10	10	10
Require Sample Rate in Samples per Second	200	22,000	400	1,800

In order to obtain information on "typical" energy spectra, a study was initiated on methods of obtaining these spectra. The details of the analysis technique are in the final stages of development and test, and therefore cannot be presented in this report. They involve obtaining the limiting spectrum of a typical reactor system. The proposed technique is implemented by the introduction of a step function on the input to the equipment to be tested and subsequent off-line computer numerical analysis of the equipment time output data. The computer analysis is a numerical method of transferring from the time domain to the frequency domain. The details of this technique will be reported in the near future.

The compromise relationship between sampling rate and interpolation error is the fundamental consideration in the design of a digital data-acquisition system. Since the sample rate is one of the prime limits on system capacity, the choice of sample rate is in reality a balance between system capacity and system accuracy.

5.2.2 Process Control - Data-scanning Speeds

It was noted above that the basic consideration in the selection of a data-scanning rate for a process-control system is process stability. "Spillover" error and/or signal high-frequency components can cause uncontrollable hunting of the system. To eliminate this problem, special signal-conditioning circuits are normally incorporated into the multiplexing and digitalizing equipment of computers. These conditioning circuits usually consist of low-pass filters which limit the bandwidth of the data or time-averaging integrating networks which average the data.⁽¹⁰⁾ This

technique allows a reduction in sampling rate with no increase and in some cases a reduction of the "spillover" error. Experience has shown that sample rates between four samples per minute and eight samples per second produce acceptable results.

5.2.3 Manufacturers' "Standards" - Data-scanning Speeds

Manufacturers' "standards" for multiplexer speeds can best be illustrated by a comparison of the speed, signal level, and cost. Table 2 provides a relative comparison of the three.

Table 2

RELATIVE COST COMPARISON FOR LOW- AND HIGH-SPEED ANALOG-TO-DIGITAL CONVERSION EQUIPMENT

Samples per Second	Signal Level, 0-50 mV	Signal Level, 0-5 V
0 to 200	Low Cost	Low Cost
200 to 10,000	Very High Cost	Low to Moderate Cost

Low-speed multiplexers (0 to 200 samples per second) are generally electromechanical mercury-wetted or special hard-contact scan relays.

The speed of the system is limited by the response time of the mechanical components of the relay. These devices can be constructed with very little contact resistance. This allows signal levels of 0-50 mV to be fed directly through the multiplexer and into the analog-to-digital converter channel without appreciable error. If a signal of higher level is available, the level is generally reduced at the multiplexer input by a temperature-compensated voltage-dividing network. This allows a single multiplexer signal input range from 0 to 50 mV.

High-speed scanners (200 to 10,000 samples per second) are normally constructed of solid-state components. Because of the variations in the electrical characteristics of solid-state components, high-level signals of the order of 0 to 1 or 0 to 10 V are required to maintain overall subsystem accuracy. If the magnitude of the transducer output signal is less than this desirable level, an amplifier is placed between the process transducers and the multiplexer input. It is important to note that many systems will require an amplifier for each signal. Thus, to reduce cost, it is extremely desirable that the process transducers utilize high-level signal transmission when operating in conjunction with a high-speed multiplexer. Economic considerations of this problem are reviewed in Section 5.3.3.

Multiplexers having much higher scanning speeds are available; however, they are not in general use in the process-computer field. Therefore, the mating of extremely high-speed multiplexers with the computer main frame will probably require intensive engineering development and thus is economically unfeasible at this time.

5.2.4 The Proposed System - Scanning Speed

Most reactor installations will require both data-gathering and process-control capabilities. Therefore, both high- and low-speed multiplexers will normally be required. Since the high-speed multiplexer will only be used for nuclear parameters and a dynamic study of the process variables, the channel capacity of the high-speed scanner can be very limited; probably 40 to 50 channels would be sufficient.

5.3 SIGNAL CHARACTERISTICS OF PROCESS TRANSDUCERS

This section will consider some of the types of process transducers which are currently available on the commercial market. Although a large variety of devices are available the discussion is limited to electronic analog equipment. For this discussion, the devices will be broken into two basic categories: voltage and current signal transmission.

5.3.1 Process Transducers Using Voltage Transmission

Several types of process transducers use voltage transmission. Devices such as variable core transformers and capacitive probes using high-level AC transmission require further signal conversion to make them compatible with the computer input. In general, this extra conversion step makes them uneconomical. This discussion will be limited to devices using "DC" transmission.

Systems are available which utilize a high-level DC voltage for signal transmission; however, most voltage-transmission equipment currently on the commercial market operates in the range of millivolts. This low signal level requires a relatively high receiver input impedance to minimize error (50 kohms or larger). A first approximation of the theoretical model for the voltage-transmission type of equipment is shown in Fig. 3, where

E = the open-circuit, transducer output voltage;

R_s = transducer output resistance;

R_c = the computer input resistance;

R_a = the analog receiver input resistance.

Fig. 3. Equivalent Circuit for Analog Voltage Signal Transmission

This model could be refined by considering the resistors as complex impedances and the battery as a complex wave generator. In such a refinement, the complex wave generator represents the dynamic characteristics of the process. Further refinement is obtained if either or both impedances are nonlinear.

A major source of error in this circuit is the voltage drop across R_s . This error can be minimized by low current flow through R_s . Since the input impedance of the computer shunts the analog receiver, the total receiving impedance is lowered. This causes an increase in load current with a resulting increase in error. However, since most computers have analog input impedances in excess of one megohm, the actual magnitude of the current increase is small.

A second, but more severely limiting, factor is the signal-to-noise ratio. In a high-noise area, low-voltage signals are highly susceptible to electrical interference. This susceptibility can be reduced by effective shielding and/or an increase in signal level. Further discussion on electrical noise susceptibility is found in Section 5.13.

5.3.2 Process Transducers Using Current Transmission

The input impedance of the process computer is not a major consideration with instrumentation using current-transmission signals. As an example, consider a signal transmission system having a span of 4 to 20 mA and a computer input requirement of 10 to 50 mV or 1 to 5 V. A simplified model is illustrated in Fig. 4, where

I = magnitude of the signal;

R_s = source resistance;

R_1 = fixed temperature-compensated resistor;

R_{in} = computer input impedance;

R_a = analog indicator input impedance.

Fig. 4. Equivalent Circuit for Analog Current Signal Transmission

Table 3 illustrates the effect of the computer input impedance on the choice of R_1 . It is evident that the effective computer input impedance (R_1 in parallel with R_{in}) is largely determined by R_1 for large values of R_{in} . Since R_1 is a fixed resistor, its characteristics can be easily controlled. Thus, any undesirable frequency characteristics, nonlinearity, or temperature sensitivity of the computer input impedance can be controlled by the choice of R_1 . This system has an additional advantage in that its zero for the scale range used allows the computer to check for a failure of the power supply or process transducer zero. In addition, as noted in Section 5.2.3, high-level input signals are required for efficient, accurate, and economic operation of a high-speed data-sampling system. A final advantage of the current-transmission system is the general improvement in the signal-to-noise ratio.

Table 3

SHUNT RESISTOR REQUIRED FOR A
4- TO 20-mA SIGNAL

Computer Input Impedance (R_{in}), ohms	Shunt Resistor (R_1), 10- to 50-mV Input, ohms	Shunt Resistor (R_1), 1- to 5-V Input, ohms
10	3.333	*
100	2.5641	*
1,000	2.5063	333.3
10,000	2.5006	256.41
100,000	2.50006	250.63
1,000,000	2.500006	250.063
10,000,000	2.5000006	250.0063
∞	2.500000	250.000

*Computer Input Impedance too Low.

5.3.3 Process Transducers - Economic Considerations

This section provides an economic comparison of the various types of instrumentation discussed above. A basic premise in the evaluation is the assumption that the computer is to be operated in parallel with conventional analog instrumentation.

The block diagrams of Figs. 5, 6, and 7 illustrate the equipment required for low- and high-speed data sampling. Table 4 provides a cost comparison for the basic instrumentation equipment, but does not take into consideration additional costs required for shielded cable on the millivoltage systems.

Fig. 5. Connection Diagram for Low-speed Data-sampling Millivoltage-signal Transmission

Fig. 6. Connection Diagram for High-speed Data-sampling Millivoltage-signal Transmission

Fig. 7. Connection Diagram for Low- and High-speed Data-sampling Current-signal Transmission

Table 4
COMPARISON OF ANALOG INSTRUMENT COSTS

Type of Signal Transmission	Sampling Speed	Transducer (mV/I), \$	DC Amplifier, \$	Recorder, \$	Resistance Network, \$	Total Cost, \$
Millivoltage	Low	-	-	625 to 1,000	-	625 to 1,000
Millivoltage	High	-	85 to 250	625 to 1,000	-	710 to 1,250
Current	Low	400	-	260	20	680
Current	High	400	-	260	20	680

This technical and economic comparison led to the conclusion that analog instrumentation equipment based on current-signal transmission provides an effective economic method of transmitting process data to the computer.

5.3.4 Manufacturers' "Standards" - Transducer Specifications

Current computer equipment can accommodate analog input signals having a span in excess of 50 mV. Signals having smaller spans can be used, although the accuracy is reduced. The one basic limitation, which most manufacturers specify, is a maximum limit of 1,000 ohms on the output impedance of the transducer.

5.4 COMPUTER SPEED

Computer speed is one of the most misused and misunderstood phrases in the process-computer industry. Computer manufacturers often quote the maximum possible operational speed for a given machine by choosing the operation which requires the least time of execution. A more meaningful measure of over-all computer speed is the time required to solve "a typical problem." In fact, one of the better techniques of evaluating a group of computers prior to purchase is to program the problems and calculations which will be required. Although this method of computer evaluation requires and provides a tremendous amount of detailed knowledge of the computers under consideration, it is extremely expensive in that many programing man-hours will be wasted.

A second approach is to develop simple "typical" problems and request that the manufacturer estimate the execution times as a part of the technical proposal. Since each vendor has detailed knowledge of his particular equipment, he can estimate problem-execution time very quickly. Thus, this approach does not require undue economical burden on the purchaser or vendor. The selection of the "typical" problems or even the types of problems cannot be determined from any rigid set of rules. The test problems obviously should contain elements of mathematics and logic which are representative of the actual process problems to be solved; however, they should not require extensive programing.

5.4.1 Typical Test Problems

A literature search was carried out to determine what types of "typical" problems have been used in the past. As a result of that search the following mathematical problems were chosen.⁽¹¹⁾

$$1. (A \times B) + C = D$$

$$2. (A \times B)^{1/2} = C$$

$$3. (A \div B) + C = D$$

$$4. AX + BY = C$$

$$DX + EY = F$$

After the preliminary vendor proposals have been reviewed and the acceptable bid list reduced to two or three bidders, these bidders should be requested to estimate the execution time or actually to program a typical logic problem.

The burden of determining the capability of a particular computer should lie with the manufacturer, since he can best evaluate his machine. The bid specifications should provide an outline of the typical program along with the statement saying that the program outlined should not require more than x% of the operating time of the computer.

5.4.2 Typical Computer Speeds

Table 5 illustrates the speed of typical process-control computers.⁽¹¹⁾

Table 5
TYPICAL PROCESS-COMPUTER CHARACTERISTICS⁽¹¹⁾

	Control Data 636	Prodac 580	SDS 910	TRW 340	PDP 4	IBM*
Word Length (Bits)	15	18	24	28	18	Variable
Memory Cycle (μ sec)	17	4	8	6	8	10 to 20
Operation Times Including Instruction Access (μ sec)						
$A + B = C$	17	8	6	8	16	-
$A \times B = C$	-	36 (avg)	248	66	-	-
$\sqrt{A} = B$	289	290	1288	948	-	-

*Control Data Corporation.

Prodac - Westinghouse Electric Corporation.

SDS - Scientific Data Systems (Used by Honeywell Incorporated).

TRW - The Bunker-Ramo Corporation.

PDP - Digital Equipment Corporation (Used by the Foxboro Company).

IBM - International Business Machines Corporation.

5.5 COMPUTER WORD LENGTH

As noted in Section 5.1, one of the requirements on the minimum length of the computer word is the arithmetical resolution. It is desirable that a minimum resolution of one part in ten thousand be incorporated as a basic specification for the computers main frame. The required effective word length for this resolution is 10 bits.

A second major factor which affects computer word length is the ease of programing. Ease of programing is an extremely important economic consideration because of the expense incurred in programing the computer. It is extremely difficult to generalize on this subject; however, it can be stated that, given two machines, one having a 28-bit word and a second having a 14-bit word, the rate at which they can perform at a given set of arithmetic calculations can easily differ by more than a ratio of two to one.⁽¹¹⁾

Thus the evaluation of a suitable word length is in reality a compromise between arithmetical resolution, program speed, ease of programing, and economics. Word length is a sensitive subject among computer manufacturers. The manufacturers all feel that their word lengths are optimum for the job requirements, although manufacturers have word-length standards which vary between 6 and 28 bits.

In conclusion, one basic point is evident. If all other factors are equal, the computer having the longer word has a definite advantage. Beyond this general statement each computer word length must be evaluated on an individual basis.

5.5.1 Typical Word Length of Current Computers

Table 5 gives typical word length for several computers.

5.6 COMPUTER MEMORY

Table 6 outlines the characteristics of the types of computer memories which are generally available in process-control computers.

In modern process-control computers, a magnetic-core memory is used to store the executive program, the program being executed, and data currently being processed. In addition, a certain portion of the magnetic core is allocated for use as a "scratch pad."

Magnetic drum or disc file is normally used for overflow data storage and to store all programs. In some of the earlier computer systems and in some of the modern low-speed systems, the drum is used as the primary memory. The basic disadvantage of this approach is the relatively long time required to obtain information stored on the drum. This long access time appreciably reduces the overall computer speed.

Table 6
TYPES OF MEMORY

Type	Typical Number of Characters	Approximate Cost per Character	Access Time	Normal Use
Flip-Flop	Very Limited	\$200-\$500	<10 μ sec	Buffer
Core	4,000-400,000	\$1-\$4	<20 μ sec	General High-speed Storage
Drum	28,000-40,000	15¢-40¢	25 to 200 msec	Common Storage Unit, Sometime Used as General Storage for Low-speed Computers
Disc	1 Million to 10 Million	1¢-5¢	50 to 200 msec	Same as Above
Magnetic Tape	1 Million	*	May Range into Minutes	Normally Used for Long-time Storage or to Store Auxiliary Information
Paper Tape	Approx. 100,000	**	May Range into Minutes	Computer Input/Output

*\$15,000 to \$30,000 for a magnetic-tape unit having a capacity of about 1 million characters. Additional units and/or tape can be obtained at a large reduction in cost.

**\$5,000 to \$10,000 for a paper-tape unit having a capacity of about 100,000 characters. Additional units and/or tape can be obtained at a large reduction in cost.

Magnetic tape is normally used for long-term storage. Because of the extremely long access time required, this type of storage is normally limited to historical data storage in "real time" on-line computer systems.

The paper-tape memory is the primary means of communication between the computer and the programmer. It is normally used to feed new programs into the computer and can also be used to make a "hard copy" of information in the computer.

The flip-flop is not extensively used because of its relatively high cost. One of the few applications for this type of memory is temporary input/output storage. The temporary storage (buffer) allows the computer to continue the program in progress until a convenient breaking point is reached.

5.6.1 Computer Memory, "Typical" Process-computer Requirements

It is extremely difficult to generalize on the exact size or type of memories required for a process-control application until the problems to

be solved and the capabilities of the specific computer are studied in detail. Obviously, the choice of type and size of memory device is immensely complicated when trying to generalize on the requirements in an invitation-to-bid specification.

Experience gained in other industries indicates that usually paper tape, core, buffers, and drum or disc memories are used. The use of magnetic tape as an auxiliary memory is dependent upon the type and amount of historical information which is to be stored, as well as by the amount of time this information is to be stored. The magnetic-tape facility allows removal of the tapes as they are filled; it also allows rapid recall of the data if required in the future.

Attempting to define the exact number of words or bits as a part of a general specification is generally impractical. The burden of determining the exact size of each type of storage should be left to the manufacturer since he has more experience with his particular machine. The bid specifications should provide a general outline of a typical program along with a statement saying that the programs outlined should not require more than x% of the computer memory.

5.7 REAL-TIME CLOCK

A real-time clock is a highly accurate electronic oscillator which furnishes the computer with readable digits for computing elapsed time between unscheduled events. The clock is also used to signal the computer at selected intervals to perform scheduled operations as specified in the executive program.

5.7.1 Differences between Clocks Used for Nuclear and "Conventional" Processes

In the "normal" process-control application, the response time of the process is generally of the order of seconds and occasionally of minutes. The conventional process instrumentation in a nuclear reactor has similar characteristics; however, the time response of the nuclear parameters can be extremely fast. Since unscheduled changes can occur in the reactor at a rapid rate, the real-time clock requires much higher resolution. A review of typical time response of a reactor reveals that the resolution should be in the order of a millisecond. If a scanning-type contact sense facility is incorporated into the the computer system, it may be necessary to reduce the resolution time to 1-2 μ sec.

5.8 BUFFERING THE CENTRAL PROCESSOR

The input/output devices which transfer data into and out of the computer are generally electromechanical in nature. Typical devices are the

logging typewriter and the paper-tape reader-punch. Being electromechanical, these devices are inherently slow. If the computer were connected directly to these devices, large central processor times would be required for operation and control. To conserve computer time, it is desirable to provide intermediate storage capacity between the peripheral device and the central processor. This type of temporary storage is commonly known as a buffer.

The buffer allows the central processor to send the data to the peripheral devices at a rapid rate and then to proceed with other operations without waiting for the peripheral device to function. Likewise, the buffer also allows an input peripheral device to accept information at a low rate, and then at a convenient point in the program, transfer the information to the central processor.

Since the ranges of speed of most peripheral devices are slower by many orders of magnitude than the cycle time of the central processor, all input/output devices should be buffered.^(12,13)

5.9 INTERRUPTS

It is often impossible to predict the occurrence of all or any unscheduled process events which will require immediate attention.⁽¹³⁾ It is necessary to provide a facility within the computer system which will continuously monitor the process and computer systems to detect and evaluate the importance of a call for program change. Such a system is commonly known as priority interrupt.⁽¹⁴⁾

The term interrupt is often misused. An interrupt is an instruction which causes the executive program to transfer from the program in progress to a specific interrupt response program. This response program automatically saves all information required to return to and resume the interrupted program at the point of interruption. A priority interrupt system is one where the interrupts are given levels of importance.

Computer-generated interrupts are used to detect such faults as a division by zero, parity error, power loss, and arithmetic error. Process-generated interrupts are received from outside the computer. These external interrupts are normally stored in an input buffer. If more than one interrupt is received, the interrupt having the highest priority is given preference and its subroutine executed first. In the event an interrupt of higher priority is received while an interrupt subroutine is being executed, the computer will immediately switch to the subroutine of highest priority. The interrupt subroutines are thus executed in the order of priority. After the last interrupt subroutine has been executed, the computer returns to the program which was in progress when the first interrupt was received. A priority interrupt system greatly simplifies on-line real-time programming by providing

an efficient method for instructing the computer when an emergency arises. It also allows each emergency condition to be evaluated with respect to the other emergencies which may concurrently exist.

The computer manufacturer is in the best position to define the number of internal interrupts which are required for a given computer system. Therefore, the burden of selecting the number and priority of the internal interrupts should be carried out by the manufacturer with the approval of the purchaser. It is important that the system be sufficiently flexible so that these interrupts and/or their priorities can be changed to meet field conditions.

Selection of the number and priority level of the external interrupts can best be made by the process engineer in coordination with the programmer. It is extremely difficult to generalize on a specific number of interrupts or priority levels since they are very dependent upon the process under consideration. However, experience has shown that the number required tends to increase as actual programming is performed. Therefore, it is necessary that the system be expandable. To allow continuity of service, it is imperative that the expansion not require excessive downtime nor the return of the computer or any of its components to the manufacturer's facilities.

5.10 STALL WARNING

A stall warning is a computer subsystem which will detect malfunctions of the computer resulting from either program or computer error. Among the items monitored by the stall-warning subsystem are:

- A. Memory Parity Error: Parity is a method of confirming that a data word has been correctly transferred from one section of the computer to another. One of the bits in the data word is used to indicate that the total number of one bits in the digital representation is odd or even.⁽¹⁵⁾ A parity error occurs when a difference is observed between the actual word and the parity bit.
- B. Failure of the 60-cycle AC-power source or the failure of any of the internal power supplies.
- C. Failure of the computer to reset the watch-dog timer: A watch-dog timer is a subsystem which provides protection against the computer program becoming "derailed" or endlessly circulating in a loop. The watch-dog timer is reset by the program at fixed intervals.

The action to be taken if the stall warning is sounded is largely dependent upon the application of the computer. The literature search showed that the following actions have been programed into existing systems:

- A. transfer of the drum to a readout-only status;
- B. locking all analog outputs at the present or some preprogrammed value;
- C. inhibit a change of state of some or all of the computer contact outputs;
- D. suitable indication that the warning has sounded.

5.11 POWER FAILURE

Since alternating-current power is used to supply the normal operating energy requirements for the computer system, careful consideration must be given to the affect of short- and long-term changes in the quality of this power. Two basic approaches can be planned in the event the power source does not meet the desired quality. These approaches are to (1) switch the computer to an alternative energy source, or (2) shutdown the computer in a controlled manner. The first approach is illustrated by Fig. 8,⁽¹⁶⁻¹⁸⁾ which shows a typical battery-backed-up system containing a solid-state rectifier and inverter. The estimated cost for such a system is \$10,000.

Fig. 8. Block Diagram of a "Typical" Battery-backed-up Computer Power-supply System

The second approach, a controlled computer shutdown, also requires an energy supply to operate the computer until the shutdown is completed. The energy required is usually stored in large capacitors placed on the output of the DC power supplies. The controlled shutdown program should include the movement of all of the information in the core and the registers to a section of the drum where it will be available for startup. This type of program guards against jumbling, or loss of data or instructions. The shutdown should be automatically initiated by a sensor on the commercial power supply at the computer input. Such a controlled shutdown can provide a scram signal to the reactor; however, the capacitor energy source does not normally provide sufficient energy to allow a programed reactor shutdown.

Subsequent computer startup can either be automatic or manual. With either type of startup, the information in each register and at each point in-core should first be checked against the prior shutdown information which had been stored on the drum. Under no conditions should the restart require the presence of a supervisor or a programmer.

5.11.1 Frequency Variation in Commercial Power Supplies

The internal logic circuitry of the computer is not affected by the line frequency until that frequency drifts sufficiently to appreciably effect the ripple voltage of the internal DC supplies. It is possible for a power-line transient to affect the positions of flip-flops within the computer logic. Both of these problems, however, can be easily counteracted by utilization of line filters and capacitors on the output of the internal power supplies.

Another effect of frequency fluctuation in the power line is the speed variation of the synchronous motors in line printers and magnetic-tape drive units. A frequency of less than 57 or more than 63 cps will produce a noticeable tilt in the data printed on a line printer. The off-normal frequency effect in the magnetic-tape unit results in a change in the bit-packing density (i.e., the number of bits stored per linear inch of tape). Both of these effects are not major problems.

5.11.2 Operational Considerations

The choice of a battery back-up power supply versus the controlled shutdown is an economic compromise of cost versus safety and convenience. One other alternative is apparent upon reviewing normal energy-back-up systems used in nuclear reactors. Shutdown cooling in most nuclear reactors requires highly reliable sources of electrical energy. If such an on-site energy source is available, the possibility of its utilization should be investigated. If the on-site energy source is not available, reactor safety requirements justify the cost of the battery back-up system.

5.12 EQUIPMENT RELIABILITY

Reliability can be defined as "the probability that a device will perform a specific function, when required, without failure under particular conditions in a specified period of time."⁽¹⁹⁾ A complete reliability evaluation of a control computer system would involve an excessive amount of time and money. Reliability engineers have developed simplified techniques which allow a measure of the reliability with a large reduction in the number of analysis hours required. This section covers these techniques.

5.12.1 Reliability Definitions and Calculations

In order to start with a common understanding, the terms to be used will first be defined. The calculations required to determine the reliability of the equipment are then outlined.

5.12.1.1 Failures

A failure shall be defined as any loss of information or function in the central processor or any input/output subsystem. A malfunction of the mechanical components in the paper-tape reader/punch or any typewriter is not normally considered a failure; however, the malfunction of any of the logic equipment associated with the paper-tape reader/punch or any typewriter shall be considered a failure.

5.12.1.2 Failure Rate

The failure rate λ in any period of time t can be defined as the ratio of the number of failures, X , during the operating time to the number of equipments, N , at the start of the operating period:(19)

$$\lambda t = X_t/N.$$

5.12.1.3 Component Count

The component count n is defined as the number of particular type of equipments or components in a system or subsystem.

5.12.1.4 "Mean Time to Failure" (MTTF)

"Mean time to failure" is defined as the measured operating time of a single piece of equipment divided by the total number of failures of the equipment during the measured period of time.(19)

5.12.1.5 "Mean Time between Failures" (MTBF)

"Mean time between failures" is the ratio of the number of equipments, N , tested times the test time t divided by the number of failures, m , which occur.(19)

5.12.1.6 "Mean Time to Maintain" (MTTM)

The "mean time to maintain" is defined as the total measured time to repair a single piece of equipment divided by the total number of failures of the equipment during the measured period of time.(19) Total measured time to maintain includes all time required to determine that a fault exists,

localize and repair the fault, and test the system to show proper operation. It also includes the time required for preventative maintenance.

5.12.1.7 Calculations

In this section will be defined a simplified technique for calculating a system failure rate, "mean time to failure," and "mean time between failure."

5.12.1.7.1 System Failure Rate

A simplified but meaningful system failure rate can be based on the assumption of noninterdependence of the components and/or their failure rates. Calculation of system failure rate is accomplished by the following equation:⁽¹⁹⁾

$$\lambda_{\text{system}} = \sum_{i=0}^P n_i \lambda_i$$

where

λ_i = failure rate for component i ;

n_i = the number of the particular components of the type designated by the subscript i ;

P = the number of different types of components.

A calculation in which this equation is used should include all types of components used in the system, and also include such hardware items as connectors and solder connections.

5.12.1.7.2 "Mean Time to Failure"

The "mean time to failure" can be calculated from the following equation:⁽¹⁹⁾

$$\text{MTTF} = (\lambda_{\text{system}})^{-1}$$

5.12.1.7.3 "Mean Time between Failures"

The "mean time between failures" can be calculated for several systems of the same type by the following equation:⁽¹⁹⁾

$$\text{MTBF} = \text{NT}/m,$$

where

N = number of systems tested;

T = test time;

m = number of failures.

5.12.2 Availability and Continuity of Service Demonstration

In order to start with a common understanding of the terms to be used in this discussion, the terms will first be defined. A continuity of service demonstration is then discussed.

5.12.2.1 Failures

See Section 5.12.1.1 for the definition.

5.12.2.2 Availability

In the field of reliability engineering, the word "availability" has several different meanings. Availability, as used in this report, can more correctly be called the operational availability of a system. It is defined by the following equation:(19)

$$A_0 = \left(1 - \frac{TDT}{T}\right) 100\%,$$

where

A_0 = operational availability in percent for any period of time T;

TDT = Total Down Time, including all operational time lost by a failure as defined above. This includes all time required to determine that a fault exists, localize and repair the fault, and test the system to show proper operation. The Total Down Time also includes the time required for preventative maintenance.

In effect, operational availability is a measure of the reliability and maintainability of the system, and can be defined in those terms:

$$A_0 = \frac{MTBF}{MTBF + MTTM},$$

where A_0 is as defined above. MTBF and MTTM are defined in Sections 5.12.1.5 and 5.12.1.6.

5.12.2.3 Confidence Level

The confidence level is a statistical expression for the degree of desired trust or assurance in a given result.⁽¹⁹⁾ A confidence level is always associated with some assertion and measures the probability that a given assertion is true.

5.12.2.4 Confidence Interval

The confidence interval is a range of values which is believed to include, with a pre-assigned degree of confidence (confidence level), the true characteristic of the lot or universe a given percentage of the time.⁽¹⁹⁾

5.12.2.5 Continuity of Service Demonstration

Some vendors can show field records of availability as high as 99.7% and a "mean time to failure" in excess of 1500 hr. However, during this study, private communication has revealed other vendors have equipment with an availability of 90% or less and a "mean time to failure" of less than 300 hr. The continuity of service demonstration is a long-term test to demonstrate that the operational availability of the equipment is equal to or greater than a given value. The test should also demonstrate whether the "mean time to failure" meets the desired requirements. Because of a finite demonstration test period and the small number of failures which occur in that period, the confidence interval of the "mean time to failure" for the demonstration is usually very wide.

Final acceptance of the entire system is normally delayed until the continuity of service has been successfully demonstrated. In the event the system fails to meet the requirements of the continuity of service demonstration, the system should be repaired and/or replaced by the vendor at his expense. After the system has been repaired it should be retested as for a normal field test and a new continuity of service demonstration carried out. In order to provide meaning for this demonstration and to obtain complete vendor cooperation, it is suggested that a percentage of the contract price, specifically that percentage representing profit to the vendor, be withheld until the machine passes the demonstration.

It is suggested that the demonstration be based on a minimum availability of 99% of a 24-hr/day basis over a period of 180 days. It is further suggested that the number of failures be limited to 5 or less to demonstrate that the machine has a "mean time to failure" of at least 1000 hr.

5.13 ELECTRICAL NOISE SUSCEPTIBILITY AND/OR EMANATION

In the past, the topic of electrical noise susceptibility and/or emanation of major electronic systems has often been overlooked in basic studies of

these systems, largely because of the difficulty in defining the problem. Although it is possible to reduce greatly the susceptibility to and the generation of nonintelligence or noise signals, the cost of total protection is excessively high. Recent theoretical work and field experience has indicated that one of the better approaches is to provide protection against the more obvious noise sources and then to meet the field problems on an individual basis as they arise. Additional confidence in the installation can be obtained by determining the type and magnitude of the noise sources which are present at the installation. This presumes that the equipment is to be installed in an existing plant.

For convenience, noise sources will be broken into two basic categories: sources which produce interequipment effects, and sources which produce intra-equipment effects. The rules outlined in the following sections have resulted from some theoretical calculations, but mostly they are the result of practical field experience. It should be recognized that, although installation standards must be set up, field conditions can radically change those standards. If noise is observed in the field after the basic installation is completed, the predominant rule is to observe, find, and eliminate the noise or the susceptibility to the noise.

5.13.1 The Intra-equipment Interference Effects

Intra-equipment interference effects will exist if there exist incompatibilities among the various subsystems within the computer. Although basically a manufacturer's problem, it is possible that a particular environment could appreciably affect intra-equipment interference signal levels. It is assumed that if the manufacturer has successfully operated similar systems, most of the intra-equipment interference problems will have been eliminated. If, however, problems do appear, they should be handled on an individual basis by the equipment manufacturer.

5.13.2 The Interequipment Interference Effects

Interequipment interference effects constitute a far more complex problem because they are a direct result of the electrical environment at the installation site. It is extremely difficult to define the electrical environment for an existing installation and even more difficult to predict the environment of an installation which is under design. If a mathematical model could be constructed defining the sources of electrical interference and the coupling coefficients, it would still be difficult to predict the susceptibility of a proposed system and hence the effect of the noise sources. The problem of predicting susceptibility arises because of the nonlinear electrical characteristics of the environment and system components, and subsequent frequency-multiplying effects which occur.

The problem should be approached by reviewing the possible interference sources which will exist in a typical environment and then considering the possible entrance points of this noise into the proposed system.⁽¹⁸⁾ At the same time, the system to be installed should be investigated for possible noise sources and methods by which the energy from these sources can be coupled to adjacent equipment.

The more predominant noise sources generally transmit their energy by a solid-wire conduction, electromagnetic radiation, and electric and magnetic fields.

5.13.2.1 Electromagnetic Radiation

In general, interference resulting from electromagnetic radiation requires (1) an electromagnetic wave of relatively high intensity, (2) a surface area acting as an antenna, (3) circuits within the computer demodulating the signal, and (4) computer circuitry which can be activated by relatively low-energy signals. An item such as a radar set, a large electrical contactor, or other arc-generating equipment located near the computer or one of its signal leads can provide such an interference source. The computer contains many nonlinear devices which act as demodulators; it also contains many flip-flop-type circuits which are activated by short rise-time signals.

5.13.2.2 Electric and Magnetic Fields

Electric and magnetic fields are the most prominent source of interference in industrial instrumentation systems. These electric and magnetic fields are generally of low frequency, 60 cps being the most predominant.

5.13.2.3 Conducted Interference

Conduction by solid metallic connection results when an interference source is directly connected to the instrumentation system. A typical example is a noisy transducer. Although transducers can be considered as a part of the intracomputer equipment, they vary from installation to installation. Furthermore, they are generally a part of the existing installation and are often incorporated into an analog as well as the digital system. Therefore, the process transducer and associated equipment are normally considered under the category of interequipment sources.

5.13.2.4 Interference Emanation

The possibility of emanation of undesirable energy from the computer is normally confined to the study of signals which are generated as continuous sinusoidal or repetitive pulses.⁽²⁰⁾ Sources of such signals are the system clock and the system memory cycle time. In general, the energies

involved are very low; a problem occurs only if a device in the environment is highly susceptible to high-frequency noise. Because the energy spectrum of a sinusoidal signal is confined to a very narrow frequency band, a sinusoidal clock is preferable from the interference standpoint.

5.13.2.5 Interference Reduction

Techniques used for interference reduction which can be planned in advance of the installation can be divided into five distinct areas. These include cable and conduit, shielding, grounding, physical isolation, and filtering.^(21,15)

5.13.2.5.1 Cable or Conduit

All cables should be run in cable tray or conduit.⁽²¹⁾ The wiring in a conduit should be restricted to but one service, either power, intrasystem, contact sense, or analog. All conduits and/or trays should be bonded with low-resistance joints and connected directly to the main site ground. All signals should be carried on twisted pair having a minimum of one complete twist every $2\frac{1}{2}$ in. A common signal ground lead is not considered adequate. Each signal should be carried by a pair of twisted wires.

5.13.2.5.2 Shielding

Each pair of low-level analog and contact input/output leads should be shielded.⁽²¹⁾ The shield should be continuous and insulated. Ideally, the shield should form an isolated guard circuit and be switched as a third multiplexer input along with the two signal leads. From a practical standpoint, the increased cost of a third switched lead is not justified by an appropriate reduction in interference-signal level. In practice it has been found that appreciable reduction of an interference signal occurs if the shield is grounded at the process transducer. It is extremely important that the shield be grounded only at one point. Ground loops and consequential circulating currents are a major source of interference injection into a low-level system. Therefore, the shield should be isolated from conduit, box, tray, and other shields.

5.13.2.5.3 Grounding

The ground line from each major piece of equipment in the system should be connected to a single point and that point connected directly to earth ground.⁽²¹⁾ The connection between the common point and earth ground should be made with a cable or bus bar having as a minimum the cross-sectional area specified in the National Electrical Code. All signal grounds with the exception of the transducer having internal grounds are usually tied together at a common point, which is then connected to ground

by a low-resistance cable or bus bar. The ground lead for the shields should be as short as possible; however, the shields should be grounded as close to the transducer as possible.

5.13.2.5.4 Physical Isolation

The computer cabling, and particularly cable carrying low-level analog input signals, should be isolated from cables connected to devices which require heavy currents (greater than 50 Amp) or devices which are known to be heavy-noise generators (arc welders, radar transmitters, large contactors, high-energy pulse generators, etc.). It is preferable to isolate these devices by use of conduits or trays. If this is not possible the cables should be run with a minimum physical separation of 12 in.⁽²¹⁾ A minimum physical separation of 2 in. is required between low-level analog input leads and other low-level circuits located in the same cable tray.⁽²¹⁾ Cables should be free from loops and only cross other cables at an angle of 90°. Under no condition should power wiring, intrasystem wiring, contact sense or closure wiring, and analog input/output wiring be mixed in the same conduit or tray. Physical isolation also implies that the most direct cable routing be used. This is particularly important when considering low-level signals.

5.13.2.5.5 Filtering

Most computer manufacturers incorporate signal conditioning circuitry into the analog subsystem.⁽¹⁸⁾ Normally, these signal conditioning circuits consist of balanced low-pass filters on the input to the multiplexer. Since filtering basically alters the pass-band characteristics of the line on which it is applied, careful consideration must be given to the effect of the filter on the process data being obtained. As noted in Section 5.2.1, filters are required to eliminate minor process perturbations when operating a stable closed-loop process-control system; however, the use of a filter may prohibit the pass band of a data-collection system, thus giving a false model of the dynamic conditions of the process.

A second type of filtering which is used by some manufacturers is commonly known as digital filtering. The filtering takes place after the data has been digitalized. The best method to explain this technique is to describe the steps which must be carried out in the technique. These steps are listed below:

- A. The principal interference frequency (F_i) is determined (usually 60 cps).
- B. A digital data sample is obtained at time t_1 .

C. A second sample is obtained at time t_2 , where

$$t_2 = t_1 + \frac{1}{2F_i}$$

D. The two signals are averaged.

The averaged value is assumed to be equal to the value of the signal prior to the addition of the interference signal. This technique is best illustrated on an analog basis by Fig. 9.

Fig. 9. Example of Data Taken Prior to Digital Filtering

This simplified version of a very powerful technique is most applicable when a predominant interference frequency exists and when the process spectrum has no components at the predominant interference frequency. It is possible to extend this technique to eliminate several undesired noise signals; however, it does require that the frequency spectra of the interference and data be known. Because this information is difficult to obtain, the application of this technique in the process-control field has been limited to the most predominant noise source, which is the power-line frequency.

5.13.3 Special Considerations for Particular Interference Suppression

Specific interference areas are discussed below. These include balanced signal-line transmission, contact input/output, and thermocouples.

5.13.3.1 Balanced Signal Lines

It can be shown that the balanced-line technique of signal transmission can appreciably reduce the susceptibility to the introduction of unwanted signals into a cable.⁽²⁰⁾ A balanced transmission system is illustrated in Fig. 10. The interconnecting cable should be a twisted pair. When the

transmission signal level is low, an insulated shielded cable should be used. This technique provides isolation between sending and receiving circuits, and eliminates interference due to differences in ground potential. Most computer manufacturers have incorporated this or a variation of this technique into their computer-input subsystem.

Fig. 10. Block Diagram of Balanced Signal Transmission

5.13.3.2 Contact Input/Output

The contact ratings of computer output switching circuits are normally 100 or 250 VA, which should never be exceeded. If they are exceeded, transient currents are a potential source of interference. If external circuits of higher capacity are required, repeater relays should be used. From the standpoint of reliability it is advisable to derate the contacts by approximately 50%. The coils on all external equipment should be arc suppressed. Typical arc-suppression circuits are shown in Fig. 11.(20,22)

Fig. 11. Typical Arc-suppression Circuits

5.13.3.3 Thermocouples

The external leads for each thermocouple must be made from the same two kinds of wire as the thermocouple itself. Equal resistance wire is preferable, but not absolutely necessary.(21) Occasionally, to reduce thermal time lags, it is necessary to ground mechanically the thermocouple at its tip. However, mechanical grounds are generally not adequate electrical grounds. The thermocouple should have an electrical ground, but it must have one and only one electrical ground. For grounded thermocouples, each thermocouple must have its own insulated, shielded, twisted pair of extension leads. The shield should extend to the tip or as close to it as

possible. The shield should never terminate more than 15 ft from the tip. The shield and the lower-resistance lead should be grounded at the field end of the shield.

In the case of ungrounded thermocouples, individual insulated, shielded, twisted-pair extension leads should be used. However, it is possible to use a multitwisted pair with a common shield, if the thermocouples are used in an area of low electrical noise and if the area is confined. The maximum unshielded length of a thermocouple extension lead should never exceed 20 ft. Furthermore, the unshielded extension leads should be approximately of equal lengths. The shield and the thermocouples should be electrically grounded at the extreme field end of the shield. If individual shields are run from the common shield, the system of shields and lower resistance leads should be grounded at the junction of the common shield and individual shields.

5.14 CALIBRATION

Calibration and long-term stability are important factors to consider when purchasing any instrumentation system. As noted in Section 5.1, the minimum acceptable accuracy of the analog input subsystem is 0.1% of span, and the minimum acceptable arithmetic resolution of the central processor is one part in 10,000 or an effective word length of 14 bits. The accuracy specification for the internal calibration sources should be an order of magnitude greater than the limiting accuracy, or 0.01%. Most manufacturers will supply several calibration signals which are permanently connected to input points on the multiplexer. The calibration sources are usually program selected, converted to a digital value, read into the computer, and compared with prestored limits. If the digitalized value lies outside the limits, a suitable alarm indication is given. After an out-of-limit alarm occurs, a system calibration curve should be obtained and the system calibration corrected.

The desirable number of internal-program-selected calibration points is dependent upon operating conditions of the system. If operating conditions allow system shutdown for calibration as required, only 3 calibration points are generally used. They are 0 to 10% of span, 50 to 70% of span, and 90 to 100% of span. If, however, operating conditions require that control-system downtime be minimized, a system to detect errors in the precision calibration sources is required. One of the simplest error-detection techniques is the use of redundant calibration sources. As an example, assume that three calibration sources having equal outputs have been installed at each point of span to be checked. If one of the three digitalized values lies outside the acceptable limits, it can be checked without removing the entire system from service. An alternative approach involves the incorporation of an externally adjustable calibration source which is permanently

connected to the multiplexer input. If the fixed calibration sources indicate an error, a calibration curve can be obtained with the system in operation.

5.15 CONTACT SENSE DETECTION

The problem of detecting an off-normal process bistable device involves consideration of the requirements for resolution time, signal characteristics, and economics. In addition, it is necessary to review two of the basic premises involved in the design and operation of a nuclear reactor. One basic premise established in many nuclear installations is the complete independence of SCRAM circuitry. The premise precludes the utilization of the computer as an intermediate device in any scrambling operation. Future operating experience may modify this premise because of the apparent reliability of the digital computer; however, this report will consider the premise a firm rule.

The second basic premise is the need to know why the reactor scrambled before the reactor can be brought back to power. The operating knowledge of the cause of a scram is far more complex than at first appears. In most installations the scram and alarm circuits are monitored by an annunciator which indicates which circuits have faulted, but does not indicate the order in which the faults occurred. Since many of the variables involved in the reactor alarm and scram circuitry are interdependent and since these interdependent variables can be annunciated almost simultaneously, it is sometimes difficult for the reactor operator to determine which variable actually causes the scram.

5.15.1 Manufacturers' "Standards"

The system usually offered by computer manufacturers for off-normal contact detection is outlined below:

- A. The contacts are sensed in word groups; that is, a number of contacts are sensed at one instant and form bits of a computer word.
- B. The bits are then compared with a prestored mask which represents the desired normal condition of the contacts.
- C. If all contacts are normal, the computer samples the next group of contacts.
- D. If an off-normal contact is detected, the computer can be programed to determine which contact of the group being sensed is off-normal.
- E. Programed actions can then be taken. These normally include attaching a time indication, ringing a bell, typing out the necessary descriptive information, and/or adjusting some or all of the computer output signals.
- F. The computer then proceeds to sample the next set of contacts.

In most installations the operator is supplied with an alarm-acknowledge pushbutton which inhibits further audible indication until the alarm has been cleared. The inhibit circuitry functions only on the alarm point which has just sounded; it does not inhibit the sounding of any other alarms.

The system sometimes incorporates a simple controlled access method for the operator to change the limits for any alarm. This facility is usually provided in the form of a locked subpanel which allows data to be put into a selected section of the computer memory from the operator's console.

Typical contact scan rates currently available range between 75,000 to 500,000 contacts per second. The scan speed of the system has a direct correlation with the contact resolution time. As an example, consider the resolution times for two different scan rates and three different contact requirements given in Table 7.

Table 7
CONTACT-SENSE RESOLUTION TIME

Number of Contacts Required	Typical Scan Rates, msec	
	Greater than 430,000 Contacts per second	Greater than 75,000 Contacts per second
250	0.58	3.33
500	1.16	6.66
1,000	2.3	13.3

In general, it is impossible to determine what resolution times are required. Indeed, even after a complete analysis of the particular facility, it is difficult to determine absolute requirements for resolution times. The resolution times of various amplifiers, relays, and switches involved in the auxiliary circuits precludes the need of resolution times less than 1 msec.

5.15.2 Economic Considerations

In order to obtain the resolution times listed in Table 7 it is necessary to scan the contacts continuously. This contact-sense function of the computer can require an appreciable amount of central processor time. The basic cost of a 250-contact-sense system ranges from \$6,500 to \$16,500, depending upon the manufacturer and equipment option. This cost does not include a lighted display panel, which adds \$20 to \$50 per point.

Certain manufacturers offer, as an option, a special subsystem which will continuously monitor the condition of external contacts with very little or no central processor-time requirement. Information is only passed to the central processor if an off-normal condition exists and nonstandard procedures are required. This subsystem can be implemented by one of two methods. The first basically consists of a small-hardware programmed computer to scan the contact input points continuously. When an off-normal condition occurs, an interrupt is sent to the computer and the necessary main computer subroutine started to determine which point is off-normal.

The second option consists of a series connection of a number of external contacts directly to an interrupt line. If one of the contacts goes off-normal, an interrupt is issued to the central processor and the necessary subroutine executed to determine which contact is off-normal and what action is to be taken. One disadvantage of this scheme is the disabling of the remaining contacts in the group by a single off-normal condition.

Another approach which can be considered is the purchase of a separate contact-sensing annunciator which is totally independent of the computer system. The disadvantage of this approach lies in the synchronizing requirements of the two clocks and the operational difficulty of two separate logs. The approximate cost of a recording scram-and-alarm annunciator with visible indication for all points ranges from \$100 to \$160 per point. This type of annunciator normally has a resolution time in the order of one millisecond. Because of a printing time requirement of 200 msec, a limited memory is usually incorporated into the system. This memory is normally limited to the first 10 to 30 sequential points.

No specific recommendation can be made as to which of the alternatives is most acceptable. Each type must be evaluated for each installation. Regardless of the choice of the system to be installed, certain basic considerations are suggested. These include:

- A. contact devices which indicate a fault condition by opening the circuit;
- B. field contact potentials in excess of 100 V DC to aid in positive contact operation. Current-limiting resistors should be incorporated into the DC power supply to protect it from a contact fault;
- C. ring-back, incorporated into the system to provide an indication when an alarm has returned to normal;
- D. adequate indication in the form of different colored lights to indicate definitely the instantaneous condition of the contact. The following is one sequence which can be used:
 - 1. steady light, color #1, for a normal contact;
 - 2. a flashing light, color #2, for an unacknowledged off-normal contact;

3. steady light, color #2, for an acknowledged off-normal contact;
4. flashing light, color #1, for an unacknowledged return to normal contact.

5.16 CONTACT OUTPUT SUBSYSTEM

The contact output subsystem consists of the equipment necessary to transmit bistable signals from the computer to the process. It also provides signals for the control of indicating devices. Contact output subsystems can be supplied by all on-line digital computer process control manufacturers. These subsystems generally consist of mercury-wetted relays. Specifications for a typical output relay are given below:⁽²³⁾

Single-pole, double-throw, magnetically latched, mercury-wetted contacts with a rating of 250 VA.

The rated life of this relay is in excess of 20-million operations at full rated load. As noted in Section 5.13.3.2, the 250-VA rating should never be exceeded; moreover, longer life is obtained if the contact is derated. If higher powers are required for the operation of external equipment, repeater relays should be used. The life rating of the relay is predicted on the assumption that its contacts are arc suppressed. Typical arc-suppression circuits are shown in Section 5.13.3.2.

5.17 ANALOG OUTPUT SUBSYSTEM

The analog output subsystem consists of the equipment necessary to translate the digital information from the computer into an analog signal. The analog outputs are supplied to the process and to certain indicating devices. The analog output subsystems currently offered by computer manufacturers can be classified into two basic types: motor-driven potentiometers, and resistance-divider networks. Either type can be combined with a constant voltage or current source to provide voltage or current output signals.

A typical motor driven potentiometer subsystem is illustrated in Fig. 12.⁽²³⁾ This type of system is available with a 30-, 60-, 120-, or 360-sec full-scale response. The approximate cost is \$700 per output.

Fig. 12

Analog Output -
Motor-driven
Potentiometer

A typical, step-voltage, analog output circuit is illustrated in Fig. 13.(23) Manufacturers normally supply 8 to 10 steps; however, systems are available which provide as many as 16 steps. Generally, the equipment is supplied with step resistors of equal value; however, it is possible to vary the value of the resistances to obtain as many as 256 discrete steps in the output signal for 8 relays, 1024 steps for 10 relays, and 65,536 steps for 16 relays. The typical cost of an 8-relay circuit is \$750 per point.

Fig. 13
Analog Output -
Relay Driven

5.18 ANALOG INPUT SUBSYSTEM

The analog input subsystem consists of the equipment necessary to receive, condition, scan, and digitalize the incoming analog signals. It also includes a buffer memory and the necessary logic equipment to feed the digitalized signal into the main frame of the computer. The characteristics of an analog input subsystem, such as accuracy, scanning speed (data-sampling rate), buffering, signal conditioning (filtering), balanced line transmission, calibration, process transducer signals, and operating temperature, are discussed in Sections 5.1, 5.2, 5.8, 5.13.2.5.5, 5.13.3.1, 5.14, 5.3, and 5.21, respectively. The characteristics discussed in this section include input-signal terminations, reference junctions for thermocouples, signal amplifiers, and analog-to-digital converters.

The analog-input signal lines are generally terminated on a single rack with 600-V screw-type barrier-terminal strips. Each input line is terminated by its own two terminals. The shields for these lines are not normally connected to the input rack, but are grounded at the transducer (see Section 5.13.2.5.3).

In systems with thermocouples, the input termination rack usually contains a monitored, isothermal, reference junction box. A resistance bulb for the determination of temperature is usually incorporated in the box for monitoring the cold-junction temperature. Overall accuracies are generally of the order of 0.2°C.

Several basic types of analog-to-digital converters are available as equipment options. Since a cursory discussion of the various types of

equipment available would require a separate report and since such detailed reports are available, the subject will not be discussed in this report.⁽²⁴⁾

The signal amplifier used with a low-speed multiplexer is usually an all solid-state device with programable range (gain) switching. The gain-switching feature allows the use of a single-range, high-signal-level analog-to-digital converter. The input impedance of the amplifier is normally of the order of 100 megohms. The amplifier normally has a balanced input which can achieve common mode rejection of 120 db for signals from DC to 60 cps. The signal amplifier is normally located between the low-speed multiplexer and the analog-to-digital converter (see Fig. 14).

Fig. 14

Typical Low-speed Analog Input Subsystem

In order to maintain the accuracy specification for the overall analog subsystem, individual signal amplifiers are required when using a high-speed multiplexer (above 200 points per second) with process transducers having low-level outputs (less than 1 V).^{*} The individual signal amplifiers are required because of the noise characteristics of the high-speed, solid-state multiplexer. It is necessary for the amplifier to have frequency-response characteristics which are consistent with the data spectrum of the process waveform. It is also necessary that the amplifier have long-term gain stability. As can be noted from Section 5.3.3, there is an economic disadvantage to this type of subsystem. The simplified block diagram in Fig. 15 illustrates this type of subsystem.

Fig. 15

Typical High-speed, Low-signal-level Analog Input Subsystem

Other subsystems are available which use several low-speed multiplexers, feeding separate signal amplifiers which, in turn, feed a single high-speed multiplexer. The high-speed multiplexer is directly connected to an analog-to-digital converter. A basic disadvantage of this type of subsystem is its failure to allow complete high-speed random selection of the input variables.

^{*}See Sections 5.3 to 5.3.3 for a technical and economic discussion of process transducers.

The buffer section of the analog input channel should be operated with the main frame of the computer so that it is asynchronous. Asynchronous, in the computer sense of the term, means that the input (output) operates on a time-sharing basis with the main frame, taking machine cycles for memory reference as required.⁽²⁵⁾

5.19 MAN-COMPUTER COMMUNICATIONS

Ease and clarity of communication between the operator and the computer is one of the most essential parts of a successful computer control installation. The process operator is generally not educated in the art of programing, nor is he indoctrinated in the detailed conceptual design of the system and the methods used by the computer to process information. The operator generally has an intimate knowledge of the process, if it is an existing process; however, if it is a new or experimental process he may have many things to learn about it.

It can be assumed that the minimum educational level of the nuclear reactor operator is four years of high school. In some cases the educational level may extend to a college degree. In any case, the communications between the operator and computer must be designed so that a reactor operator can understand and efficiently utilize the system. In addition, the communication system should be designed so that any information required for normal or emergency operation is easily obtained and presented in a convenient form for the operator.

The second phase of the problem involves programmer-computer communications. In general, it is desirable to select and train as a programmer, an engineer who has an intimate knowledge of the process and its physical, chemical, and nuclear constraints. However, the engineer's background may not include the language or operation of digital computers. Therefore, it is expected that special educational courses will be required to improve the programmer's knowledge in the area of programing, control system theory, mathematical model development, and optimization theory.

5.19.1 Program Preparation and Input

After the program has been written, it is necessary to transmit it into the computer accurately and rapidly. Two basic methods are available to implement this communication: on-line typewriters or off-line typewriters. The first method involves the typing of the information on a keyboard which is directly connected to the computer. The second method involves the off-line preparation of a paper-tape reader which is connected directly to the computer. The first method has virtually been abandoned because of the possibilities of errors and the extremely low rate of data input.

The preparation of paper tape on an off-line typewriter equipped with a paper-tape punch is normally used. The paper tape is then fed to the computer by a paper-tape reader. Since the typewriter used in preparing the paper tape also produces a standard typed (hard) copy, the tape can be proofread before the information is fed into the computer.

Two general types of paper-tape reader can be obtained: mechanical and photocell readers. The range of speeds available for the mechanical units is 60 to 120 characters per second.⁽²⁶⁾ The speed of the photocell unit is approximately 300 characters per second.⁽²⁶⁾

Some systems also have a capability of inserting information in the computer via punched cards.⁽²³⁾ This option is not generally used within the process computer field and only a few manufacturers offer it. The card readers which are available are similar to the standard business, 80-column, punched-paper card readers having a maximum reading rate of 200 cards per minute.

5.19.2 Data Readout

The process operator is not directly interested in the program reading system; however, he is interested in the techniques used in the readout system. As noted above, the readout equipment should be extremely simple to operate and should provide data to the operator in a form which he can quickly understand. As a result of visits to many computer users and an investigation of the type of equipments already in use, a system will be proposed in the next section of this report. This display system is quite similar to that being tested by the Atomic Energy of Canada Limited at their Chalk River installation.⁽²⁷⁾ Apparatus which is generally available as readout equipment for process computers will be briefly discussed in this section.

5.19.2.1 Typewriters

Several types of typewriters are available.^(23,26,28) They are available in 12-, 16-, 20-, and 30-in. carriage lengths with standard pin-fed platen. Typing speeds generally range from 10 to 15 characters per second with a horizontal character spacing of 10, 12, or 14 characters per inch. Some units can be obtained with an option of a side-mounted paper-tape-punch reader. This option allows typing without punching, punching without typing, or typing and punching simultaneously. Subsequently the paper tape can be fed to the typewriter and produce a hard copy and/or punch an identical paper tape. The exact choice of characteristics is entirely dependent on the particular application and the economics. The cost of typewriters generally range from \$3,000 to \$7,000 each.

5.19.2.2 Paper-tape Punch

Paper-tape punch units can be directly coupled to the computer. The units are normally used as a medium-speed readout device. Units are available which operate at speeds of 60 and 120 characters per second.⁽²⁶⁾ Since the paper-tape punch is many times faster than a typewriter, it is normally used to receive large quantities of data from the computer. The data are then transferred to a hard copy on an off-line typewriter-punch reader. This appreciably reduces the central processor time required to obtain a typed (hard) copy of the data.

5.19.2.3 Line Printer

Many types of high-speed line printers are available which are compatible with control computers.^(26,28) Table 8 illustrates the speed, the length of the line, and the approximate cost of several units. As can be noted, the units have extremely high printing rates. They are generally used as high-speed data-printout devices. They can be justified when large quantities of data must be printed out.

Table 8
SPEEDS AND COSTS OF LINE PRINTERS

Lines per minute	Line Length in Characters	Estimated Cost, \$
300	120	30,000
300	72	20,000
300	11	5,000
20	20	10,000

5.19.2.4 X-Y Plotter

The X-Y plotter provides an analog graphical representation of the data stored in the computer memory.⁽²⁸⁾ Although this equipment is not normally required in a process-control installation, the plotter would be very useful in a test-evaluation installation.

Standard units can be obtained which have plotting widths from 11 to $29\frac{1}{2}$ in. The maximum rate at which data can be fed to the plotter ranges from 2 to 100 msec per point. If a continuous curve is required, the average plotting rates are 12,000 to 18,000 points per minute. If the plotting requires pen-up-down movement, average plotting rates are reduced by a factor of 30.

5.19.2.5 Magnetic Tape

Magnetic-tape units are usually considered a form of low-access-speed storage; however, they can also be used as high-speed data readouts for special applications. In the event that a particular problem requires an excessive amount of computational time, the data can be transferred from the computer to magnetic tape, placed on a larger compatible computer, and processed.(23,26,28) Magnetic tape is also used for off-computer data storage. This is best illustrated by an example. Historical data can be transferred to and stored on the tape and then the tape removed. At a later time, the tape can be returned to the computer, the data obtained, the calculation completed, and the tape removed and restored.

5.19.2.6 Quick-look Scope

Small- and large-screen cathode-ray oscilloscopes have been integrated into computer systems to form visual display units.(23,26,28) They are used to provide a rapid means for the operator to observe alpha-numeric and graphic data. In the past the units were experimental and offered only on a custom basis. Recently, however, the manufacturers have had sufficient experience to develop standard units. These standards are not industry wide and vary greatly from manufacturer to manufacturer. The units utilize scopes of 8-, 12-, 14-, 17-, 19-, and 21-in. diameter. They have scan speeds of approximately 20 complete displays per second, which is well beyond the persistence of vision. Experience has proven this display rate is satisfactory in reducing operator fatigue. The units have vertical and horizontal resolutions better than one part in one thousand; thus, the average display area contains over one-million possible display points. This type of resolution allows the scopes to be used for displaying tables, graphs, charts, and alpha-numeric letters and figures. Options which are available include a "light pen," programed functioned keyboards, alpha-numeric keyboard, character generator, and display multiplexer.(28)

5.19.2.6.1 Light Pen

A "light pen" is a hand-held, penlike device consisting of a hollow tube having a photosensitive solid-state device in the end. The pen is normally used in conjunction with a scope display and input keyboard. It is used to identify, to the computer executive program, a particular point displayed on the face of the scope about which information is desired.

5.19.2.6.2 Programed-functioned Keyboard

A programed-functioned keyboard is a device which allows the operator to choose a display subroutine program for the scope, such as a program for using the "light pen."

5.19.2.6.3 Alpha-numeric Keyboard

The alpha-numeric keyboard is a typewriter keyboard which permits the entry of alpha-numeric and symbolic information into the display unit.

5.19.2.6.4 Character Generator

The character generator is a unit used to translate the stored information in the computer memory into a suitable analog signal to trace the character on the face of the scope. This releases the central processor from the task of character generation.

5.19.2.6.5 Display Multiplexer

This unit is a control unit used to feed several "quick-look" scope displays from one central processor.

5.19.2.7 Operator's Console

The operator's console is usually custom built to purchase specifications by the manufacturer. Although special fabrication is available, the unit is normally constructed from standard console components. The equipment on the operator's console is custom designed; therefore, it is difficult to give a specific description. It can be said, however, that all equipment on this console should be chosen for ease and simplicity of operation. All read-out on the console should be in decimal form with a base of ten.

5.19.2.8 Programmer's Console

The layout of the programmer's console is generally predesigned by the manufacturer; however, this basic design should be modified to meet the specific requirements of the purchaser.

One special option which can be considered is the possible utilization of the programmer's console for emergency operations. Such an option may be necessary if the reactor has a containment shell which can become inaccessible because of radioactive contamination. The programmer's console can be placed outside the containment shell and used to monitor reactor conditions continuously. If this option is chosen, it is imperative that the design of the emergency operating section of the programmer's console be identical with the operator's console. This is considered necessary because of the familiarity that the operator will have with the layout of his own console.

5.19.3 "Typical" Nuclear Reactor Operator Readout System Requirements

It should be pointed out that each installation must be treated on an individual basis; therefore, it is extremely difficult to specify any set of guide

lines for a typical nuclear reactor readout system. The general outline below may not conform to the desired operating mode of a particular installation and should be modified as required.

- A. The system should be designed so that it can be operated and maintained by reactor operators and engineering technicians.
- B. All displays should give data in engineering units.
- C. The layout should be convenient for the operator.
- D. The system should be designed for ease of operation.
- E. The system should provide periodic logs.
- F. The operator should be able to demand an entire log at any time.
- G. The operator should be able to demand, at any time, the latest value of a point or calculation.
- H. The operator should be given the ability to observe past data and calculation results. It is preferable that this data be displayed in the form of trend curves; however, the operator should be able to obtain the value of any point on a curve.
- I. The operator should not be required to use more than two controls to select any of the above functions.
- J. The system should provide a simple but supervisor-controlled method to allow the operator to change alarm limits.

Section A-17 of Appendix A contains the specifications for the readout equipment for the proposed CP-5 installation. Section A-12.17 of Appendix A provides a description of the programs to be used with the "quick-look" oscilloscope. Sections A-12.14 and A-12.15 of Appendix A provides a list of the points to be logged by the proposed system.

5.20 PROGRAMING

Programing can simply be defined as telling the computer what to do. Most manufacturers of on-line, real-time, control computers have a library of programs (software) which can be used or easily modified for use on most process-control applications. However, each process has its own particular requirements which usually necessitates a special programing effort.

5.20.1 Standard "Software"

Programing routines which are normally available from the vendor's library are briefly described below. (26)

5.20.1.1 Fortran Compiler

A Fortran compiler is a program which provides a means for engineers and scientists to write a program for the computer easily and efficiently. Fortran programming is accomplished by using symbols which represent accepted mathematical notation.

5.20.1.2 Symbolic Assembler

A symbolic assembler translates symbolic programs into machine-language programs. This allows the programmer the full capability of the computer without requiring him to keep track of the bookkeeping details connected with machine-language programming.

5.20.1.3 Executive Program

An executive control program acts as a computer internal coordinator. Although each process has different requirements, most executive programs are sufficiently flexible so they can be adopted to meet specific application requirements.

5.20.1.4 Diagnostic Test Programs

Diagnostic test programs are used to test the system. These programs usually include memory test, arithmetic and control-unit test, drum-memory test, peripheral input/output test, analog input/output test, and contact input/output test.

5.20.1.5 Input/Output Programs

Input/output subroutines control the operation of standard input/output peripheral devices.

5.20.1.6 Floating- and Fixed-point Conversion

Standard routines for floating-point arithmetic and for conversion to and from fixed-point notation are used in calculations.

5.20.1.7 Arithmetical Evaluation Programs

Arithmetical evaluation programs are used for evaluating such functions as sine, cosine, tangent, exponential, square root, logarithm, inverse sign, and inverse tangent. Programs are generally available for evaluation in fixed- and floating-point arithmetic.

In addition, most manufacturers have many wired-in commands which aid in programming, and decrease for program execution time and storage-space requirements.

5.20.2 Special Programs

Each installation will require special programing to comply with the individual requirements of the particular process to be controlled. Either the vendor or buyer may provide programmers to program this material. Most vendors have programing schools which will train the buyer personnel in the art of programing. The vendor has a large backlog of programing experience; however, he does not have an intimate knowledge of the process and its restraints. Therefore, to take advantage of vendor programing experience and the process knowledge of the buyer, the first set of programs is often written on a cooperative basis. This allows the buyer's programmers an opportunity to obtain "on-the-job training" under experienced programmers.

5.21 UTILITY REQUIREMENTS

The utility requirements for several on-line computer systems have been reviewed. (23,26,28) Typical and extreme requirements are outlined in Table 9.

Table 9
OPERATING UTILITY REQUIREMENTS

Parameter	Minimum	Nominal	Maximum	Units
Electrical				
Power	3,000	6,000	10,000	Watts
Voltage	104.5	115	126.5	Volts
Frequency	57	60	63	Cycles per second
Ambient				
Temperature	50	72	120	Degrees Fahrenheit
Relative				
Humidity	10	40	90	Percent
Ventilation	850	1,700	2,850	SCFM
Cooling	170	350	570	BTU per minute

Most manufacturers claim that special ventilation or cooling is not necessary for their equipment, if the equipment is used in an area where the ambient temperature is maintained below 120°F. Below this ambient temperature, natural convection and forced cooling which is provided as part of the computer will efficiently cool the system. The ventilation and cooling requirements outlined above are based on the assumption that all power supplied to the computer system is converted to heat. The cooling

and ventilation requirements listed in Table 9 are those necessary to maintain the ambient temperature in the equipment room. No ventilation or cooling allowances have been provided for operating or maintenance personnel.

5.22 WEIGHTS AND DIMENSIONS OF MAJOR SYSTEM COMPONENTS

It is difficult to define a standard weight and size for the various systems available. Some manufacturers fabricate special containers for their equipment; however, some manufacturers have standardized on equipment mounted in 22-in. relay racks. The depths of these racks vary from 24 to 36 in., and the rack heights vary between 72 and 84 in. Although the equipment can be housed in single racks, it is common to bolt and interwire three adjacent racks. Thus an effective equipment rack width is 66 in. Six or seven standard relay racks are generally required for the "typical" system.

The weight of each 22-in.-width relay rack varies with the type of equipment included in the rack. Generally, the rack floor loading is approximately 200 lb/ft²; however, the extreme limits vary from 100 to 400 lb/ft².

The operating console is usually custom designed, consisting of a standard desk-shaped console, approximately 36 x 48 x 30 in. If the operational requirements do not necessitate such a large unit, a small typewriter stand having dimensions of 36 x 36 x 36 in. is used. The programmer's console is often wired into one of the 22-in. relay racks which makes up the main frame. The weight of the console varies with the amount and type of installed equipment.

5.23 SERVICE CONDITIONS

Most control computers currently being manufactured have been designed to operate in an industrial environment. Allowable temperature variations range from 50 to 120°F; however, better equipment operation is obtained if the ambient temperature is held at $72 \pm 5^\circ\text{F}$.

A second major environmental service condition is the possibility of high-voltage electrical shock. The inadvertent application of high voltage to a process-control computer is possible because of the many different electrical potentials present in an industrial environment. An additional factor is the presence of a large staff of personnel for normal maintenance and operation of any plant. In a research reactor, this problem is complicated by the vast number of experiments which have electrical requirements. Since these experiments are continuously updated more field labor is utilized than in the conventional industrial installation. Since the additional personnel are not completely familiar with the installation, the probability that inadvertent high voltage will be applied to the computer is increased.

A review of the possible sources of high potential shows that these sources can be classified by voltage. These voltages include 4160, 480, 240, 208, 120 V at a frequency of 60 cps and voltages of 250, 120, 48, 24, and 6 V DC. These systems can be single- or three-phase, grounded or ungrounded. The use of 4160 V AC and of 250 V DC is very limited and these potentials are usually well isolated; therefore, they are generally not considered a significant hazard. The 480-V, three-phase power system is usually a three- or four-wire system having a potential of 277 V to ground. A single fault on a three-wire system can raise the potential of two of the leads to a full 480 V to ground.

Since the power system which appears most often in a nuclear reactor installation is a 480-V, three-phase, 60-cps system, it is necessary that the specification of the computer control system include a section stating that the computer and its associated equipment be completely self-protecting against this potential. It is also necessary for the computer to be self-protecting against an unscheduled application of a 150-V DC potential.

5.24 COMPONENTS

In general, the computer manufacturers have selected components which are conservatively rated, adequately tested, highly reliable, and easily attainable. High-quality plug-in printed-circuit boards are normally used. The equipment normally uses solid-state components wherever possible. Vacuum tubes are only used in applications where they have a proven superiority over similar solid-state devices. Mechanical equipment is only used when absolutely necessary and then only if it has a sufficiently low failure rate. All relays should be capable of a minimum of 20-million operations at rated load.

5.25 FAIL-SAFE FEATURES

The system should include fail-safe equipment and programing features whenever possible. Examples of fail-safe features are: parity checking, watch dog timer, and controlled power-loss shutdown. These have been discussed in Sections 5.10 and 5.11.

5.26 MECHANICAL CONSTRUCTION

The mechanical construction of the computer equipment should be modular so that the system can be expanded as the applications become more complex or as the process itself is enlarged. It is imperative that this expansion be done in the field without the return of any or all of the equipment to the manufacturer's facility and that it be done without extensive downtime.

The equipment should form a self-supporting mechanical structure which can be transported, set up, and operated without special mechanical

considerations. If possible, the equipment should be designed for front access so that the rear of the equipment housing can be placed against the wall. This implies that all equipment should be mounted on the front of the back panel by drilling and tapping that panel. It also implies that there should be no wiring or components behind the back panel. The front access only is considered a convenience of installation and not a necessity.

For simplicity of maintenance, all equipment, components, and wiring should be installed at right angles to the horizontal and vertical. Some manufacturers currently mass produce computers which use point-to-point wiring (i.e., wires that run from one point directly to the other by the shortest, most direct route).

As a part of this study an attempt was made to evaluate soldered versus plug-in cards. Sufficient data on failure rate were not found. Apparently the use of one technique or component in favor of the second is mostly personal choice.

6. THE PROPOSED INITIAL INSTALLATION

After reviewing the state of the art of digital-data processing and computer-control equipment, it appears that the flexibility offered by the computer-controlled process system will allow:

- A. more complete and accurate operating data;
- B. better technical information about the process;
- C. automatic indication of malfunction in the process;
- D. better control, offered by the computer ability to change more than one variable at a time, taking into account interactions of the variables;
- E. more complete and accurate data analysis and complex calculations;
- F. improved plant safety;
- G. accurate process scheduling;
- H. rapid access to past operating data;
- I. increased thermal stability;
- J. advanced warning of possible equipment failures.

It was noted that this type of equipment has found application in certain process industries and that other industries are now doing basic design and development engineering studies. With a few notable exceptions (one in Canada and one in France), the nuclear industry has no digital reactor-control installations. The following sections discuss a proposed installation,

its purpose, the initial programs, the equipment cost, and the equipment specifications.

6.1 FACTORS AFFECTING THE CHOICE OF THE INITIAL ARGONNE REACTOR INSTALLATION

The following is a list of factors which affected the choice of the first Argonne reactor digital-control installation.

- A. The Argonne Research Reactor, CP-5, has successfully operated for a period in excess of 10 yr; thus, the reactor has time proven stability.
- B. Currently CP-5 is being renovated. Its analog instrumentation could be designed to be consistent with the shielding and analog-input signal characteristics required by a digital control system.
- C. The proposed Argonne Advance Research Reactor (AARR), a 240-MW machine with a maximum flux of 10^{16} n/cm²-sec, is being analyzed for safety. Information obtained from the CP-5 installation would allow knowledgeable application of digital-computer control techniques to AARR.
- D. The basic techniques of compatibility between the reactor and the computer can be best investigated and demonstrated with:
 - 1. a reactor that is known to be stable;
 - 2. operating and engineering personnel who are familiar with the characteristics and limitations of the reactor;
 - 3. a digital-computer control system having known characteristics and proven reliability and availability.

The development and verification of these techniques would provide the basic "know how" for the direct application of computer control systems to future large reactors while they are in the design stage.

6.2 EQUIPMENT REQUIREMENTS AND COST

A preliminary proposed specification for a CP-5 computer-driven data-acquisition and reactor control system is contained in Appendix A. One of the major items which has not been included in the specification is a detailed definition of the analog-signal characteristics for the variables. CP-5 is in the first phase of a renovation program which will include major instrument modifications. After the instrument design has been completed, detailed signal characteristics will be available.

A preliminary equipment, training, and initial programing cost estimate based on the specifications in Appendix A is contained in Appendix B. An estimate is also included on the rental cost of the equipment. The rental

cost is based on the assumption that the manufacturer will maintain the equipment on a one-man, 40-hr/wk basis. The estimate can be reduced by \$1000-2000/mo if the manufacturer will allow Argonne personnel to maintain the equipment.

6.3 THE INITIAL PROGRAMS

The initial computer programs for the proposed installation are outlined in Section 12 of Appendix A. These programs were selected initially to develop the system to:

- A. serve as an operator guide;
- B. provide a test installation for evaluating the success of the reactor-computer interface;
- C. determine the reliability and the availability of the computer in a nuclear reactor environment;
- D. allow a detailed study of the proposed operator-computer communications system.

Concurrent with these evaluations, programs would be developed which would allow the gathering and evaluation of engineering data to determine the dynamic characteristics of the reactor.

7. THE FUTURE

Future work should include an evaluation of the dynamic characteristics of the reactor and the construction of a mathematical model defining these characteristics. The next step will involve an investigation of advanced techniques for programing, such as linear, nonlinear, stochastic, integer, and dynamic programing, to determine the most appropriate methods for solving the problems of reactor control. The final phase consists of adding the necessary computer-output hardware to test and evaluate these programs.

7.1 ADVANCEMENT IN THE STATE OF THE ART

Advanced techniques of mathematical programing have gained wide recognition in recent years as effective tools for the solution of a broad class of complex problems. However, these techniques have found relatively little application in the design and operation of control systems. A major aim of the proposed project is the study, utilization, and evaluation of these techniques as applied to a control system for a nuclear reactor. Thus the project would advance the state of the art and reduce the complexity of the future application of this type of control system.

7.2 A DATA-GATHERING SERVICE FOR EXPERIMENTERS

The initial concept of the preliminary study for this project was limited to the utilization of the computer-driven data and control system for the reactor only, because of the limited man-power available. Recent investigation by other groups have demonstrated the basic compatibility between the needs of the experimenter and the capabilities of a large digital data-acquisition and processing system. Therefore, an evaluation study should be made of the requirements for a central facility for digital data gathering and processing for the experimenter. If such a system is warranted, the possibility of fulfilling both needs by utilizing a single computer-driven system should be investigated.

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APPENDIX A

Proposed Specifications for the CP-5 Research Reactor Computer-driven Digital-data-processing and Reactor-control System

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A-1 SCOPE

This specification covers the general design, performance, programing, and equipment requirements of a solid-state, stored-program, digital computer-driven Data Processing and Reactor-control System to be used with the Argonne National Laboratory CP-5 Research Reactor.* CP-5 is a 5-MW, enriched uranium, heavy water reactor having a maximum thermal neutron flux of 1×10^{14} n/cm²-sec. The prime purpose of CP-5 is to provide abundant radiation, primarily neutrons, for research. The fuel section consists of up to 17 fuel elements suspended in a 6-ft-diameter aluminum tank filled with heavy water. The fuel elements are clustered together forming a core 2 ft in diameter and 2 ft high. The heavy water (D₂O), serving as a moderator and a coolant, is normally pumped through the core at a rate of 1800 gpm. The warm heavy water is cooled by light water (H₂O) in a heat exchanger and the heat dissipated in a cooling tower.

It is not the intent of this specification to specify completely all details of operation, design, and construction; however, equipment shall in all respects conform to high standards of engineering, design, and workmanship, and shall be capable of performing all functions described at the specified rate of speed with rated reliability and accuracy. The system will be initially connected to 129 analog inputs from reactor transducer elements. The system shall provide logging and calculating capabilities. The system shall be expandable by the addition of analog and contact closure outputs so that the computer can be used to control the reactor partially or totally. The system shall be modular in construction for ease of future expansion, shall be programable for use in off-line calculations, and shall be constructed to operate in an industrial environment where electrical noise susceptibility, environmental tolerance, and continuous operation are of prime importance.

A-2 REQUIRED VENDOR EXPERIENCE

Proposals will be considered only if submitted by vendors who have built, installed, and placed in successful operation a minimum of four comparable on-line computer systems for process monitoring and control. Second- and third-generation systems will be permitted with fewer than four systems in the field; however, the vendor shall demonstrate operation of, at least, one such system. Under no conditions is the computer system or any part thereof to be the first unit of a particular model built by the vendor or by any of his outside sources of equipment.

The vendor shall provide assurances, to the satisfaction of Argonne National Laboratory, that he will remain in the on-line computer business for a minimum of 5 yr after the system outlined in this specification is

*This specification is based on the assumption that the equipment will be purchased rather than rented.

delivered. During this period it is expected that minor equipment additions and modifications will be required before the system assumes its final configuration; it is imperative that the vendor be available for consultation during this phase of the project.

A-3 APPLICABLE STANDARDS

Argonne National Laboratory Reactor Operations Division Standards

STD-1 (1964) Standard for the Preparation of Electrical, Electronic, and Instrumentation Drawings.

American Society of Mechanical Engineers

ASME N1.1 A Glossary of Terms in Nuclear Science and Technology (1957).

Institute of Radio Engineers

IRE 8. Standards on Electronic Computers (1956).

National Board of Fire Underwriters

NBFU 70. National Electric Code (1959).

In addition to the above, all other applicable standards and codes including the latest revisions shall be used.

A-4 VENDOR DRAWINGS, MANUALS, DELIVERY SCHEDULE, REPORTS, MEETINGS, AND SITE VISITS

Argonne National Laboratory (henceforth called Argonne) will specify technical and business project representatives and alternates in its purchase order. The vendor shall specify the name of his technical and business project representative(s) and alternate(s) as a part of the technical proposal. All technical communication between Argonne and the vendor which does not affect the scope or cost of the project shall be carried out exclusively between the two technical project representatives. All information, drawings, procedures, or other matters which require Argonne approval shall be submitted in six (6) copies. The specific material which requires approval will be defined after the equipment vendor has been chosen. Within two (2) weeks after receipt of such material, Argonne shall return one copy signed and dated by the Argonne technical project representative. This copy will be identified as "Approved," "Approved Except as Noted," or "Returned for Correction." Material identified as "Approved" or as "Approved Except as Noted" shall authorize the vendor to proceed with design and/or manufacture in accordance with the material submitted and changed as noted. Material identified as "Return for Correction" shall be resubmitted for approval after the vendor has made the indicated changes. Any work completed prior to these approvals shall be

at the vendor's risk. Any changes in the designs which are necessary to make the system conform to the original provisions of this specification shall be made without additional cost to Argonne.

The vendor shall furnish the following information for the initial and final system as indicated below. Corrected "as built" manuals and drawings shall be supplied within one week after the equipment is shipped. All material is to be supplied in eight copies. Reproducible transparencies of all drawings shall be supplied.

A-4.1 Drawings

The following certified drawings are to be supplied not later than eight (8) weeks after the date of the order.

A-4.1.1 Complete Block Diagram

A-4.1.2 Completely dimensioned assembly drawings showing plan, elevation, and section views of each mechanical assembly of the entire initial, as well as the final, Data Processing System.

A-4.1.3 Complete interconnection diagrams showing all cable and terminations in the control systems, main and input/output frames, all consoles, and all peripheral devices.

A-4.1.4 Schematic diagrams of all units and subunits.

A-4.2 Technical Manuals

Preliminary operation, programing, and maintenance manuals are to be provided within eight (8) weeks of the date of the purchase order to enable Argonne personnel to operate, program, and maintain the equipment without assistance beyond the usual customer training. The final manuals are to be provided four (4) weeks prior to the date of shipment of equipment. The manuals shall include, but not be limited to the following:

A-4.2.1 Complete internal wiring diagram with wire designations.

A-4.2.2 Programing, Operating, and Maintenance Instruction Manuals for all equipment, in sufficient detail that Argonne can program, operate, and maintain this system. The manuals shall include, but not be limited to manufacturer name, model number, range, accessories, speed, accuracy, power requirements, sequence of operation, schematic and wiring diagrams, and timing diagrams. The manuals shall also include a complete description of the logic used and procedures for running diagnostic tests.

A-4.2.3 A complete list of spare parts giving all necessary information to order any part. This list shall include, but not be limited to, the part's name, model, type or catalog number, price, and manufacturer.

A-4.3 Delivery Schedule

The vendor shall provide a detailed project completion schedule as a part of the technical proposal. The schedule shall include items such as:

A-4.3.1 Release of Specifications on Purchased Items

A-4.3.2 Start of Fabrication

A-4.3.3 Training

A-4.3.4 Factory Test

A-4.3.5 Finish of Fabrication

A-4.3.6 Factory Acceptance Test

A-4.3.7 Equipment Delivery

A-4.3.8 Installation

A-4.3.9 Field Acceptance Test

A-4.4 Reports

The vendor shall provide the Argonne project representative with two copies of a written monthly report outlining the progress to date and any requested changes in schedule. The report shall be due at the Argonne National Laboratory on the first working day of each month.

A-4.5 Meetings

Technical meetings shall be held at such times and locations as determined by mutual agreement of the vendor and the Argonne business or technical representatives. The vendor shall prepare written summaries of these meetings covering matters discussed and agreements reached. Four (4) copies of all such summaries shall be submitted within one week after the meeting to the Argonne National Laboratory for concurrence.

A-4.6 Site Visit

It shall be the responsibility of the vendor to be completely aware of the physical and electrical environment, process-signal characteristics, and all other factors which will affect the vendor's proposal.

Arrangement may be made for a site visit by the vendor. Requests for such a visit should be forwarded to the attention of Argonne's Purchasing Department at least two weeks prior to the desired visit dates. The request should include desirable visit dates and at least one set of alternative dates, a list of topics to be discussed, a list of site locations to be visited, and the names of the persons who will be visiting.

A-5 INSPECTION AND TRAINING

A-5.1 Inspection

Representatives of the Argonne National Laboratory and/or their agents shall be permitted, at any reasonable time, to visit the manufacturer's facility to ascertain whether or not the material and processes used in the manufacture of the equipment conform to the specification and to good engineering practice, and whether or not the work is progressing at a rate sufficient to meet the completion scheduled.

A-5.2 Training

The vendor shall, as a part of his bid, include the cost of training the following Argonne personnel. The scope of the training shall be determined by the vendor and shall be outlined in the technical proposal. The starting dates for all training shall be determined by mutual agreement of the vendor and the Argonne technical representatives.

A-5.2.1 A minimum of two (2) maintenance personnel having experience with electronic circuits, but not necessarily with computer design, maintenance, or programing, are to be trained. The training is to include operation, basic programing, and maintenance of the machine. As a result of this training these personnel will be responsible for training technicians to maintain the machine. This course shall include a minimum of 200 hr per man of classroom lectures and field work. It is expected that most of the field work will take place during the debugging and testing period of the computer to be supplied to Argonne.

A-5.2.2 A minimum of two (2) and a maximum of four (4) personnel are to be trained in programing. The men selected for this assignment will be engineers, but may have had no prior computer training. These men are expected to form the nucleus of the programing team. One (1) man from this group will be assigned to work with the vendor in the preparation of the special programs required.

A-5.2.3 A minimum of six (6) and a maximum of thirty (30) personnel shall be trained in operation. The training classes are to be held at the Argonne National Laboratory, Argonne, Illinois.

A-6 FACTORY ACCEPTANCE TESTS

The system shall be completely assembled (in final packaging) and operationally tested for program accuracy, system accuracy and stability, and environment for a period of time sufficient to demonstrate proper operation prior to shipment. The vendor shall advise the Argonne project technical representative at least fourteen (14) days prior to the start of these tests so that arrangements can be made to witness the tests. Six (6) weeks prior to the start of these tests, the vendor shall submit in writing to the Argonne's technical representative a detailed description of the test procedures and results for review and approval. The vendor shall furnish certified reports to the effect that equipment and materials have been tested in accordance with this specification and found satisfactory. The Argonne technical representative may waive any of the factory tests. Such a waiver does not relieve the vendor of his full responsibility to meet all requirements of this specification. Shipment shall not be made without written approval of the Argonne technical representative indicating the satisfactory completion of these tests. The vendor shall supply all equipment and personnel required to perform these tests. The tests shall include, but not be limited to the following:

A-6.1 Application of 500-V rms AC across analog and binary input and output devices to test the adequacy of the protection against electrical damage.

A-6.2 Application of a 500-V DC megger test voltage to all analog and binary inputs and outputs to test adequacy of electrical insulation. All insulation resistance readings shall exceed 2.5 megohms to ground. The full megger voltage shall be applied between the two points under test until the megger pointer holds at a steady deflection for ten (10) seconds.

A-6.3 The data system shall be tested for freedom from electrical noise and other random errors by operating the high- and low-speed multiplexers at normal scanning speed and ambient temperature continuously for a period of 200 hr with a known level of analog input signal. These errors shall not exceed specified system accuracy.

A-6.4 The system shall be tested for freedom from drift and other errors by operating at temperatures of 60°F and 110°F, for four (4) hours at each temperature. These errors shall not exceed specified system accuracy.

A-6.5 The system shall be tested for error-free operation, within specified accuracy, over a period of 12 hr, with an exercise program which utilizes all inputs, all outputs, all output devices, all commands, all logic, and all memory. This exercise program shall be provided by the vendor and shall become the property of Argonne.

A-6.6 The system shall be tested to demonstrate ability to provide analog-to-digital conversion within specified accuracy by reading input quantities every 2% of span at the specified scanning rates.

A-6.7 The system shall be tested to demonstrate its ability to reject a 60-cps AC common mode signal of 150 V, superimposed upon a typical DC input signal, while maintaining specified accuracy.

A-6.8 The system shall be tested to demonstrate its ability to reject a 60-cps AC series mode signal of 10-mV peak, superimposed upon a DC signal of 10 mV, while maintaining specified accuracy.

A-7 SHIPMENT

Shipment of the Data Processing System shall be made by a special electronic-equipment moving van from the point of manufacture to the installation site without any intermediate truck transfers.

Equipment shall be adequately protected from the effects of weather, shock, and vibration; all openings shall be adequately protected to prevent corrosion or entrance of foreign matter during shipment. All items shall be adequately boxed, crated, and otherwise protected to prevent loss, damage, or pilferage in transit. The equipment shall be suitably packaged for moving by rolling, skidding, fork-lift truck, and crane.

All equipment crates and pieces in them shall be clearly identified by the vendor in accordance with his drawings in order to facilitate component inventory and assembly.

The input/output frame shall be shipped one month prior to any other equipment.

A-8 INSTALLATION SUPERVISION

The vendor shall furnish a service engineer to perform the following functions.

A-8.1 Check the system installation, including freedom of all inputs from dangerously high extraneous voltages, and assume for the vendor the responsibility for starting the system.

A-8.2 Supervise all on-site tests considered necessary by Argonne to demonstrate the ability of the system to pass or duplicate the factory tests specified under Paragraph A-6 to A-6.8 inclusive.

A-8.3 Supervise starting of the system on its six months of service demonstration as specified under Section A-11. This demonstration is expected to

begin within two months of completion of on-site tests, specified under Section A-8.2, but in no case shall it begin later than 12 months after completion of the on-site tests. Eight percent of the total cost of the system shall be withheld until the continuity of service demonstration is successfully completed.

A-9 DIMENSIONAL AND WEIGHT LIMITATIONS

Maximum dimensions of any piece shall not exceed 34 in. long, 41 in. wide, and 80 in. high, so that it can be moved through existing door openings. The computer shall be suitable for placing upon a floor having a maximum local capacity of 150 lb/ft².

A-10 SERVICE CONDITIONS

A-10.1 The system will be situated at, or adjacent to, the CP-5 Research Reactor, Argonne National Laboratory, Argonne, Illinois.

A-10.2 The main system components including the input/output rack will be installed in the air-conditioned Reactor Auxiliary Equipment Room. The operator's console will be located in the reactor control room. The programmer's console will be located outside the reactor shell in an emergency operations room.

A-10.3 The system will be operated in a plant where it is exposed to possible environmental shock, defined as: unscheduled application of high voltage from external sources to the data system inputs or outputs. These unscheduled voltages may be as high as 500 V rms. The system shall be completely self-protecting up to and including 500 V AC or 150 V DC. Above 500 V AC or 150 V DC, the first internal device on which the voltages are impressed may be considered expendable. The vendor shall be held responsible for any failure of system internals beyond the above-mentioned expendable first internal device. Since voltage differences may exist between any grounded input device and the system frame, the system-measuring circuits shall be the "full floating type" with respect to ground.

A-10.3.1 Woven-braid type of shield will be provided by Argonne as required for each analog input. This shield will be grounded at the end remote from the computer input frame.

A-10.3.2 Any shunts, voltage-dividing networks, or other signal-conditioning equipment required by the system shall be furnished by the vendor as a part of this system.

A-10.3.3 These shunts and potential-dividing networks shall be of material with a zero temperature coefficient of resistance and shall be accurate to at least $\pm 0.025\%$.

A-10.3.4 The system shall be furnished with isolating and/or expendable input and output devices, so that all components of the system between these input and output devices are protected against damage from environmental electrical shock. Wherever appropriate, simple protection such as instrument fuses with emergency shunting devices may be used on analog inputs. Where relays are used for isolation of digital outputs, they shall be of the mercury-wetted type, hermetically sealed type, or approved equal. All power supplies for the operation of the coils of all isolating relays shall be supplied by the vendor.

The vendor shall be responsible during the entire pre-acceptance period for the cost of replacement parts, including both material and labor, of any components damaged because of the failure of his equipment or his service engineer to comply with conditions of this specification.

A-11 DEMONSTRATION OF CONTINUITY OF SERVICE

A-11.1 Final acceptance of the entire system shall require demonstration of continuity of service and reliability. The system shall provide 99% availability on a 24-hr/day basis over 180 days. The only devices not included under the above requirements for continuity of service are the input/output mechanical devices. All outage time resulting from normal in-service failure of components, inability to meet specified override of voltage dips or interruptions without the loss of memory, poor execution of program due to inherent design, etc., shall be charged against the continuity of service. Outage time resulting from Argonne-initiated program changes, loss of 60-cycle AC supply power, or improper operation on the part of Argonne's operating personnel shall not be charged against continuity of service. All other machine downtime, including preventive maintenance, shall be charged against the continuity of service.

A-11.2 In order to demonstrate a minimum "mean time to failure" of 1000 hr, the number of failures in the 180-day period (4320 hr) shall be five or less. A failure shall be defined as any loss of information or function in the central processor or input/output system. A malfunction of the paper-tape reader/punch or any typewriter shall not be considered a failure; however, a malfunction of the logic equipment associated with the paper-tape reader/punch or any typewriter shall be considered a failure.

A-11.3 In the event the machine fails to meet the requirements for continuity of service and reliability, the equipment shall be repaired and/or replaced by the vendor at his expense under a time table established by the vendor and the Argonne business and technical representatives. All repairs required shall be in accordance with this specification. After the equipment has been repaired, the equipment shall be retested as per Sections 6.0 to 6.8 of this specification. A new demonstration of continuity of service shall be scheduled at a time agreeable to both the vendor and Argonne technical and business representatives.

A-12 FUNCTIONAL AND ON-LINE CALCULATION REQUIREMENTS

The system shall be capable of performing, digitally, the following on-line computations and mathematical manipulations to 12 significant figures, even though most will require only six significant figures. Items marked future are not to be programed by the vendor as a part of the initial purchase order; however, memory storage and execution times are to be included when determining initial computer memory and execution requirements (see Section A-15.4).

A-12.1 Linearize Thermocouples Output

The types of thermocouples are to be determined in the future.

A-12.2 Extract Square Root of Each Flow Signal

A-12.3 Reactor Power Generation

Once each second the reactor thermal power shall be calculated by determining the quantity of the heat extracted by the main and shield-cooling heat exchangers.

A-12.3.1 Power removed by the main heat exchanger is given by

$$P_M = K_1 C_{p1} D_1 F_1 \Delta T_1,$$

where

P_M = Power (kW);

K_1 = A constant;

C_{p1} = Average specific heat of primary coolant at the reactor inlet temperature;

D_1 = Specific gravity of the primary coolant at the reactor inlet temperature;

F_1 = Flow of primary coolant;

ΔT_1 = Differential temperature across the reactor.

A-12.3.2 The power removed by the shield-cooling heat exchanger is given by

$$P_S = K_2 C_{p2} D_2 F_2 \Delta T_2,$$

where

P_S = Power (kW);

K_2 = A constant;

C_{p2} = Average specific heat of shield coolant at the inlet temperature;

D_2 = Specific gravity of the shield coolant at inlet temperature;

F_2 = Total flow of shield coolant;

ΔT_2 = Differential temperature across the shield.

A-12.3.3 The total power is thus

$$P_T = P_M + P_S$$

A-12.4 Integrated Reactor Power

The integrated reactor power shall be updated once each second:

$$E_A = E_B + \frac{P_T}{3600},$$

where

E_B = Energy prior to updating (in kWhr);

E_A = Energy after updating (in kWhr);

P_T = Reactor power (in kW) (see Section A-12.3).

A-12.5 Generation of Power in Fuel Rod

Once each second the thermal power of each fuel rod shall be calculated by the addition of the heat added to the main D_2O flow in the rod. In this calculation it is assumed that the heat transferred through the wall of the fuel element to the bulk D_2O in the reactor is constant. The number of fuel rods can vary up to a maximum of seventeen; therefore, it is necessary to allocate sufficient computer time and word-storage space for seventeen calculations.

The power removed by the rod's D_2O flow

$$P_r = KC_p DF \Delta T,$$

where

P_r = Power (in kW);

K = A constant;

C_p = Average specific heat of the primary coolant at the reactor inlet temperature;

D = Specific gravity of the primary coolant at the reactor inlet temperature;

F = Fuel rod flow;

ΔT = Differential temperature in fuel rod.

A-12.6 Integrated Fuel-rod Power

The integrated fuel-rod power for each rod is to be updated once each second:

$$E_{Cn} = E_{Dn} + \frac{P_{Rn}}{3600},$$

where

E_{Dn} = Energy extracted by the nth fuel rod prior to updating (in kW);

E_{Cn} = Energy extracted by the nth fuel rod after updating (in kW);

P_{Rn} = Power in nth rod (in kW).

A-12.7 Computer Flow of Stack Gas (Future)

The flow of air from the stack is given by

$$Q_a = KF \frac{T_{\text{design}}}{T_{\text{actual}}},$$

where

Q_a = Flow of Air (in scfm);

K = A constant;

T_{design} = Design temperature (in $^{\circ}\text{F} + 460$);

T_{actual} = Actual temperature (in $^{\circ}\text{F} + 460$);

F = Measured flow at T_{actual} .

A-12.8 Compute the Rate of Radioactive Gas Release Once Each Minute for Each of the Following (Future)

A-12.8.1 Beta-particulate Activity

A-12.8.2 Alpha-particulate Activity

A-12.8.3 Gross Gaseous Activity

A-12.8.4 Fission Gas Daughter Activity

A-12.8.5 Net Gaseous Activity

To calculate the rate of release of radioactive gas, the following expression is used:

$$Q_R = KAQ_a,$$

where

Q_R = release rate (in Ci/unit time);

K = a constant relating the counting geometry efficiency and volume of the gas-counting apparatus;

A = specific activity of the gas being discharged (in Ci/unit volume);

Q_a = total gas flow rate (in unit volume/unit time).

A-12.9 Integrated Radioactive Gas Release (Future)

Once each second the integrated radioactive gas discharge shall be updated.

A-12.10 Compute Poison Inventory

The important two fission-product poisons are Xe^{135} and Sm^{149} . The computer must calculate the concentrations of these poisons at any given operating instant and forecast future concentrations under shutdown conditions.

The Xe^{135} concentration during operation is given by a set of differential equations:

$$\frac{dI(t)}{dt} = -\lambda_I I(t) - \sigma_I \phi I(t) + \nu_I \Sigma_f \phi; \quad (1)$$

$$\frac{dX(t)}{dt} = \lambda_I I(t) + \nu_X \Sigma_f \phi - \lambda_X X(t) - \sigma_X \phi X(t), \quad (2)$$

where

I = the concentration of I^{135} ;

X = the concentration of Xe^{135} ;

λ_I = the I^{135} decay constant;

λ_X = the Xe^{135} decay constant;

ν_I = the direct fission yield of I^{135} ;

ν_X = the direct fission yield of Xe^{135} ;

σ_X = the thermal-neutron capture cross section for Xe^{135} ;

σ_I = the thermal-neutron capture cross section for I^{135} ;

ϕ = the average neutron flux;

Σ_f = the macroscopic fission cross section for U^{235} .

The quantities λ_I , λ_X , ν_I , ν_X , σ_X , σ_I , and Σ_f are constants; ϕ is supplied by the reactor instrumentation as an instantaneous measure of the average power level; and X must be computed.

The Sm^{149} concentration, during operation, is given by a set of differential equations:

$$\frac{dP(t)}{dt} = \nu_P \Sigma_f \phi - \lambda_P P(t) - \sigma_P \phi P(t); \quad (3)$$

$$\frac{dS(t)}{dt} = \lambda_P P(t) + \nu_S \Sigma_f \phi - \sigma_S \phi S(t); \quad (4)$$

where

P = the concentration of Pm^{149} ;

S = the concentration of Sm^{149} ;

λ_P = the Pm^{149} decay constant;

λ_S = the Sm^{149} decay constant;

ν_P = the direct fission yield of Pm^{149} ;

ν_S = the direct fission yield of Sm^{149} ;

σ_S = thermal-neutron capture cross section for Sm^{149} ;

σ_P = thermal-neutron capture cross section for Pm^{149} .

As an illustration of the calculation requirements, an outline of a typical core history and necessary calculations is given below.

A-12.10.1 Reactor starts operation at some value of ϕ_0 with a new core.

A-12.10.1.1 Compute X and S for $\phi = \phi_0$, meeting the conditions that, at $t = 0$, we have $X = 0$, and $S = 0$, by solving equations (1), (2), (3), and (4).

A-12.10.1.2 After some time $t = t_1$, solve equations (1) through (4) with the hypothetical conditions $\phi = 0$, $X(\tau_1 = 0) = X(t_1)$, $S(\tau_1 = C) = S(t_1)$ where τ_0 is the time since $\phi \rightarrow 0$ to give $X(\tau_0)$ and $S(\tau_0)$.

A-12.10.1.3 Infer from the rod position the value of P_1 , and calculate and display every 5 min the first time τ_1 at which xenon poisoning can no longer be overridden by solving the following equation:*

$$P_1 - \frac{[X(\tau_1) \sigma_X + S(\tau_1) \sigma_S]}{\Sigma_U \beta} = 0,$$

where

P_1 = rod reactivity (in \$);

σ_X = microscopic cross section of X;

σ_S = microscopic cross section of S;

Σ_U = macroscopic cross section of uranium;

β = fraction of delayed neutrons.

A-12.10.2 Reactor shuts down at time t_2 after operating at a flux ϕ_0 .

A-12.10.2.1 Solve the set of equations with the real conditions $\phi = 0$, $X(\tau = 0) = X(t_2)$, $S(\tau = 0) = S(t_2)$, where T is the time since the flux really went to 0, to give $X(\tau)$ and $S(\tau)$.

A-12.10.2.2 By means of the last value of τ_1 (from A-12.10.1.2), calculate and display $\tau_1 - T$.

A-12.10.3 Reactor starts up again to a flux ϕ_0 after being shutdown a time T which may be greater than τ_1 .

A-12.10.3.1 Solve the set of equations for $\phi = \phi_0$ with conditions at $t' = 0$, $X = X(T)$, and $S = S(T)$, and compute $X(t')$ and $S(t')$.

A-12.10.3.2 Same as A-12.10.1.2, but with $X(t'_1)$ and $S(t'_1)$ from A-12.10.3.1.

A-12.10.3.3 Same as A-12.10.1.3, but with results of A-12.10.3.2.

A-12.10.4 Reactor shuts down again.

A-12.10.4.1 Same as A-12.10.2.1, but with $X(t'_2)$ and $S(t'_2)$ from A-12.10.3.1.

A-12.10.4.2 Same as A-12.10.2.2, but with τ'_1 from A-12.10.3.3.

*This equation has two solutions: τ_1 and $\tau_2 > \tau_1$.

A-12.10.5 Reactor starts up again to a flux $\phi_1 = \phi_0$ after being shutdown a time T' .

A-12.10.5.1 Solve set of equations for $X(T'')$ and $S(T'')$ for $\phi = \phi_1$ with conditions at $t'' = 0$, $X = X(T')$, and $S = S(T')$.

A-12.10.5.2 Same as A-12.10.1.2, but with $X(T'')$ and $S(T'')$ from A-12.10.5.1.

A-12.10.5.3 Same as A-12.10.1.3, but with results of A-12.10.5.2.

A-12.11 Compute Time to Poison Release

On demand, τ_2 (the time to poison release) shall be calculated. This calculation requires the solution of the equation

$$P_1 - \frac{[X(\tau_2) \sigma_X + S(\tau_2) \sigma_S]}{\Sigma_U \beta} = 0.$$

The variables are defined in Section A-12.10.1.3.

A-12.12 Shim Rod Startup Position

On demand, the positions of the shim rods required to override negative reactivity shall be calculated.

A-12.13 Shim Rod Worth

On demand, the worth in dollars of a shim rod shall be determined. The rod will be positioned and dropped manually. During the rod drop, current data from four special ion chambers shall be monitored and stored.

If any ion chamber current becomes larger than 90% of full scale or less than 10% of full scale, the computer shall provide an output signal to be used to change the range of the ion-chamber amplifier. Since four chambers and amplifiers are used, eight signals are required. After the rod has been dropped, the calculations outlined below shall be carried out by the computer.

A-12.13.1

$$\frac{N(t)}{N(u)} = \frac{I_j(t) - I_j(900)}{I_j(o) - I_j(900)}; \quad j = 1, 2, 3, 4,$$

where

$I_j(t)$ = the current from the j^{th} ion chamber at the time t ;

$I_j(o)$ = the current from the j^{th} ion chamber at the instant the rod is dropped;

$I_j(900)$ = the current from the j^{th} ion chamber 900 sec after the rod is dropped.

Calculation shall be made for $t = 2, 4, 6, 8, 10, 15, 20, 40, 60, 80, 100, 120$ sec.

A-12.13.2 The computer shall store a table constructed from 40 graphs. A typical graph is shown in Fig. A-1. The computer shall make use of the table to obtain the values of k , the negative reactivity in dollar units.

Fig. A-1. Flux Ratio N/N_0 vs Negative Reactivity Step k dollars at Time t sec after Step

A-12.13.3 Extaneous values of k shall be rejected by the application of Chauvenet's criterion to the data.

Chauvenet's Criterion

For each ion chamber compute the standard deviation as follows:

$$\sigma^2 = \frac{\sum_{i=1}^n (k_j - \bar{k})^2}{n - 1},$$

where

n = the number of data points for the chamber;

$\bar{k}$ = average of the n values of k for each chamber.

Find $\tilde{x}$ from the following:

<u>n</u>	<u>$\tilde{x}$</u>
5	1.6458 σ
6	1.7335 σ
7	1.8077 σ
8	1.8616 σ
9	1.9156 σ
10	1.9628 σ
11	2.0033 σ
12	2.0370 σ

Compare each $(k - \bar{k})$ with $\tilde{x}$. If $|(k - \bar{k})| > \tilde{x}$, reject the data point.

Reapply Chauvenet's Criterion for the unrejected data until no points are rejected or until n is reduced to 4.

A-12.13.4 Find the average of the unrejected data points for each chamber:

$$\bar{k} = \frac{\sum_{i=1}^h k_i}{h}$$

where

$\bar{k}$ = the average of the unrejected data points for each channel
(Note: $j = 1, 2, 3$, and 4);

k' = the unrejected data points for each chamber at times 2, 4, 6, 8, 10, 15, 20, 40, 60, 80, 100, and 120 sec;

h = number of unrejected data points.

A-12.13.5 Calculate the probable error PE for each channel as follows:

Calculate

$$\frac{\sigma^2}{k} = \frac{1}{h(h-1)} \sum_{i=1}^h (k_i - \bar{k})^2,$$

where σ/k is the standard deviation of the mean value, and substitute in the expression

$$PE = 0.647 \sigma/k.$$

Report the values from each channel, or

$$P = \bar{k} \pm 0.647 \sigma/k.$$

A-12.13.6 The data indicated in Fig. A-2 is to be typed out at the end of each calculation.

Run # _____ Date _____ Time _____ Channel _____
 Shim _____ Rod _____
 Dropped _____ Position #1 _____ #2 _____ #3 _____ #4 _____ RP _____
 Buildup Time _____ D₂O Temperature _____
 Poison _____

TIME	DEF.	SCALE	DEF'	DEF'-B	N/NO	k	k - $\bar{k}$	(k - $\bar{k}$) ²
0								
2								
4								
6								
8								
10								
15								
20								
40								
60								
80								
100								
120								
900								

j	1	2	3	4
h				
σ^2				
σ				
X				
σ_k^2				
$\sigma_{\bar{k}}$				
P				

Fig. A-2
 CP-5 Shim-safety Rod
 Calibration

A-12.14 30-minute Log

Each 30 min the computer shall make the calculations required to type out the values in engineering units of selected input variables and calculated parameters. The following is a partial list of the parameters to be included in the log:

Time - Date		Reactor Helium Supply Tank Pressure	psi
Reactor on Auto or Manual		Reflector Helium Supply Tank Pressure	psi
D ₂ O Storage Tank Level	in.	Power Galvanometer	mW
Shield Cooling H ₂ O In	°C	Power Demand	%
Shield Cooling H ₂ O Out	°C	Regulating Rod	cm
Shield Cooling Flow	gpm	Shim Safety Rod #1	degrees
Main Cooling H ₂ O In	°C	Shim Safety Rod #2	degrees
Main Cooling H ₂ O Out	°C	Shim Safety Rod #3	degrees
Main Cooling H ₂ O Flow	gpm	Shim Safety Rod #4	degrees
D ₂ O Flow	gpm	Catalyst Temperature In	°C
D ₂ O Differential Temperature	°C	Catalyst Temperature Out	°C
D ₂ O Reactor Inlet Temperature	°C	Fuel Rod #1 D ₂ O Flow	gpm
Thermal Power	kW	Fuel Rod #2 D ₂ O Flow	gpm
Reservoir Tank Flowmeter	gpm	Fuel Rod #3 D ₂ O Flow	gpm
Reservoir Tank Overflow	gpm	Fuel Rod #4 D ₂ O Flow	gpm
D ₂ O pD	pD	Fuel Rod #5 D ₂ O Flow	gpm
Conductivity In	μmhos	Fuel Rod #6 D ₂ O Flow	gpm
Conductivity Out	μmhos	Fuel Rod #7 D ₂ O Flow	gpm
Reactor Gasometer Level	cu ft	Fuel Rod #8 D ₂ O Flow	gpm
Graphite Helium Pressure	in.	Fuel Rod #9 D ₂ O Flow	gpm
D ₂ O Heat Exchanger Pressure In	psi	Fuel Rod #10 D ₂ O Flow	gpm
D ₂ O Heat Exchanger Pressure Out	psi	Fuel Rod #11 D ₂ O Flow	gpm
H ₂ O Heat Exchanger Pressure In	psi	Fuel Rod #12 D ₂ O Flow	gpm
H ₂ O Heat Exchanger Pressure Out	psi	Fuel Rod #13 D ₂ O Flow	gpm
D ₂ O Overflow Return	gpm	Fuel Rod #14 D ₂ O Flow	gpm
Building Air Supply	psi	Fuel Rod #15 D ₂ O Flow	gpm
Dump-valve Air Pressure	psi	Fuel Rod #16 D ₂ O Flow	gpm
Catalyst Helium Pressure	psi	Fuel Rod #17 D ₂ O Flow	gpm
Reactor Helium Pressure	in.	Fuel Rod #1 Differential Temperature	°C
Instrument Air Pressure	psi	Fuel Rod #2 Differential Temperature	°C
Helium Circulating Flowmeter	cfm	Fuel Rod #3 Differential Temperature	°C
Shield Cooling H ₂ O Flow	gpm	Fuel Rod #4 Differential Temperature	°C
Shield Cooling Water Level	in.	Fuel Rod #5 Differential Temperature	°C
Cleanup-system Flowmeter	gpm	Fuel Rod #6 Differential Temperature	°C
pD Flowmeter	gpm	Fuel Rod #7 Differential Temperature	°C
pD Transmitter Reading	gpm	Fuel Rod #8 Differential Temperature	°C
D ₂ O to H ₂ O Leak Monitor Flowmeter	gpm	Fuel Rod #9 Differential Temperature	°C
D ₂ O Throttle-valve Position	% Open	Fuel Rod #10 Differential Temperature	°C
Spray Bypass Position	% Open	Fuel Rod #11 Differential Temperature	°C
Disaster Monitor	R/hr	Fuel Rod #12 Differential Temperature	°C
Workroom Monitor	mR/hr	Fuel Rod #13 Differential Temperature	°C
Pumproom Monitor	mR/hr	Fuel Rod #14 Differential Temperature	°C
Basement Monitor	mR/hr	Fuel Rod #15 Differential Temperature	°C
Rod Storage Area Monitor	mR/hr	Fuel Rod #16 Differential Temperature	°C
Trip Chamber #1 Current	μA	Fuel Rod #17 Differential Temperature	°C
Trip Chamber #2 Current	μA	D ₂ O Plenum Pressure	psi
Trip Chamber #3 Current	μA	Reflector Gasometer Level	cu ft
Trip Chamber #4 Current	μA	D ₂ O Reactor Level	in.
Vapor-sphere Level	% Full		

A-12.15 Hourly Log

Each hour the computer shall make the calculations required to type out the values in engineering units of all variables and calculated parameters.

A-12.16 Demand Log

The computer shall type out upon operator demand either of the above logs.

A-12.17 Display of "Quick Look Scope" Data

The computer shall make the calculations required to allow the reactor operator to use the "quick look scope" to observe trend data and to allow the operator a simplified technique for obtaining the value of individual data points.

A-12.17.1 Trend Data

The "quick look scope" shall be used to display, at the request of the operator, "trend" curves. Each scope display shall consist of at least the last 128 time-averaged data points for each of four variables. The time-averaged periods and the overall-curve lapsed times listed below shall be selectable by the operator:

Approximate Time of Average Period*	Lapsed Time for the Curve
0.937 sec	2 min
7.0 sec	15 min
2.78 min	8 hr
1.31 hr	7 days
11.2 hr	60 days
5 days, 15 hr	730 days

*(0.937 sec x 128 points $\approx$ 2 min)

The particular four variables displayed and the time-averaged period shall be selected by pushbutton by the operator. The "write" speed of the scope shall exceed the persistence of vision.

The "quick look scope" display-system equipment shall include a "light pen." It will be used by the operator in conjunction with the scope and a pushbutton for instruction to the computer to type out information on a particular point displayed. The sequence of operation shall be as follows:

- A. The operator will point the "light pen" at a particular point of light on the "quick look scope."
- B. The operator will press a pushbutton.
- C. The typewriter shall type out the name of the variable, the time represented by the point, and the value represented by the point in engineering units to four significant figures.

A-12.17.2 Typing Individual Data Points

The scope shall be equipped with a removable plastic overlay which will be used in conjunction with the "light pen" and a pushbutton as an operator data-demand system. The overlay shall consist of a reactor flow sheet showing the relative position of various input variables. The location of each input shall be numbered and color coded to define the exact variable as well as its particular class. Unused areas on the overlay shall be marked with code numbers to designate the calculated parameters.

The sequence of operation shall be as follows:

- A. The operator will point the "light pen" at a particular variable or calculation location on the overlay.
- B. The operator will press a pushbutton.
- C. The typewriter shall type out in engineering units, to four significant figures, the latest value of the particular variable or calculation.

In the event the entire flow sheet cannot be shown on a single overlay, it shall be divided into several sections. Each overlay will require a separate pushbutton.

A-12.18 High-speed Emergency Scan

In the event that the reactor is manually or automatically SCRAMMED, or the period becomes less than 5 sec, or by pushbutton request from the operator, an automatic high-speed scan shall be initiated, made at a rate in excess of 5000 points per second. However, the number of data points shall be appreciably less than a normal scan. The computer shall have sufficient storage space to allow the scan to recycle continuously for a minimum of 5 min without affecting any of the other stored data or calculations.

The data gathered during the emergency scan shall be stored in its raw form, and then converted to engineering units and typed out at a later date. A pushbutton shall be provided to initiate the print-out.

If the high-speed scan is initiated by a manual or automatic SCRAM, or at the request of the operator, the computer shall return to its normal program at the end of 5 min. If, however, the scan is initiated by a short period, the computer shall check the following and take the indicated action:

SCRAM	Period, sec	Computer Action
No	> 9	Return to normal program
Yes	Any	Return to normal program
No	< 9	Recycle scan

A-12.19 Alarm Check

Forty of the analog variables shall be continuously scanned at the rate of 5000 points per second, and their values checked against high and low limits. All other analog variables shall be scanned and limit checked at the rate of 100 points per second. Each time a calculation is made it shall be checked against high and low limits. In the event that an input variable or calculation is off normal, the computer shall type in red the time, the name of the variable, and its value in engineering units to four significant figures. Pushbuttons shall be provided for the operator to acknowledge the alarm condition. When the point returns to normal, the computer shall type the time, the name of the variable, and its value. A locked subpanel shall be provided on the control panel which will enable the operator to change the value of any alarm limit. When a limit is changed, a record is to be typed of the time, the name of the variable, and both the previous and new limit setting. A key switch shall be provided to allow the operator to stop and start the alarm scan. A typed record shall be provided each time the alarm scan is stopped or started.

A-12.20 N-16 Calibration Curve (Future)

The computer shall store a curve of N-16 activity versus thermal power. During the data print-out, the computer shall print both the value of the N-16 signal and equivalent thermal power obtained from the curve.

A-12.21 Flux Map (Future)

Computer time and word-storage space is to be provided for an automatic flux-mapping program. It shall be assumed that there will be 64 data points having a required scan rate of one point per second.

A-13 "SOFTWARE"

A-13.1 General Programs

A complete set of utility "software" for the proposed computer system shall be supplied. These programs shall be suitable for "on-line"-real time" computer operation. This package shall consist of, but not be limited to the following:

A-13.1.1 Diagnostic Programs

A-13.1.2 A Compiler for Fortran II

A-13.1.3 A Symbolic Assembler

A-13.1.4 Routines for floating-point arithmetic, and for conversion to and from fixed-point notation.

A-13.1.5 Fixed- and floating-point subroutines for sine, cosine, tangent, exponential, square root, logarithm, inverse sine, and inverse tangent.

A-13.1.6 Input routines to read decimal and/or alphabetical information.

A-13.1.7 An executive program which is flexible and simple to modify. This program shall be used to direct the operation of the computer.

A-13.2 Special Programs

The vendor shall provide all special programs required by this specification. The special programming shall start upon the completion of the training course and shall be completed prior to the factory-acceptance tests.

At least one of the two Argonne programmers, upon completion of the training course, will be assigned to work with the vendor while the special programs are being written. It is expected that this will provide "on-the-job" training for the Argonne programmer.

A-14 GENERAL EQUIPMENT REQUIREMENTS

It shall be the vendor's responsibility to design the computer system in accordance with accepted engineering standards and practices in the process-computer industry. The vendor shall ensure that the various system equipments are conservatively rated, complete, reliable, accurate, simple to maintain, and expandable. In addition, the vendor shall ensure that the equipment and programs are versatile, incorporating fail-safe features wherever possible.

A-14.1 If possible, the equipment shall utilize solid-state electronic components. Vacuum tubes shall be used only when they have been proven to be superior to solid-state devices.

A-14.2 The equipment shall be housed in free-standing enclosed panels. If possible, the equipment shall be constructed so that only frontal access

is required for maintenance and/or equipment alternation. The main and input/output frames shall have provisions for top cable connections. All other equipment shall have cable connections on the bottom or on the back near the bottom. The location of cable connections shall be noted on approval drawings.

A-14.3 Particular attention shall be given to the reduction and/or elimination of spurious noise susceptibility and/or generation.

A-14.4 The entire system shall be designed to deliver a 99% continuity of service. In addition, the system shall be designed to provide a minimum "mean time to failure" of 1000 hr. The equipment shall be designed and constructed so as to minimize preventive maintenance and fault-analysis downtime.

A-14.5 The system shall operate from 480-V, 3-phase or 117-V, single-phase, 60-cycle AC power derived from the CP-5 emergency or commercial power-supply system. This supply has a high degree of reliability; however, it may be interrupted for as much as 3 to 20 sec while switching transfer takes place. The voltage may be subjected to random momentary variations of $\pm 0.5\%$. During system faults, service may be interrupted. In order to maintain a high degree of continuity of service, the data and control system shall be designed to preclude loss of magnetic core memory, loss of other memory, and/or jumbling of register storage as a result of power-supply transients and total interruptions. The system shall be equipped with a power-supply sensor which will initiate a controlled shutdown. An isolated set of contacts shall be de-energized in the event a controlled shutdown takes place. The data and control-system restart and return to normal operation shall be initiated by a pushbutton which shall be installed on the operator's and programmer's panel.

A-14.6 All input controls and visual indicators shall be decimal. All indicators shall be bright enough to be clearly visible at normal room illumination levels (100 ft-candles).

A-14.7 All wiring points, plugboard locations, cables, wires, controls, indicators, sockets, test points, etc., shall be labeled in a permanent manner. The coding shall correspond with the codes and symbols used in all manuals.

A-14.8 In order to fulfill the intent of this specification, the equipment shall be capable of operating upon two independent programs simultaneously without operator intervention. A higher-priority status shall be reserved for the routine functions. The unscheduled functions, such as performing "on demand" calculations, shall have a lower-priority status. Machine organization shall be such that it can be automatically returned

from the high- to the low-priority operation as required. Any system organization which performs to the intent of these operational descriptions shall be satisfactory.

A-14.9 A breakpoint feature shall be provided, making it possible to halt the program whenever an instruction entered by programmer or operator is encountered. This feature shall primarily be used for debugging, in that it provides a facility for passing over a large number of instructions in order to locate and deal with a few troublesome ones.

A-15 THE CENTRAL PROCESSOR

A-15.1 General Requirements

The central processor shall be reliable and simple to program for on-line data reduction, display, and process control. The central processor shall be fully buffered. It shall have the characteristics outlined below.

A-15.2 Word Size

A large word size is considered an advantage because it provides versatility in program instructions and because it provides high accuracy without special programming care. Each word is to include a parity bit. The parity of each word shall be checked on each transfer. In the event that a parity error occurs in the main frame logic or memory, the program shall be interrupted and suitable indication given. In the event that a parity error occurs in an input device, the program shall not be interrupted; however, suitable indication shall be given and the data having the parity error shall be rejected.

A-15.3 Real-time Clock

An adjustable counter clock shall be incorporated into the system. The clock shall be read in hours, minutes, seconds, and milliseconds. Manual synchronization with real-time is acceptable. Provisions shall be made so that the internal clock can be synchronized with or provide a synchronizing signal for an external clock.

A-15.4 Memory and Speed

There shall be three types of memory provided with the system: magnetic core, magnetic drum or disc, and magnetic tape. The memory size (number of bits) and machine speed shall be determined by the vendor according to the following specification and minimum requirements. The initial system shall be capable of performing all the routine and unscheduled functional and on-line calculations required by this specification, using no more than 40% of the machine memory and time. The tape memory shall be used for long-term data storage and shall not be considered available for the

above operations. A core capacity of 8000 words and a disc or drum (or additional core) capacity of 40,000 words (both based on six digit accuracy per word shall be considered the minimum requirement. A machine read-write cycle time of 20 ms shall be considered a minimum requirement.

The system shall be designed so that the core can be increased in modular units to 16,000, 24,000, or 32,000 words. The secondary memory shall be designed to be expandable to 80,000 or 120,000 words. The system design shall allow these modifications to take place in the field and not require the return of the machine or any of its parts to the vendor for factory modification. Details of the field modifications shall be included in the vendor's technical proposal.

A magnetic-tape unit shall be included as a part of the initial system. It shall have a magnetic-tape control unit and one magnetic-tape transport, capable of recording seven-level, 1/2-in.-wide tape, 200 frames per inch, in standard IBM code. The unit shall operate under full computer program control. The unit shall be designed to be expandable.

A-15.5 Special Commands

The system shall have program instructions for the following commands:

A-15.5.1 Add

A-15.5.2 Subtract

A-15.5.3 Multiply

A-15.5.4 Divide

A-15.5.5 Change Sign

A-15.5.6 Block Transfer Data between Core, Tape, and Disc or Drum

A-15.5.7 Transfer Data between Registers and Memory

A-15.5.8 Unconditional Transfer

A-15.5.9 Transfer If Accumulator Is Positive, Negative, or Zero

A-15.5.10 Compare and Branch

A-15.5.11 Input/Output Selection

A-15.6 Registers

A double-length accumulator shall be provided to allow the full product of multiplication of two words. Other registers shall be included as required by these specifications.

A-15.7 Elapsed-time Counter(s)

A minimum of one elapsed-time counter shall be included in the initial system. The counter shall be under complete program control and shall provide an interrupt at the end of the interval. The vendor's technical proposal shall give details on the time intervals available and the effect of the counter(s) on the computer speed of calculation.

A-15.8 Stall Warning

A subsystem shall be incorporated in the main system which will serve to detect a malfunction of the computer from either program or computer error. The warning shall be initiated by a parity error, power-supply failure, manual pushbutton, or computer failure to reset an adjustable stall-warning timer. In the event the warning is initiated, a set of external contacts shall change state, and all power shall be removed from the output analog and contact circuits of the computer.

A-15.9 Interrupts

The system shall have a minimum of twelve programable priority interrupts. This number shall not include standard internal interrupts used for memory transfer, etc. If, in the opinion of the vendor, more interrupts are required for the efficient use of the programs outlined in this specification, the vendor shall provide his estimate of the required number. The system shall be designed so that a minimum of twelve additional interrupts can be added by field modification at a later date. The vendor's technical proposal shall provide complete details on the initial interrupt system and the expansion of that system. The external interrupts shall be initiated by a change of state of the pair of external contacts.

A-16 INPUT/OUTPUT EQUIPMENT

A-16.1 Terminal Racks

The vendor shall provide terminal racks for all input/output equipment. Special terminals shall be used where required. All other terminals shall be heavy-duty, screw-type barrier-terminal strips (Buchanan Catalog #0525 or equal). A common ground bus shall be provided for the racks. Sixty spare input channels shall be provided as a part of the initial system. The spare channels are to be completely wired; however, input cards shall not be provided.

A-16.2 Environmental Temperatures and Electrical Shocks

The system shall be free from drift and errors over a range of operating ambient temperatures between 60 and 110°F with a maximum allowable error not to exceed that defined in Section A-16.3.4.1

Voltage-limiting and/or isolating devices shall be used on all input and outputs to protect the system from environmental electrical shocks. The system shall be protected up to the level of 500 V rms, 60 cycle, across the input lines or between either input line and ground. If necessary, the input circuit of the first set of lines in contact with the high voltage shall be considered expendable. The insulation of each input line shall be tested with a 500-V DC megger and shall have a minimum insulation resistance of 2.5 megohms to ground. Full megger voltage shall be applied between the points under test until the megger pointer holds at a steady deflection for 10 sec.

A-16.3 Analog Input Subsystem

A-16.3.1 General

The analog input subsystem includes all the equipment necessary to bring the analog signals into the computer. This includes, but is not limited to, signal-conditioning equipment, sampling multiplexers, amplifiers, A/D converters, buffers, logic equipment, and a precision voltage source.

All multiplexing equipment shall be completely random addressable and shall be under complete program control.

A-16.3.2 Sample Rate

The sample rates shall be suitable for the alarm scanning and on-line calculations which are detailed in other sections of this specification. The low-speed analog multiplexer shall have a minimum sampling rate of 100 samples per second. The high-speed analog multiplexer shall have a minimum sampling rate of 5,000 samples per second. A list of the variables is contained in Section A-17 of this specification. Details of the types of transducers and their process and electrical spans will be supplied by Argonne for use in the design of the system.

A-16.3.3 Signal-input Terminations

All millivolt signals leads shall be terminated without shunts. The thermocouple reference junction box shall be accurate to $\pm 0.2^\circ\text{F}$. All current-signal leads shall be terminated on precision resistor networks with separate zero temperature coefficients.

A-16.3.4 Accuracy of the Analog Input Subsystem

A-16.3.4.1 Accuracy

The accuracy of the analog input subsystem shall be 0.1% of the input signals span. This error shall be at normal input sampling rates and shall include all errors which are due to the analog input subsystem as defined in Section A-16.3.1.

A-16.3.4.2 Calibration

The stability of the entire input system shall be defined by the vendor in the technical proposal. It is assumed that programmed calibration will not be required oftener than once per hour.

The vendor shall provide fixed calibration signals which are connected to the input system. The number of fixed sources and the actual voltage levels supplied shall be selected by the vendor. Minimum requirements governing this selection shall be redundant signals of equal voltage at 10% and 90% of span. In addition, a variable, precision voltage source shall be provided as a part of the input system. The accuracy and stability of this source shall exceed the accuracy specifications of the input system by an order of magnitude (ten times).

A-16.3.5 Analog Input Characteristics

A-16.3.5.1 The DC insulation resistance between any input and ground shall exceed 2.5 megohms to ground when tested with a 500-V DC megger. The full megger voltage shall be applied between the two points under test until the megger pointer holds at a steady deflection for 10 sec.

A-16.3.5.2 The input impedance for all signals of 100 mV or less shall be at least 1.0 megohm, higher if possible. The AC input impedance shall be as high as possible. The vendor is to provide information on the input impedance as a part of the technical proposal.

A-16.3.5.3 The common mode rejection shall be a minimum of 100 db for DC signals and 60 db for all frequencies up to and including 60 cps.

A-16.3.5.4 The 60-cps AC series mode rejection shall be a minimum of 60 db with no more than 3 db attenuation to input signals at 2 cps. The input channels to the high-speed multiplexer shall be equipped with suitable filters having a 60-cps AC series mode rejection of 60-db minimum with no more than 3-db attenuation to input signals at 20 cps.

A-16.3.5.5 The above specifications shall not relieve the vendor of the responsibility for additional shielding and/or noise rejection where required by the system.

A-16.3.5.6 A list of variables is contained in Section A-17 of this specification. The system shall be expandable to 250 inputs in the future.

A-16.4 Contact Closure Inputs (Future)

A-16.4.1 The contact-closure input subsystem includes all the equipment necessary to bring the contact-closure signals into the computer. This includes, but is not limited to, a power supply, current-limiting resistors, and multiplexer.

A-16.4.2 The variables shall be scanned and compared against known relationships at no less than 10,000 contacts/sec. The multiplexing equipment shall be completely random addressable and shall be under complete program control.

A-16.4.3 In the event that the input indication is off normal, the computer shall type out, in red, the name of the point and the time. When the point returns to normal, the computer shall type out the name of the point and the time.

A-16.4.4 A simple means of changing the programed status of any contact shall be provided as a part of the operator's console. When the programed status is changed by the operator the name of the point, the time, and new status shall be typed out.

A-16.5 Analog and Contact Closure Output Subsystems

Except for the contact-closure outputs required to comply with the on-line calculations, the power-loss signal, computer-off signal, and interrupt signals, no analog nor contact-closure output subsystems are required by this specification. However, future plans call for the addition of such subsystems when the computer is used as a control device for the reactor. As a part of the technical proposal the vendor shall supply details in his bid on contact-closure subsystems which are compatible with the equipment.

This information shall include, but not be limited to, detailed instructions on field installation, price, contact form, contact type, speed of response, and such electrical characteristics as frequency, maximum volt-amp capacity, and maximum voltage and current.

A-16.6 Input/Output Buffer Registers

All input to and output from the computer shall be through buffer registers. The speed of the computer shall not be appreciably reduced due to input or output requirements.

A-17 MAN-MACHINE COMMUNICATIONS EQUIPMENT

The input/output peripheral equipment supplied by the vendor shall be designed for ease and clarity of communications between the operator and the computer system. This equipment shall include a paper-tape punch and reader, two logging typewriters, one typewriter with integral paper-tape punch and reader, and one "quick look scope." The vendor is to bid on a second "quick look scope" and an x-y plotter on an alternative basis. All of the equipment with the possible exception of the typewriter having integral paper-tape reader-punch shall be under computer-program control. The vendor shall quote interconnecting cable for this equipment on a per foot basis.

A-17.1 One paper-tape punch for use with one-inch paper tape and eight-level tape code. The punch shall be capable of punching at least 60 characters per second.

A-17.2 One paper-tape reader for use with one-inch paper tape and eight-level tape code. The reader shall be capable of reading at least 120 characters per second.

A-17.3 Two identical logging and off-normal typewriters with full keyboard. The typewriters shall conform with one of the following specifications. The vendor shall quote on one as a part of the main bid and shall quote on the others if available as alternates.

A-17.3.1 Fifteen and one-half ($15\frac{1}{2}$)-in. pin-feed platen, 12 characters per inch, and typing speed of 15 characters per second.

A-17.3.2 Twenty-four (24)-in. pin-feed platen, 14 characters per inch, and typing speed of 10 characters per second.

A-17.3.3 Twenty (20)-in. pin-feed platen, 16 characters per inch, and typing speed of 10 characters per second.

A-17.3.4 One typewriter with integral paper-tape punch and reader for use with one-inch paper tape and eight-level tape code. This unit will be used off-line for preparation and editing of input/output tapes and shall be compatible with the paper-tape reader and punch. The vendor shall include one of the following as a part of the main bid and shall quote on the other if available as an alternate.

A-17.4.1 Dura Mach 10 (IBM Electrical) with 15-in. pin-feed platen with a speed of 15 characters per second. This unit shall be interchangeable with the logging typewriters specified above and shall act as an on-line spare when necessary.

A-17.4.2 Freiden Flexowriter with 12-in. carriage.

A-17.5 One "quick look scope" with a "light pen" shall be provided, complete with the necessary control panel. The scope shall be connected to the computer through a buffer register. The scope shall have a minimum viewing area of 172 in.² (19-in. cathode-ray oscilloscope) with an aspect ratio of 3 to 4. It shall have plots of sufficient brightness to be easily seen in a normally lighted control room (100 ft-candles). It shall have a minimum resolution of 1 part in 1,000. The equipment shall be suitable for performing the program outlined in Section A-12.17 of this specification. As an alternate, the vendor is to quote on a second "quick look scope" display which shall be operated in parallel with the first unit. The second unit shall be equipped with a key-controlled control panel. When the key switch is in the "on" position, the second unit shall be used to control the displays. The first unit shall be incorporated as a part of the operator's console; the second unit shall, if purchased, be incorporated as a part of the programmer's console. The vendor shall provide complete details for both scope display systems as part of the technical proposal.

A-17.6 X-Y Plotter

The vendor's bid shall include as an alternate an x-y plotter which is compatible with the proposed system. The vendor's technical proposal shall include the complete technical specifications for the plotter. If available and compatible with the proposed system, the vendor shall include bids on devices having 11-in. and 29½-in. plotting widths.

A-17.7 Input/Output Buffer Registers

All input to and output from the computer shall be through buffer registers. The speed of the computer shall not be appreciably reduced because of input or output requirements.

A-17.7.1 There shall be at least one buffer register for input/output of the on-line paper-tape reader, paper-tape punch, and logging typewriters.

A-17.7.2 There shall be a buffer register for the "quick look scope(s)" and its controls, and the x-y plotter.

A-17.8 Operator's Control Console

The operations-control console shall provide communications between the operator and the computer. The console shall be designed for use by reactor operators. The console shall be designed so that programming ability is not required for its operation. All communication between the computer and the operator shall be in decimal form, using a base of ten. The console shall contain the necessary controls and display equipment

to provide efficient use of the computer system. The vendor shall be responsible for the design and layout of this console; however, Argonne's technical representative shall have the right to approve or change the final layout before the console is fabricated. The following equipment shall be considered the minimum requirement for this console.

A-17.8.1 One logging typewriter as specified in Section A-17.3.

A-17.8.2 One "quick look scope" with "light pen" and control panel as specified in Section A-17.5.

A-17.8.3 One operator's control panel containing, as a minimum, the following:

A-17.8.3.1 An off/on key switch.

A-17.8.3.2 A means for changing the information at any address in core. The necessary devices shall be located in a locked subpanel.

A-17.8.3.3 One electronic digital display unit capable of displaying at least seven decimal digits. Sufficient switches shall be provided to allow the selection of the point to be displayed. This unit shall normally be used to display the output of the digital clock.

A-17.8.3.4 Selector switches used for operator requests such as alarm acknowledge, demand log, read input tape, and demand calculations.

A-17.8.3.5 One computer status display panel showing such items as on/off, power loss, halt, parity error, overflow, and input/output malfunction.

A-17.9 Programmer's Control Console

The programmer's control console shall be specifically designed to contain the equipment, controls, and visual displays required for efficient and convenient programming, and debugging the entire system. In addition, it shall be designed so that it is possible to use the console as an emergency control console. It is imperative that the equipment used in emergency operation be identical with that used in the operator's control console. The vendor shall be responsible for the design and layout of this console; however, the Argonne technical representative shall have the right to approve or change the final layout before the console is fabricated.

The following equipment shall be considered the minimum requirement for this console:

A-17.9.1 One logging typewriter as specified in Section A-17.3.

A-17.9.2 One operator's control panel as specified in Section A-17.7.3. An interlock key switch shall be provided which performs the following functions:

A-17.9.2.1 With the key switch in the "off" position, the programmer's console shall be disabled, allowing the operator's console full control of the system.

A-17.9.2.2 With the key switch in the "on" position, the operator's console shall be disabled, allowing the programmer full control of the system.

A-17.9.3 One paper-tape punch with the necessary controls as specified in Section A-17.1.

A-17.9.4 One paper-tape reader with the necessary controls as specified in Section A-17.2.

A-17.9.5 As an alternate, if specified in the purchase order, one "quick look scope" with "light pen" and the necessary controls as specified in Section A-17.5.

A-17.9.6 As an alternate, if specified in the purchase order, one x-y plotter with the necessary controls as specified in Section A-17.6.

A-17.9.7 A minimum of four sense (break-point) switches shall be included.

A-17.9.8 Switches for disabling the write heads of the drum (or disc) memory.

A-18 VENDOR TECHNICAL PROPOSAL

The vendor shall submit a technical proposal which shall include detailed descriptions of the equipment and services being offered. This proposal shall be submitted to the Argonne National Laboratory at no charge. The proposal shall include, but not be limited to, the following items:

A-18.1 Arithmetic Unit.

A-18.2 Buffers.

A-18.3 Registers.

A-18.4 Calibrated Signal Source.

A-18.5 Analog Input/Output System (Accuracy, Noise Rejection, Sample Rate, Type of Multiplexer, etc.).

A-18.6 Contact-sense Input/Output System.

A-18.7 Peripheral Equipment (Paper-tape Reader/Punch, Typewriters, "Quick Look Scopes," X-Y Plotter, etc.).

A-18.8 Type, Size, and Description of Core, Tape, and Drum or Disc Memory Devices.

A-18.9 Operator's and Programmer's Panels.

A-18.10 Priority Interrupts, Parity Check, and Stall Warning.

A-18.11 Detailed description of all alternates and/or exceptions to this specification. The vendor shall include justification for proposing the alternates and/or exceptions.

A-18.12 Complete details about the method of instruction, programing, and addressing.

A-18.13 Typical execution times for various commands.

A-18.14 Word length, clock frequency, internal number base, and operating mode.

A-18.15 Description of self-checking and fail-safe features of the system.

A-18.16 A theoretical calculation and field data showing "mean time between failures." Only field data obtained from on-line computers which are the same model as the proposed system shall be used. This section shall include an estimate of the total number of various types of components used. The section shall also include the estimated failure rates of the components.

A-18.17 Electrical power, air conditioning, humidity, and any other utility requirements. Maximum, normal, and minimum requirements shall be given.

A-18.18 Outline drawings showing major dimensions and weights.

A-18.19 Programing and "Software" details.

A-18.20 Paint Specifications.

A-18.21 Type of connections used and a photograph of the "typical" wiring on the back of the main frame.

A-18.22 Mechanical Accessibility Required.

A-18.23 Typical wiring diagrams; maintenance and operating instructions manuals.

A-18.24 "In chassis" component-identification labels or markings.

A-18.25 Machine time and memory required for the programs outlined in Section A-12.

A-18.26 Memory required for additional "software."

A-18.27 Typical times for add, multiply, and divide, including access and execution.

A-18.28 Estimated times required for the following operations (0.1% accuracy).

A-18.28.1 $A \times B + C = D$.

A-18.28.2 $\sqrt{A \times B} = C$.

A-18.28.3 $\frac{A}{B} + C = D$.

A-18.28.4 $Ax + By = C$;

$Dx + Ey = F$.

A-18.29 Maximum length and cost per foot of cables.

A-18.30 Provisions for expansion and field modifications required for expansion.

A-18.31 Previous Vendor Experience.

A-18.32 Name of vendor's business and technical representatives and the names of their alternates.

A-18.33 Details of standard factory and/or field tests.

A-18.34 A detailed outline of the scope of the training programs to be provided by the vendor (see Section A-5.2).

A-18.35 Detailed description of the controlled shutdown due to power interruption and/or total power loss.

A-18.36 A detailed project schedule as per Section A-4.3.

A-18.37 Details of the AC and DC input impedances of all input channels.

A-18.38 A list of normal test equipment and tools required for the maintenance of the system. This section shall include the cost of special test equipment and/or tools required which have not been included elsewhere in the proposal.

A-18.39 Special signal-conditioning and/or special electrical-grounding requirements.

A-18.40 Detailed costs for all basic equipment, training, installation, demonstration of continuity of service, and special programing as outlined in this specification. The bid shall be in sufficient detail to allow the Argonne National Laboratory to evaluate alternative purchasing plans.

A-18.40.1 The basic equipment bid shall include the cost of the following:

A-18.40.1.1 All equipment items specified as a part of the original installation.

A-18.40.1.2 All meetings and site visits required to define any details not covered by the specification.

A-18.40.1.3 All general programs outlined in Section A-13.1.

A-18.40.1.4 The exercise program outlined in Section A-6.5.

A-18.40.1.5 All Factory Tests.

A-18.40.1.6 All Drawings, Manuals, and Reports.

A-18.40.1.7 All Costs for Equipment Delivery.

A-18.40.1.8 All other items required to comply with the specifications except the items specifically outlined below.

A-18.40.2 The alternative equipment bid shall include the cost of the following:

A-18.40.2.1 The second "quick look scope," "light pen," and controls.

A-18.40.2.2 The X-Y Plotter and Controls.

A-18.40.2.3 Alternative Off-line Typewriters.

A-18.40.2.4 Alternative On-line Typewriters.

A-18.40.2.5 All other alternates offered by the vendor.

A-18.40.3 The training bid shall include the cost of all training outlined in the specification. The bid shall be subdivided to show the cost of each course and the cost per man week of on-job training.

A-18.40.4 The installation bid shall include all of the vendor's field costs with the exception of those associated with the demonstration of continuity of service. Field costs shall include labor, parts, transportation, and living expenses.

A-18.40.5 The bid for demonstration of continuity of service shall include all costs including field costs required to successfully complete the demonstration.

A-18.40.6 The special programing bid shall include all costs required to completely program and "debug" the special programs outlined in Sections A-12 to A-12.21.

A-19 LIST OF VARIABLES

A-19.1 Time - Date.

A-19.2 D₂O Flow (Main).

A-19.3 Reactor Inlet D₂O Temperature.

A-19.4 Reactor (D₂O) ΔT (Temperature Rise).

A-19.5 Heat Exchanger, D₂O Inlet Pressure.

A-19.6 Heat Exchanger, D₂O Outlet Pressure.

A-19.7 D₂O pH Recording.

A-19.8 D₂O Conductivity, Cleanup System Inlet.

A-19.9 D₂O Conductivity, Cleanup System Outlet.

A-19.10 D₂O Storage Level.

A-19.11 D₂O Reservoir Overflow.

A-19.12 Reactor D₂O Level.

A-19.13 Heat Exchanger, H₂O Flow.

- A-19.14 Heat Exchanger, H₂O Inlet Temperature.
- A-19.15 Heat Exchanger, H₂O Outlet Temperature.
- A-19.16 Heat Exchanger, H₂O Inlet Pressure.
- A-19.17 Heat Exchanger, H₂O Outlet Pressure.
- A-19.18 Shield Cooling Flow.
- A-19.19 Shield Cooling Inlet Temperature.
- A-19.20 Shield Cooling Outlet Temperature.
- A-19.21 Shim Rod Supply Voltage.
- A-19.22 Shim Rod Clutch Supply Voltage.
- A-19.23 Regulating Rod Position.
- A-19.24 Shim Rod #1 Position.
- A-19.25 Shim Rod #2 Position.
- A-19.26 Shim Rod #3 Position.
- A-19.27 Shim Rod #4 Position.
- A-19.28 Chamber Current - Regulating Rod.
- A-19.29 Chamber Current - Hi-flux #1.
- A-19.30 Chamber Current - Hi-flux #2.
- A-19.31 Chamber Current - Hi-flux #3.
- A-19.32 Chamber Current - Hi-flux #4.
- A-19.33 Building Activity Monitor #1.
- A-19.34 Building Activity Monitor #2.
- A-19.35 Stack Activity Monitor #1.
- A-19.36 Stack Activity Monitor #2.
- A-19.37 Pump Room Activity Monitor.

- A-19.38 Service Area Activity Monitor.
- A-19.39 Rod Storage Activity Monitor.
- A-19.40 Reactor Room Activity Monitor.
- A-19.41 Rabbit Activity Monitor #1.
- A-19.42 Rabbit Activity Monitor #2.
- A-19.43 Period Meter #1.
- A-19.44 Period Meter #2.
- A-19.45 Reactor Plenum Pressure.
- A-19.46 Reactor Gasometer Helium Pressure.
- A-19.47 Graphite Gasometer Helium Pressure.
- A-19.48 Reactor Gasometer Helium Level.
- A-19.49 Graphite Gasometer Helium Level.
- A-19.50 Reactor D₂O Overflow.
- A-19.51 Cooling Water Activity Monitor.
- A-19.52 Shim Rod Operation Timer.
- A-19.53 Voltage of Regulated Instrument Power..
- A-19.54 Ion Exchange Temperature.
- A-19.55 Graphite Helium Flow.
- A-19.56 Reactor Helium Flow.
- A-19.57 Dump Valve Air Pressure.
- A-19.58 Cooling Tower Spray Bypass Valve Position.
- A-19.59 Vapor Sphere Diaphragm Level.
- A-19.60 D₂O Throttle Valve Position.
- A-19.61 H₂O Throttle Valve Position.

- A-19.62 D₂O Reservoir Throttle Valve Position.
- A-19.63 Dump Valve Position.
- A-19.64 Scram Relay Position.
- A-19.65 D₂O Pump #1 Inlet Valve Position.
- A-19.66 D₂O Pump #2 Inlet Valve Position.
- A-19.67 D₂O Pump #1 Outlet Valve Position.
- A-19.68 D₂O Pump #2 Outlet Valve Position.
- A-19.69 Reactor Bulk D₂O Temperature.
- A-19.70 Reservoir Tank Flowmeter.
- A-19.71 D₂O Overflow Return.
- A-19.72 Cleanup System Flowmeter.
- A-19.73 pD Flowmeter.
- A-19.74 D₂O to H₂O Leak Monitor Flowmeter.
- A-19.75 Reactor Helium Supply Tank Pressure.
- A-19.76 Catalyst Helium Supply Tank Pressure.
- A-19.77 Power Galvanometer.
- A-19.78 Power Demand.
- A-19.79 Catalyst Temperature In.
- A-19.80 Catalyst Temperature Out.
- A-19.81 Fuel Rod D₂O Flow #1.
- A-19.82 Fuel Rod D₂O Flow #2.
- A-19.83 Fuel Rod D₂O Flow #3.
- A-19.84 Fuel Rod D₂O Flow #4.
- A-19.85 Fuel Rod D₂O Flow #5.

A-19.86 Fuel Rod D₂O Flow #6.
A-19.87 Fuel Rod D₂O Flow #7.
A-19.88 Fuel Rod D₂O Flow #8.
A-19.89 Fuel Rod D₂O Flow #9.
A-19.90 Fuel Rod D₂O Flow #10.
A-19.91 Fuel Rod D₂O Flow #11.
A-19.92 Fuel Rod D₂O Flow #12.
A-19.93 Fuel Rod D₂O Flow #13.
A-19.94 Fuel Rod D₂O Flow #14.
A-19.95 Fuel Rod D₂O Flow #15.
A-19.96 Fuel Rod D₂O Flow #16.
A-19.97 Fuel Rod D₂O Flow #17.
A-19.98 Fuel Rod Outlet Temperature #1.
A-19.99 Fuel Rod Outlet Temperature #2.
A-19.100 Fuel Rod Outlet Temperature #3.
A-19.101 Fuel Rod Outlet Temperature #4.
A-19.102 Fuel Rod Outlet Temperature #5.
A-19.103 Fuel Rod Outlet Temperature #6.
A-19.104 Fuel Rod Outlet Temperature #7.
A-19.105 Fuel Rod Outlet Temperature #8.
A-19.106 Fuel Rod Outlet Temperature #9.
A-19.107 Fuel Rod Outlet Temperature #10.
A-19.108 Fuel Rod Outlet Temperature #11.
A-19.109 Fuel Rod Outlet Temperature #12.

- A-19.110 Fuel Rod Outlet Temperature #13.
- A-19.111 Fuel Rod Outlet Temperature #14.
- A-19.112 Fuel Rod Outlet Temperature #15.
- A-19.113 Fuel Rod Outlet Temperature #16.
- A-19.114 Fuel Rod Outlet Temperature #17.
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- A-19.116 D₂O Flow Through Cleanup System.
- A-19.117 Temperature into Helium Compressor.
- A-19.118 Temperature into Catalyst Chamber.
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- A-19.121 Temperature Out of Shield Cooling Loop B.
- A-19.122 Temperature Out of Shield Cooling Loop C.
- A-19.123 Temperature Out of Shield Cooling Loop D.
- A-19.124 Temperature Out of Shield Cooling Loop E.
- A-19.125 Laboratory Water Temperature into the Shield Cooling Heat Exchanger.
- A-19.126 Laboratory Water Temperature Out of the Shield Cooling Heat Exchanger.
- A-19.127 Cooling Tower #1 Temperature.
- A-19.128 Cooling Tower #2 Temperature.
- A-19.129 Laboratory Water Flow to Shield Cooling Heat Exchanger.
- A-19.130 ΔP Heat Exchange H₂O Inlet - Outlet (Future).
- A-19.131 ΔP Heat Exchange D₂O Inlet - Outlet (Future).
- A-19.132 ΔP Heat Exchange Low Pressure D₂O (Future).

A-19.133 ΔP Heat Exchange High Pressure H_2O (Future).

A-19.134 Cooling Tower pH (Future).

A-19.135 Cooling Tower Conductivity (Future).

A-19.136 Aspirator Vacuum (Future).

A-19.137 N-16 Detector #1 (Future).

A-19.138 to A-19.188 Experimenter Variables (Future).

A-19.189 to A-19.250 Other Possible Future Equipment.

APPENDIX B

A Preliminary Cost Estimate for the Equipment, Software,
and Special Training for the Proposed CP-5 Computer-driven
Digital-data-acquisition and Reactor-control System

The following cost estimate is based on the equipment and services called for in the specification contained in Appendix A.

PURCHASE COST

Basic Computer	\$50,000	
Magnetic Core with 8000 Words	40,000	
Magnetic Drum	46,000	
Magnetic-tape Equipment	20,000	
Multiplexers, A to D Converter, and Signal-conditioning Equipment	<u>28,000</u>	
		\$184,000

Operator's Console	\$ 1,000	
Typewriter	3,000	
Quick Look Scope	30,000	
Digital Display	<u>4,000</u>	
		\$ 38,000

Programmer's Console	\$ 2,000	
Typewriter	3,000	
Quick Look Scope (Slave)	4,000	
Digital Display	4,000	
Paper-tape Read-write	<u>5,000</u>	
		\$ 18,000

Flexowriter		\$ 5,000
		<u>\$245,000</u>

TOTAL EQUIPMENT COST

Special "Software" Required	\$50,000	
Special Training Provided by the Vendor for Argonne Personnel	<u>12,000</u>	
		\$ 62,000

TOTAL COST OF EQUIPMENT, SPECIAL PROGRAMS AND TRAINING		\$307,000
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Contingency		<u>\$ 33,000</u>
TOTAL INCLUDING CONTINGENCY		<u>\$340,000</u>

Typical Rental Cost (See Appendix D Numbers 89 and 90)

$$\$340,000 \times 2.2\% \approx \$7,500/\text{mo.}$$

The rental estimate is based on the assumption that the manufacturer will maintain the equipment. The cost can be reduced by approximately \$1,300 to \$1,700 per month if Argonne personnel maintain the equipment.

NOTE ADDED IN PROOF: Since this report was written, new equipment has been developed which permits a 20-30% reduction in cost.

APPENDIX C

Special Procurement Considerations

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C-1. SPECIAL PROCUREMENT CONSIDERATIONS

The material covered in this section is generally confined to topics which can appreciably effect the installation yet cannot be classified as a system or programing parameter. In general, this concerns the vendor-buyer relationship. It is imperative that equipment specification cover as many details as possible. If the vendor is given the opportunity to determine accurately the scope of the contract prior to his bid, he will not need to include a large contingency factor in the bid nor will he have grounds to ask for additional funds because of misunderstanding the scope of the project.

C-1.1 THE VENDOR-BUYER COMMUNICATIONS

The buyer's purchase order or some other official document should define individuals and alternates in the buyer's company who have responsibility for the project. The documents should also define the limits of authority of these individuals. The vendor's technical proposal should provide the same information for the vendor's organization. All communications between the vendor and the buyer should be carried out between these individuals.

C-1.1.1 Meetings

Meetings should be held at times and places required by the project. Prior to awarding a purchase contract a meeting should be held between the buyer and the vendor having the most acceptable system consistent with cost and the specification. At this meeting the project, technical, and business representatives from the buyer and the vendor should carefully cover all aspects of equipment and services to be supplied by the vendor. This meeting will provide a means to resolve any questions as to the intent of the specification and technical proposal. The meeting should normally be held at the buyer's installation so that the site can be visited and other buyer personnel can be consulted. The basic purpose of this meeting is to discuss the specifications and technical proposal in order to eliminate any misinterpretations of these documents which could result in a request for additional funds by the vendor.

C-1.1.2 Inspections

The specifications should include a statement permitting the buyer to visit the vendor's manufacturing and programing facilities to:

- A. determine the progress of the job;
- B. allow the buyer or his representative the opportunity to determine if the equipment will meet the specifications and delivery date;
- C. determine if the equipment is being constructed to conform with the specification and good engineering practice.

C-1.1.3 Check Out

The specifications should include a complete description of the check-out tests, the location(s) where they are to be performed, the witnesses to be present, and the procedure in the event the equipment fails to meet any of the tests.

C-1.1.4 Programing

The programing responsibility should be defined in the specifications. Programing can be implemented in several ways. The total responsibility can be given to the vendor, assumed by the buyer, or carried out as a co-operative undertaking. A "typical" case cannot be defined; however, the following facts usually apply:

- A. The manufacturer has personnel who are very familiar with programing the particular machine to be purchased.
- B. The buyer will normally write all programs at some future date.
- C. The buyer may not be familiar with process modeling or control techniques.
- D. The buyer usually has a clear picture of the physical constraints of a process which may not be immediately apparent to the vendor.

In view of above, it is suggested that the initial programs be written as a cooperative effort. It is assumed that this effort would not begin until buyer programing personnel have attended the programing school. The co-operative effort also allows the buyer to have an intimate knowledge of the programs in the computer so that he can easily modify them. An additional advantage is the opportunity for the buyer programing personnel to obtain "on the job training."

C-2 VENDOR EXPERIENCE

Bids should be accepted only from companies which have successfully placed in operation several similar systems. When viewed from the standpoint of an inexperienced equipment vendor, this may seem like an undue restriction. It should be noted, however, that the purpose of the installation is not to advance the state of the art of the equipment, nor to provide computer research and development funds, nor to provide the vendor a field of installation to work the "bugs" out of his equipment. The major purpose of this project is to utilize reliable equipment with a known reactor to develop reactor-computer compatibility and to determine the most effective operational techniques and programs. In other words, the installation is to prove that a digital control system can safely and efficiently operate a large reactor.

C-3. TRAINING

The training required by the buyer can best be determined by the vendor's past experience. The vendor should provide the necessary training courses as a part of the scope of the equipment contract. The buyer's specification should define the number and educational background of the personnel to be trained as well as the training location. The vendor's technical proposal should define the scope of the training, the time required, and the cost of the training.

C-4. VENDOR SERVICE AFTER INSTALLATION

Most vendors can provide programming and maintenance service after the installation is complete. The service is generally available to meet the requirements of the buyer. The first year's service is usually purchased as a part of the initial order. Future service is available on a negotiated yearly basis. It should be noted, however, that the vendor's prime function is to build and sell computer control systems and that he provides service as a convenience to implement sales. As evidence of this it was noted that the "typical" yearly service contract for one service man on a 40 hour per week basis for 50 weeks per year, normally costs between \$16,000 and \$20,000.

C-5. SHIPMENT

The system should be shipped from the point of manufacturer to the installation site via a special electronic equipment moving van. No intermediate truck transfers should be allowed. The equipment should be adequately protected from the affects of weather, shock, and vibration. All openings should be covered or adequately protected to prevent corrosion or the entrance of foreign matter during shipment. All items should be adequately crated, boxed, and otherwise protected to prevent loss, damage, or pilferage during shipment. The equipment should be packaged so it is suitable for moving by rolling and skidding or for handling with fork-lift truck or crane. All pieces of equipment should be clearly identified in accordance with the vendor drawings so that no difficulty is encountered in field assembly.

C-6. DELIVERY SCHEDULE

The vendor should provide a detailed delivery schedule as a part of his technical proposal. This schedule should include such items as:

- A. release of specifications on purchased items;
- B. start of fabrication;
- C. start of training;

- D. factory test;
- E. finish of fabrication;
- F. factory acceptance test;
- G. equipment delivery;
- H. installation;
- I. field acceptance test;
- J. demonstration of continuity of service.

If the system consists of standard "off the shelf items," steps A to G above take approximately 8 to 12 months after the vendor has received a purchase contract. Vendors are currently trying to reduce this lead time by prefabricating central processors. They hope that this technique will reduce delivery time to 6 months; however, the recent demand for systems and the high capital investment required to stock-pile components has prevented most manufacturers from practicing such prefabrication.

C-7. FACTORY TESTS

Prior to shipment, the equipment is usually operated on a full functional factory test under a simulated environment. The factory test checks the validity of the programs, guaranteed accuracy, reliability, and proper functioning of the components as a system. The buyer normally witnesses and approves these tests. Similar field tests are normally run on the equipment. Special conditions of test operation or approval requirements should be outlined in the specifications.

C-8. FUTURE CHANGES

Experience has shown that the original installation is usually modified before the system assumes its final configuration. For this reason it is imperative that the system be field expandable. In order to assume that the vendor will be available for consultation on these modifications, the vendor should provide assurances, in the technical proposal, that he will remain in the on-line control computer business for a minimum of 3 to 5 yr. It is extremely difficult to define what type of "assurances" are required; however, such things as manufacturer capital investment, financial rating, and general business interest should be considered.

C-9. VENDOR TECHNICAL PROPOSAL

The vendor's proposal should be as detailed as possible. It should cover all the pertinent characteristics and advantages of the equipment offered by the vendor. Vendors should also be encouraged to submit alternates to the specifications; however, these alternates should be submitted as an addition to the bid on the basic specification.

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