APR 21 1965

LA-AC-6891 (Full Paper)

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84224

CONF-650413-1

ULTRA HIGH TEMPERATURE REACTOR EXPERIMENT
ON-LINE PROCESS COMPUTER

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ABSTRACT

An on-line process computer has been purchased for the Ultra High Temperature Reactor Experiment (UHTREX). It will be used to aid in the operation of the UHTREX reactor, the reactor coolant loops, and the coolant purification system.

The computer system includes a central processor with 4000 words of magnetic core memory, 32,000 words of drum memory, an input-output typewriter, and a paper tape punch and reader. There are 4 logging typewriters and one visual display unit. The system can sample some 600 analog and 300 digital inputs; and it can set 444 digital and 24 analog outputs. Twenty interrupt channels will be used to allow time sharing of input-output equipment and to initiate special programs dependent on UHTREX system conditions.

The computer will sample analog channels at a rate of 200 channels per second and monitor them for out-of-limit conditions. It will also prepare logs, perform on-line calculations, keep reactor fuel and other system histories, and monitor reactor operator activities. Capability is being provided for sequencing valves in operations such as full loading and for controlling coolant flow rates, thermal power output of the cooling system, etc. In addition, system diagnostic programs and emergency shutdown programs will be available to help in system operation.

*Work done under the auspices of the U. S. Atomic Energy Commission.

INTRODUCTION

The Ultra High Temperature Reactor Experiment (UHTREX) involves the use of simple, unclad, refractory fuel elements in a helium-cooled, graphite moderated reactor. The reactor will be operated at a thermal power of 3 Mw and a maximum coolant temperature of 2400°F. Unique features of UHTREX are:

1. The use of a very simple fuel element.
2. The capability to load and unload fuel during operation at full power.
3. The design of the reactor and coolant system for the high temperature of the coolant outlet.
4. The design of the coolant system with the expectation that there will be complete release of fission products from the fuel elements.

These features make UHTREX especially well suited for testing a variety of refractory fuel element designs that have application in the gas-cooled, advanced converter program.

The reactor, Figure 1, has a vertical cylindrical graphite core, surrounded by carbon reflector and insulation. It is encased in a thirteen foot diameter spherical pressure vessel. Hollow cylindrical fuel elements 5.5 inches long, with a 1.0 inch outside diameter and a 0.5 inch diameter central hole, lie freely in 1.1 inch diameter radial holes in the core. There are 312 such channels with four elements per channel for a total of 1248 elements.

Since the reactor may be loaded at power, it is planned to use fuel load to determine temperature, and depend on the negative coefficient of reactivity for control. The use of poison rods for reactivity control will be done during restart operations following a shutdown. For normal operation the rods are withdrawn and will only be used for shutdown. The relative ease of fuel loading also simplifies many problems of fuel element testing.

To load fuel, an element is fed into the fuel elevator by means of conveyors and gas lock valves. In the elevator it is positioned vertically and is pushed into a core fuel channel by a fuel loader ram. When it forces the innermost element to drop down the fuel discharge slot. All channels in the core may be fueled by rotating the core to align any of the twenty-four radial columns of channels with the thirteen fuel loader rams.

The associated coolant system is shown schematically in Figure 2. It should be mentioned that the small block titled Gas Cleanup represents a considerable number of components required for purification, helium storage and pressure regulation. The purification system has a copper oxide bed, molecular sieve beds, several activated carbon beds and the associated complex set of valves, compressors, heat exchangers, coolers, etc.

A mathematical model of the reactor and its coolant loops has been derived for UHTREX. A digital simulation program has been written and used to study the transient response of the system. Simulation results indicate that the reactor is stable and that the overall system is well behaved. Typical time constants are in the range of 100 to 1000 seconds; and since performance requirements are not severe, it is anticipated that relatively simple low band-width control systems will be adequate.

PROCESS COMPUTER

The control and data system for UHTREX will include an on-line computer to aid in the operation of the reactor system. It is anticipated that the reactor will be run for extended periods of time at steady conditions. The computer will relieve the tedium and greatly improve the quality of records, and will provide supervision and control to enhance the reliability of the operation.

The central processor of the system is a small solid-state general-purpose computer which has some additional features that make it suitable for on-line process use. The equipment that is included with the central processor and is characteristic of a general purpose computer is listed in part A of Table I. Part B of this same table lists equipment ordinarily associated with process computers. The large number of analog and digital inputs and outputs in Part B provide considerable capability for monitoring and controlling. The special equipment in part C of Table I is of particular significance in the application of a process computer and is discussed in more detail below.

There are 20 system interrupts, ordered as shown in Table II. These interrupts are used to facilitate "time sharing" of input/output and to provide immediate recognition of special external or internal conditions. The computer automatically scans the interrupts after executing each instruction (with three exceptions) and will either transfer control to the program associated with the highest level of interrupt that is present, or continue the current sequence of instructions if no new interrupt has occurred. On completion of an interrupt program, control is returned to the sequence of instructions from which control was transferred. However, after this return,

TABLE I

Process Computer Components

A. "General Purpose" Computer Equipment

Arithmetic Unit - - - - -	24 bit word plus parity bit
	16 μ sec to add
	32 μ sec to multiply
4096 Word Magnetic Core Storage	
31,680 Word Drum Storage	
Input-Output Typewriter - - - - -	10 Characters/sec
Paper Tape Punch - - - - -	60 Characters/sec
Paper Tape Reader - - - - -	300 Characters/sec

B. Process Computer Equipment

Visual Display	
4 Logging and Alarm Typewriters- - - -	10 Characters/sec
608 Analog Inputs - - - - -	Scanned at 200/sec (Max)
300 Digital Inputs - - - - -	Scanned at 190,000/sec
24 Analog Outputs - - - - -	Updated twice/sec
444 Digital Outputs - - - - -	20 to 4000 outputs/sec

C. Special Equipment

- 20 Interrupts
- Automatic Safe Shutdown on Power Failure
- Stall Warning
- Watchdog Timer
- Real Time Clock

TABLE II

UHTREX Interrupt Order

1. Power on
 2. Power outage
 3. W-buffer, end of word
 4. W-buffer, end of block
 5. Watchdog timer
 6. Real time clock
 7. Analog to digital converter complete
 8. Elapsed time counter complete
 9. UHTREX system
 10. UHTREX system
 11. UHTREX system
 12. UHTREX system
 13. Relay output (matrix) complete (digital output matrix)
 14. Analog output complete
 15. Punch (on EOM-POT lines) complete
 16. Alarm typewriter complete
 17. Log typewriter complete
 18. Computer console
 19. Main system operations
 20. Auxiliary system operations
- Drum-core transfers
- from UHTREX system operation panels

the interrupts are again scanned, so that the current highest level of interrupt will be effective. Thus, the program associated with the highest level of interrupt is always the one being executed. Fortunately, the computer will neither forget an interrupt nor will it get lost if multiple interrupts occur.

A majority of the time, however, there will not be any active interrupts and the computer will be in the "executive" program or a program controlled from the executive. In the "executive" the computer is constantly looping through a list of about 30 programs to see if it is time to run one of them. These programs include the input scans (which are done once per second), two logs (which are done once per hour), operator console programs (that are done only on request of the operator), etc. There will be a sporadic sequence of interrupts to the "executive" from input/output equipment indicating that information is ready to be transferred into memory (every 5 milliseconds during an analog scan for example) or that an output has been completed and another output may be made (every 100 milliseconds in the case of a log).

The executive program and the ordering of the interrupts assure that computer programs are handled in a sensible sequence, with high priority given to the most important activity. To illustrate this point, consider the case of automatic shutdown on input power failure. On detection of low voltage, well before the computer dc power is low enough to interfere with normal operation, the power failure interrupt (number 2) is activated and a transfer is made to the automatic shutdown program. This program will store the contents of all registers and stop the computer on a HALT instruction. There is time to finish this program before the power can fall low enough to hinder

operation, even if the computer power is removed "instantly". On power resumption, interrupt number 1 takes the computer to a restart program that could simply restore the registers and resume operation. It is more probable that the restart program will go through an initialization and start the computer out anew. Thus, the automatic shutdown equipment, through its use of a high priority interrupt, assures a safe computer shutdown and restart with no loss of information. This feature is particularly appealing in a reactor system.

Interrupts 9 through 12 are reserved for special UHTREX signals, at least some of which will be associated with emergency conditions. Thus, certain neutronic signals, signals indicating loss of pressure in the primary or secondary loops, etc. will activate interrupts. One might think that these "emergency" interrupts should be higher on the list. Clearly, however, they should not be above numbers 1 and 2, for if the computer power is off nothing can be done anyway; and they should not be above 3 and 4, for chances are that one would like to transfer a diagnostic or emergency program from the drum to core immediately. Similar arguments lead to the UHTREX system interrupts being placed as shown in Table 2. Admittedly, the particular ordering is somewhat, but not completely, arbitrary.

The stall warning equipment listed in part C of Table I is provided to take the computer off-line automatically upon receipt of certain signals. In the event of a memory parity error, manual operation of the "Inhibit Computer" pushbutton, failure of certain power supplies, or if the watchdog timer (described below) "times out" the computer will be put in the so called "stall" condition. Except for parity error and some power supply failures, the computer

operation is not stopped during stall. However, the computer is prevented from making changes in any of the analog or digital outputs that are connected to process equipment. The computer has no control capability in the stall condition, but, depending on the source of the stall signal, will continue to monitor inputs, run typewriters, operate lights and recorders, etc. Thus, the stall warning equipment serves to transfer the whole system from computer operation if a computer malfunction is detected.

The watchdog timer is another safety device, and it has a fairly high position on the interrupt list. It is basically a five-second alarm clock that is ordinarily reset to zero by the executive routine many times per second. However, if the computer stops, if an endless loop is encountered, or if for any reason the computer does not return to the executive program and reset the watchdog timer at least once every five seconds, the timer "times out", generates interrupt number 5, and puts the computer in stall. On receipt of a watchdog timer interrupt a computer diagnostic program will be run (if the computer is running at all).

The real time clock generates an interrupt (number 6) every second, causing transfer to a program that increments the real world "time" count stored in the computer, does a couple other short jobs, and returns to the interrupted program. Time is used by the executive program to initialize programs that are to be run periodically.

DATA ACQUISITION AND MONITORING APPLICATIONS

It is believed that the computer system can be used to improve UHTREX reliability and the quality of data that is obtained from the experiment in comparison to that which would be obtained with conventional instrumentation

and data handling techniques. Some of the computer jobs, which are all passive in the sense that they do not involve any control functions, are described in the following.

Monitor and Alarm

About fifty vital analog signals will be sampled, linearized, and compared with high and low limits each second. If any signal is found to be out of the limits an annunciator will be operated and a message will be typed on the alarm typewriter. A second set of fifty analog signals will be sampled every 3 seconds and treated in the same way. The remaining 508 signals, which include calibration signals, will be sampled once every fifteen seconds.

All digital inputs will be scanned once per second and comparisons will be made with acceptable configurations. An alarm will be initiated if an unacceptable or inconsistent configuration is found.

Calculations

A small number of process variables such as flow rates, blower coefficients and reactivity will be calculated each second and compared with limits in the same manner as the analog signals. Calculations such as heat balances and a reactivity balance will be made once a minute and any unusual results will be printed as an alarm message. A larger number of calculations of heat balances, blower efficiency, heat transfer coefficients, helium inventories, molecular sieve bed saturations, etc. will be calculated when needed for logs, histories or when requested by the operator.

It is planned to have a calculation of dynamic reactivity as a function of time, based on reactor power, available as a demand program for use in operation.

Hourly and Demand Logs

The computer will prepare and type two hourly logs of some 40 entries each. These logs will be on paper with preprinted headings and will be in engineering units. Two of the four typewriters will be used for these logs. In addition there will be as many as 20 demand logs that can be requested by the operator and will be typed on the third typewriter. The fourth typewriter is reserved for alarm messages. The demand logs include those to type the current value of all analog points, a summary of points currently on alarm, a summary of limits, a summary of points which are not being scanned for one reason or another, a summary of all surface temperatures or all internal temperatures, a summary of strain gage readings, results of special calculations, etc. The fuel history log, which is discussed later in this paper, will be the longest demand log.

Operation Monitoring

The control switches on the UHTREX system operator's panels are connected to a computer digital input matrix and to interrupt number 19 or 20. Thus, every time the operator actuates one of these momentary control switches to open a valve, the computer receives an interrupt and by scanning the digital inputs related to that interrupt, the computer is able to identify the particular control switch that has been actuated. As a minimum, it is planned to have the computer type a message on the alarm typewriter to record the action and the time. In some cases the computer may check this action to see

if it is acceptable, based on the current status of other valves, rod positions, analog signals, etc. The computer may take some type of action if it determines that the operator made a mistake. The computer could simply initiate an alarm or it could prevent the operator action through an interlock. In any event, the computer does have capability to provide a good operation log.

System Histories

The computer will keep a modest number of histories such as the number of Mw days of operation, number of days of operation, amount of contaminants removed in the gas purification system, number of revolutions of the core, etc. as seem appropriate and useful. The one large job of this type will be to keep a history of the 1248 fuel elements in the core. A fuel history program will include a record of each fuel element serial number, its loading, and its position in the reactor as a function of time. These data, when combined with a computer record of reactor power, operating time, and temperature will allow the computer to type or punch each fuel element's history in considerable detail. This history will be available to the operator on demand and will be logged each time an element is discharged from the computer.

The computer maintained histories of fuel elements, power, temperature, flow, etc. will be logged on the paper tape punch at some interval such as once per day or week in a format that is compatible with the Laboratory EDP equipment. Thus, historical data from the UHTREX system will be available in a convenient form for later analysis.

COMPUTER CONTROL

As shown in Table 1, the computer has 24 analog outputs and 444 digital outputs. Twelve of the analog outputs are 0 to +20 volts and twelve are 0 to 20 ma. The digital outputs include 288 magnetically latching relays, 102 48-volt single shots of various durations, and 54 flip-flop type outputs producing 48 volt signals. Some of these outputs will be used to run recorders and panel lights. Many outputs, however, will be available for use to operate valves and motors in the reactor, the coolant system, and the gas purifications system; and they will be used whenever it is sensible to do so.

Control Modes

Each control switch for a valve or motor in the UHTREX system will have an associated mode selector switch. The mode selector has three positions: Manual, Computer, and Both. When the mode selector is in the Manual position and the operator actuates a control switch (or adjusts a potentiometer), the signal is transmitted directly to the controlled device as is normal for manual control. The computer can monitor this action, but does not have any active control. If the selector switch is in the Computer mode the situation is just reversed and the computer output is transmitted to the device.* In the Both mode the circuit requires simultaneous signals from both the operator

* As noted previously, a variety of computer malfunctions will automatically put the computer into stall; and while in stall the computer can not change any output that is connected to the system. The operator can put the computer into stall by pushing the "Inhibit Computer" switch.

and the computer to transmit a signal to the system.

The mode selection feature provides considerable flexibility in dividing authority between the computer and operator. It also can be used in checking out computer programs, and provides the mechanism for having manual control when desired.

Sequencing and Interlocking

The computer has the capability to operate any of the valves or motors in the system and can be programmed to do so in the proper sequence. Loading fuel, for instance, is a natural sequencing job for the computer. After receiving the fuel element identification number, its fuel load, and the channel to which it is to be loaded, the computer may schedule the operation of the core indexing motor, the two secondary gas lock valves, conveyor No. 1, three more gas lock valves, three pressure equalization valves, the elevator, and a loading ram. A similar sequence of operations is required to remove the discharged fuel element. Checks on valve positions, loader positions, system pressures, etc. will be made throughout the loading and unloading sequence.

Fuel loading is a job that must be done with utmost care to avoid damage to the loading mechanisms or fuel elements and to prevent any leakage of contaminated gas to the containment structure. It will be a tedious job and must be repeated many times. Thus, it is suited for computer operation. There is an additional advantage in having the computer do this particular job, in that it will be programmed to refuse to load a fuel element until the operator has entered the fuel element data required for the fuel history. This will greatly reduce the possibility of errors in the fuel histories.

Until confidence in the computer is established, the programs are thoroughly tested, many of the mode selector switches in a sequence of operations will be in either the Both or Manual position. Then the sequence of operation by the computer always will stop at these points until the operator actuates the correct switch. By putting most switches in the Manual position but leaving a few in Both, the computer can be used to check a sequence of operations done by the operator. Thus the computer can provide interlocks on the operator actions, just as it is possible for the operator to check the computer operation.

Reactor startup, shutdown, helium venting to reduce inventory, and bed regeneration are other jobs that are being considered for computer sequencing.

Emergency Shutdown

It should be noted here that there is a nuclear safety system completely separate from the computer which will shut down the reactor in the event of too high a power, too short a period, etc. However, there are other system failures such as failure of the heat dump fan, that call for rapid system shutdown, and the computer can handle these. If the analog or digital scan programs discover an alarm, or if an emergency interrupt signal is received, the computer will transfer to a diagnostic program. This program will determine if a true emergency exists or if perhaps, a single transducer has failed. If it is an emergency the computer will determine the type and initiate the shutdown of the system. A good diagnostic program will help to avoid unnecessary shutdowns, which in UHTREX, could lead to early failures of the blowers and the carbon insulation and support structure. Typically, a diagnostic program can be executed within one second of receiving the alarm.

On-line Control

Provision will be made in the design of the control system for computer control of primary and secondary coolant flow rates and pressures, reactor outlet gas temperature, rod position, reactor power, and recovery from a scram. Those control systems that require sampling as frequently as once a second will be handled by programs associated with the real time clock interrupt. Systems that require sampling less frequently will have timed or periodic compensation programs initiated by the executive program.

The compensation program for any particular control system can be quite complex if necessary. Switching from one compensation program to another dependent, say, on system operating conditions is a simple matter in the computer.

A process computer with time and storage available suggests many interesting analysis and control activities. Correlation programs to determine system characteristics come to mind immediately. It appears now that the computer will have some free time, perhaps half of every second, but the storage question is another matter.

DISCUSSION

Current Status

The computer is due for delivery in mid June 1965, a little over two months from now. When installed at Los Alamos, the factory demonstration tests will be repeated and a six months, 24 hour per day, reliability demonstration run will be made. The specifications for the system require that during this six month demonstration test, the computer, excluding typewriters

and the paper tape punch and reader, have a 99% availability and no more than four failures (about 1000 hours mean time between failure). During this demonstration period a substantial portion of the connections between the computer and the system will be made.

The executive, analog scan, linearization, log, and one second calculation programs are being done now, and it is hoped that they will be complete at the start of the demonstration run, so that the computer can be doing useful work during this period. All programs, of necessity, will be checked prior to bringing the reactor to criticality. The hardware and any programs that are prepared for control of the reactor and its associated equipment will be given especially close attention. Dry runs with simulated neutronics and reactor heat exchanger will be made to check connections and interaction of the computer, rod system, and reactor.

Computer Ability

The question of whether the computer that we are getting is powerful enough to do all its current jobs arises constantly. At this point it is clear that we don't really know the answer. It is suspected that the 4096 words of core storage and 31,680 words of drum storage may not be sufficient. Another core module of 4096 words can be added and the drum can be expanded to 84,840 words by adding read/write heads if either storage system should prove to be insufficient. It now appears that the computer is sufficiently fast to do all of the anticipated jobs.

Safety

It has been noted by the authors that other people who are not especially familiar with computers feel a certain apprehension, bordering on suspicion,

about letting a computer run any part of the reactor system. An analogy between "a computer run amok" and "a monkey loose in the control room" has been made. There is no basis for such an analogy, for a "computer run amok" either stops very quickly or gets itself into a tight loop and stays there. As those readers who have done some programming know, it is, in fact, difficult to get a computer to do anything at all. Correct instructions must be written and placed in the right sequence to produce an output. For instance, the computer that we will use requires from 2 to 6, 24 bit instructions of exactly the right form to change a digital or analog output that might affect the UHTREX system, and this output will have the same safety interlock as the corresponding manual control switch.

It is recognized, however, that computer failures will occur and a number of operational and programming features have been included to assure safe operation. These include

1. The reliability demonstration.
2. Hardware and program check out with simulated inputs.
3. Stall warning device.
4. Watchdog timer.
5. Automatic safe shutdown on power failure.
6. Memory parity error checking.
7. UHTREX System interrupts.
8. On-line computer diagnostic programs.

We think and certainly hope that the computer system will prove to be reliable, and that its use will improve the safety and operation of UHTREX.