Conf-920538--21

EBR-II COVER GAS CLEANUP SYSTEM UPGRADE

PROCESS CONTROL SYSTEM STRUCTURE

Reed B. Carlson, Jeffery D. Staffon
Integral Fast Reactor Operations Division
Argonne National Laboratory
P. O. Box 2528
Idaho Falls, Idaho 83403-2528

ANL/CP--74459

DE92 011836

ABSTRACT

The Experimental Breeder Reactor II (EBR-II) Cover Gas Cleanup System (CGCS) control system was upgraded in 1991 to improve control and provide a graphical operator interface. The upgrade consisted of a main control computer, a distributed control computer, a front end input/output computer, a main graphics interface terminal, and a remote graphics interface terminal. This paper briefly describes the Cover Gas Cleanup System and the overall control system; describes the main control computer hardware and system software features in more detail; and, then, describes the real-time control tasks, and how they interact with each other, and how they interact with the operator interface task.

INTRODUCTION

Cover Gas Cleanup System

The EBR-II reactor primary tank has an argon cover gas blanket over the liquid sodium coolant. This blanket becomes contaminated with highly radioactive xenon and krypton from the gas plenums in experimental fuel pins that breach during reactor operation. This radioactivity must be reduced for continued reactor operation and the contaminated cover gas analyzed to identify the subassembly that contains the breached fuel.

The Cover Gas Cleanup System cleans and analyzes the primary tank cover gas. The CGCS consists of a main cleanup loop and a gas analysis loop. The cleanup loop, called the main loop, takes argon cover gas from the primary tank, runs it through a cryogenic distillation column to clean it, and returns the clean gas to the primary tank. The gas analysis loop, called the tag system, takes a portion of gas from the cleanup loop, concentrates the xenon impurities in the gas through a cryogenic adsorption/desorption process, and runs the gas through a mass spectrometer to determine the ratios of the xenon isotopes in

* Work supported by the U.S. Department of Energy, Reactor Research Technology under Contract No. W-31-109-ENG-38.

the cover gas.

A simplified view of the CGCS is shown in Figure 1. The main loop is shown in the lower part of the figure and the tag system is shown in the upper part. The main loop consists primarily of a supply valve, a flow sensor, six compressors, two pressure sensors, a distillation cleanup column, a flow sensor, and a return valve. The tag system consists primarily of two compressors, three bed paths, a vacuum system, a sample vial, a mass spectrometer, and miscellaneous valves, heaters, flow sensors, and pressure sensors. Each bed path consists of a primary tag bed, a secondary tag bed, and supporting and interconnecting valving and piping. The vacuum system consists of two cryogenic vacuum pumps with associated piping, valving, and vacuum sensors. The beds, vial, and vacuum pumps are cooled with liquid nitrogen. Heating is done with internal resistance heaters.

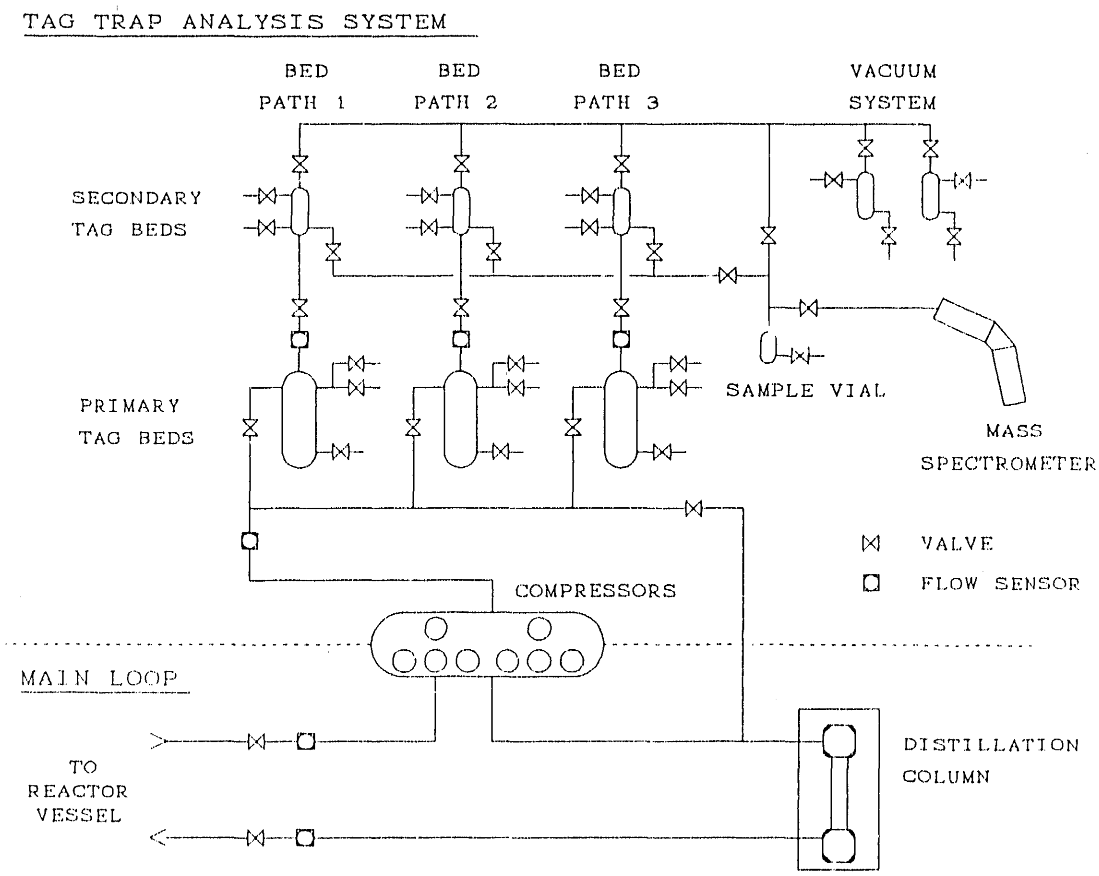

Figure 1. Cover Gas Cleanup System

During operation the main loop removes entrained sodium from the cover gas; removes the xenon, krypton, and other condensable impurities by means of a cryogenic distillation process in the distillation column; and then returns the cleaned argon to the primary tank.

The tag system takes a portion of gas from the main loop before it reaches the distillation column, concentrates the gas in a chilled primary tag bed, chills the secondary bed, heats the primary bed and the gas flows from the primary bed to the secondary bed, chills the sample vial, heats the secondary bed and the gas flows to the sample vial. The sample vial is heated and the gas flows to the mass spectrometer where it is analyzed. Since argon, krypton, and xenon adsorb and desorb at different temperatures the use of bed temperature control and venting at specific points removes the argon and krypton and concentrates the xenon as the gas progresses through the beds to the sample vial.

The mass spectrometer collects data on ten specific xenon isotopes. The xenon isotopes originate from experimental fuel in reactor core subassemblies. The fuel is tagged with xenon gas in specific isotope ratios so that experimental subassemblies whose fuel pins breach during reactor operation can be identified.

Control System Upgrade

Prior to the control system upgrade, the tag system was controlled by a number of discrete controllers and alarm units that were in turn controlled by a Data General Nova computer. The main loop was controlled by discrete controllers. The operator interface to the system was through graphics panels with meters, indicating lights and switches. The Nova computer ran a program that stepped through a sequence of states. At each state-transition point controllers, alarm units and valves would be given setpoints or position commands appropriate for the operation of the state. Periodically through the state certain parameters would be checked and compared to verify proper operation. When the mass spectrometer was being run, the Nova essentially relinquished monitoring and control of the rest of the system to the discrete controllers and alarm units and ran the mass spectrometer control program. The Nova computer basically functioned as a single tasking system with interrupt handlers to handle certain types of events. The system was unreliable and high maintenance, it was difficult to work with the Nova computer, and many of the 300 plus components were becoming obsolete.

The system was upgraded to provide a CRT based graphical user interface in the reactor control room and in the CGCS building in place of the meters, indicating lights and switches; to replace the Nova computer with a more state of the art computer system; to control the system directly, not through discrete controllers; to improve reliability and reduce maintenance; and to provide a system that allowed the CGCS to be monitored and controlled in a more timely, safe, and accurate manner. The upgrade consisted primarily of a new computer control system.

DESCRIPTION OF COMPUTER CONTROL SYSTEM

Overall Computer System

The layout of the CGCS computer control system is shown in Figure 2. The system consists of three computers: a main control computer; a main loop distributed control computer; and a tag system front end computer. The main operator interfaces with the system are through two 19 inch color graphics terminals. The main loop computer drives a main loop backup control terminal and the tag system computer drives a printer and an optional maintenance terminal. The main loop and tag system computers communicate with the main control computer through serial fiber optic links. The main control room graphics terminal directly connects to the main control computer and the remote graphics terminal, an X-terminal, connects to the main control computer through a fiber optic ethernet.

The main control computer with its associated console terminal is located in a computer room directly below the EBR-II control room. The X-terminal, main loop computer, tag system computer, main loop backup terminal, and the tag system printer are located in the CGCS building.

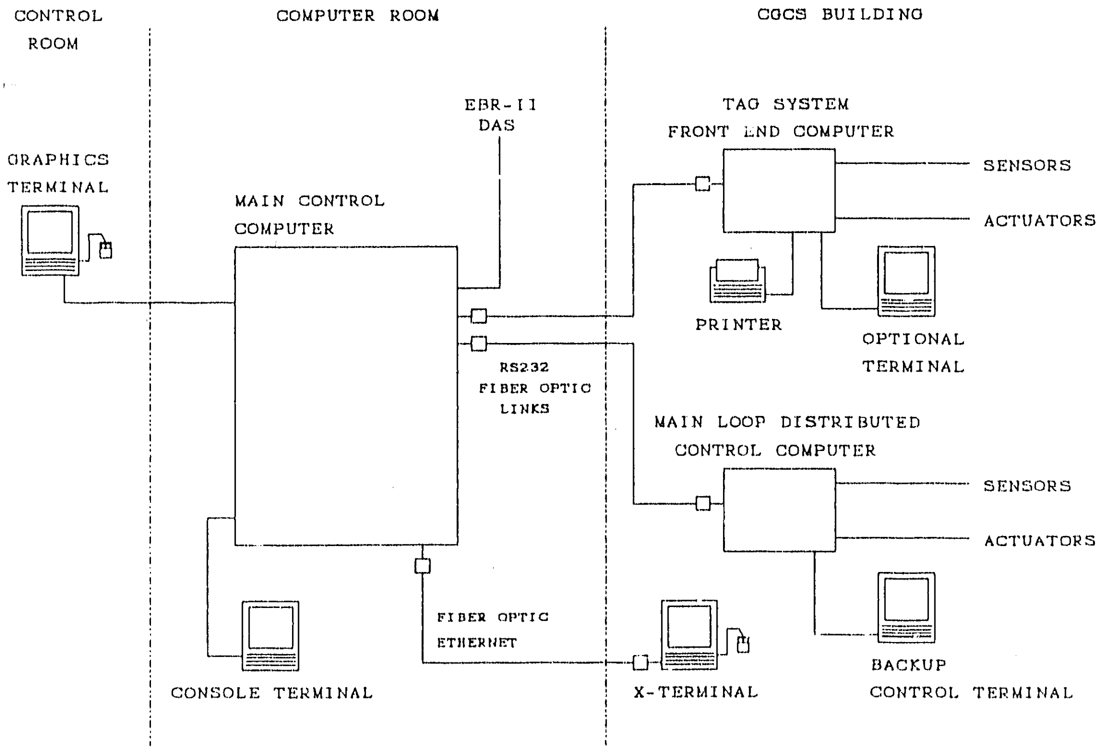

Figure 2. CGCS Computer Control System

The main control computer directly controls the tag system through the front end computer and supervises the main loop distributed control computer. The main control computer controls and supervises the CGCS through four main tasks: the operator interface task that handles the two color graphics terminals, the process control task, the mass spectrometer task, and the communications task. The operator interface task with its associated graphical interface is described in a paper by Jeffery D. Staffon and Gregory G. Peters entitled "EBR-II Cover Gas Cleanup System Upgrade Graphical Interface Design"[1]. The main loop distributed control computer and the tag system front end computer are described in a paper by Reed B. Carlson entitled "EBR-II Cover Gas Cleanup System Upgrade Distributed Control & Front End Computer Systems"[2].

MAIN CONTROL COMPUTER HARDWARE AND SYSTEM SOFTWARE

Main Control Computer Hardware

The computer is a Concurrent Computer Corporation MC6450 with dual 68030 CPUs running at 33MHz, two 68882 floating point processors, 64 KB cache memory, 8 MB of ECC memory, one 318 MB SCSI hard disk drive, one 1/4 inch 150 MB cartridge tape drive, one 5 1/4 inch floppy disk drive, one ethernet controller, 12 serial ports, and one GA1550 color graphics subsystem. Eight of the serial ports are on a High Performance Serial Multiplexer (HPSM). The HPSM has its own MC68010 processor so the serial port handling is done independently of the main CPUs. The GA1550 graphics subsystem includes a 19 inch 1280 X 1024 non-interlaced color display, a keyboard, mouse, and a graphics driver board with a TMS34010 processor and 512 KB of memory. The graphics processor performs the basic graphic functions independently of the main CPUs.

The computer is built around a VME bus and a high speed memory (HMI) bus. The graphics subsystem board and the HPSM connect to the system through the VME bus. The floppy, hard disk, and tape connect through a SCSI adapter. The CPUs each have a floating point processor and share the 64 KB cache, the ethernet controller, and four serial ports. The 64 KB cache connects to the SCSI adapter, the VME adapter, and the 8 MB of memory through the HMI bus. The system architecture is shown in Figure 3.

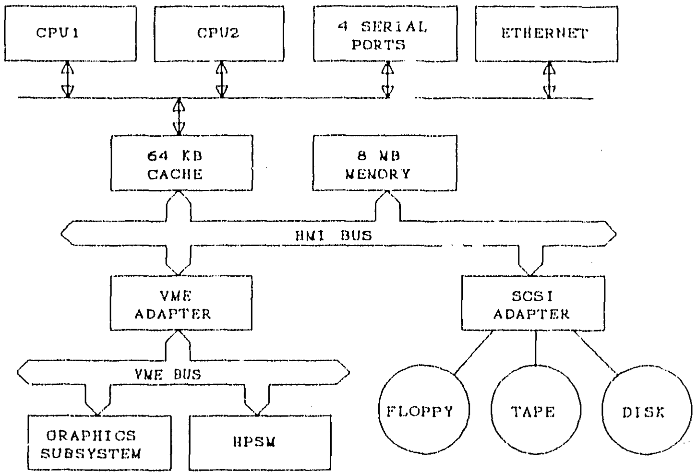

Figure 3. Main Computer Architecture

Main Control Computer System Software

The main control computer operating system is RTU, Concurrent Computer Corporation's real-time enhanced UNIX operating system. The operating system looks and feels like standard UNIX but has been enhanced with a number of features that make it useable in real-time applications. The enhancements that were utilized in this upgrade are fixed priority scheduling, process preemption, main memory process locking, control over which CPU runs which process, ability to dedicate a CPU to real-time processes, and asynchronous system traps (ASTs). The operating system lets one process run on one CPU while another process runs concurrently on the second CPU. It also allows a given process to use both CPUs concurrently through the use of threads.

In the CGCS upgrade three of the processes (or tasks) are run as real-time processes at three different priority levels. These are the communications task at the highest priority, the process control task at the next to the highest priority, and the mass spectrometer control task at the lowest real-time priority. The communications task can preempt the process control and mass spectrometer control tasks and the process control task can preempt the mass spectrometer control task. All three tasks run on CPU 2 which is dedicated to real-time processes. Two of the three processes are locked into memory to eliminate any memory paging or process swapping overhead.

The asynchronous system traps are the primary mechanism used to synchronize the tasks and to initiate the running of a particular task or part of a task. The ASTs are similar to the UNIX signal mechanism in that they are a type of software interrupt that the system can send to tasks or that tasks can send to each other or themselves. ASTs can be assigned priorities, can never be lost, can be queued, and can pass a 32 bit word of information. The ASTs are assigned to a specific handler in the receiving task. The receiving task can block ASTs that are below a specific priority. Two types of ASTs are used - ordinary ASTs and clock ASTs. Ordinary ASTs are used when a task wants to notify another task or itself of a condition. Clock ASTs are sent in response to a repetitive or one-shot time interval completion. Typically a task goes into an AST pause where it waits for ordinary or clock ASTs. The bulk of the task functions are implemented as AST handlers or run in response to AST handlers.

A UNIX feature that is utilized is shared memory. The four CGCS tasks share a memory area. This area is used to store data that is needed by more than one task, to pass data from one task to another, and to store data that is used by only one task but needs to be easily changeable.

REAL-TIME CONTROL TASKS

Overall Intertask Structure

Figure 4 gives the overall intertask structure for the CGCS operator interface, process control, mass spectrometer control, and communications tasks. The tasks access a common shared memory area and send ASTs to one another for intertask communications and synchronization purposes.

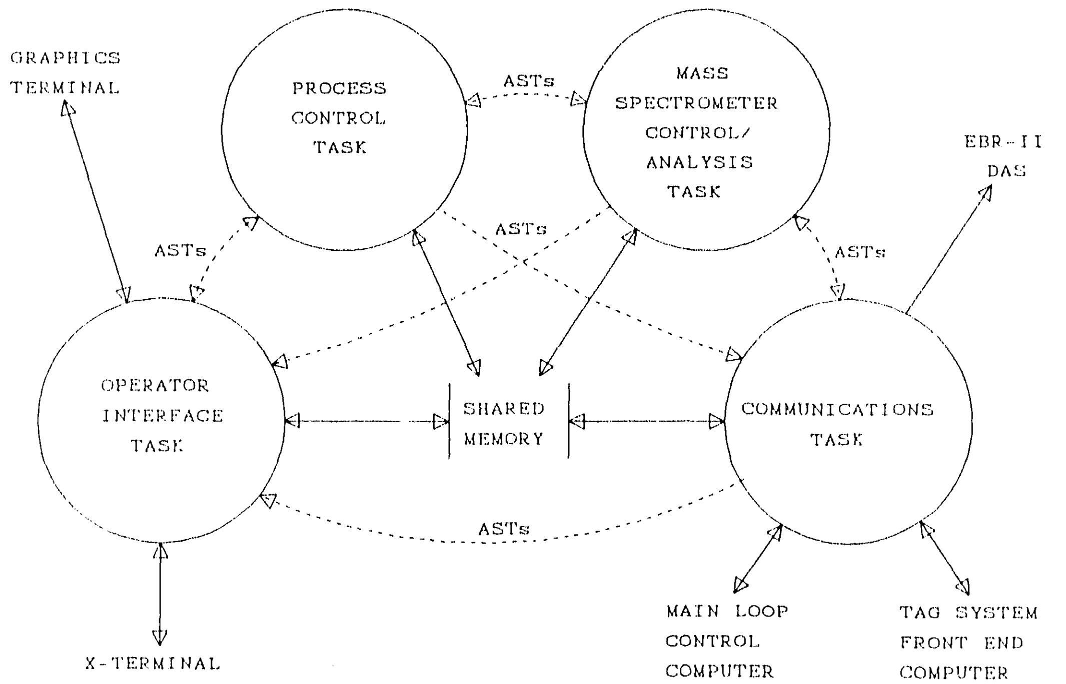

Figure 4. Task Structure

The shared memory area contains task process IDs; AST handler addresses; tag bed path control, vacuum system control, and mass spectrometer control information that is needed by more than one task; process and component alarm information; manual component control information; commands and setpoints for the process control task; commands and setpoints for the main loop distributed control and tag system front end computers; raw analog input, digital input, and engineering unit data from the main loop and tag system computers; and mass spectrometer analysis results data.

A task not shown on the task structure diagram is a small task called the kreator task. This task starts and monitors the other tasks. If one of the four main tasks terminate for any reason the kreator will make up to two restart attempts on the task. If the task can't be started the kreator task will log that information in an error log file on the hard disk. This task also provides a maintenance interface that allows the tasks to be terminated with no restart attempts and then restarted later after the maintenance is completed.

Process Control Task

The Process Control Task (PCT) controls the portion of the Tag System that cryogenically captures the sample so that it may be analyzed by the Mass Spectrometer. The sample starts as impurities in the argon cover gas. When a portion of the argon cover gas is brought into the Tag System the PCT controls the temperature and valve line-up to sequence the sample through the system until it reaches the Mass Spectrometer.

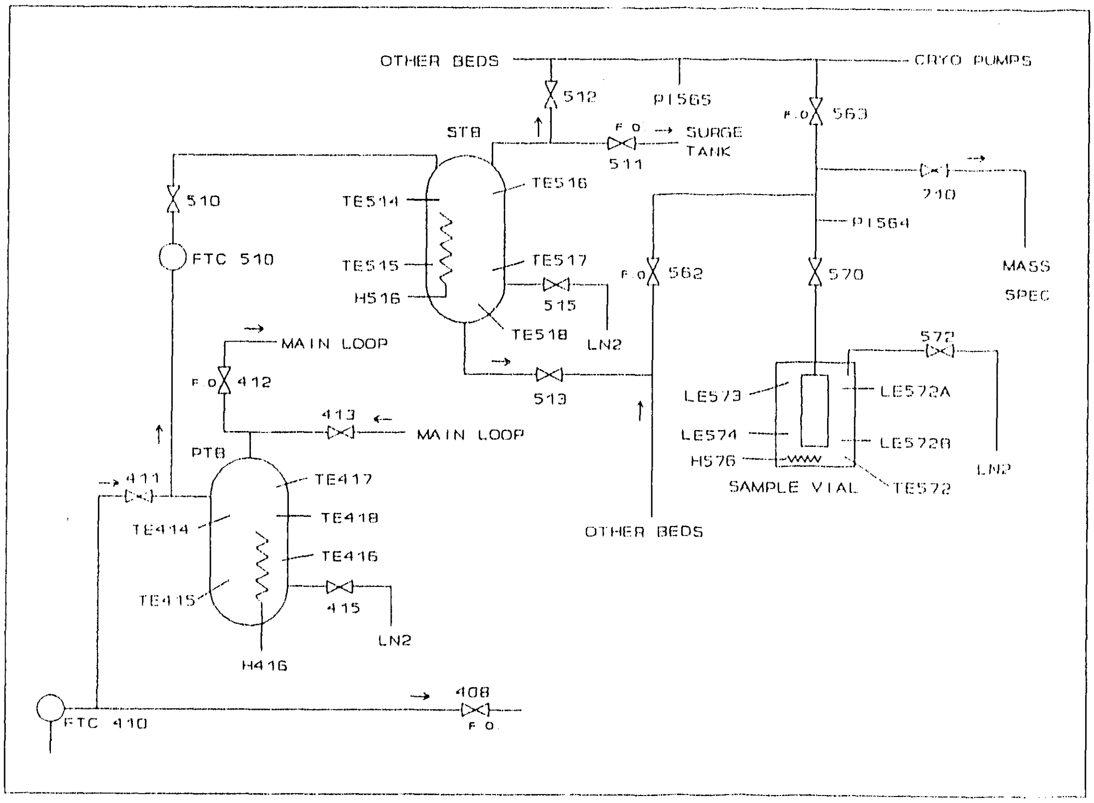

Figure 5 - Tag System Bed Path

There are 19 states that the Tag System sequences through to ensure that the sample has the highest purity level possible before it is analyzed. Four of the states are recovery states that are entered only when the normal sequence is interrupted. The Tag System consists of three bed paths, this enables up to three samples to be processed simultaneously, with some limitations. Since there is only one Mass

Spectrometer and one inlet source from the Main Loop, only one sample can be analyzed at a time and only one bed path can be connected to the Main Loop at a time. Once the sample is in a bed path, other samples can be taken from the Main Loop and placed in the remaining bed paths. Figure 5 is a diagram of one of the bed paths. The Primary Tag Bed (PTB) is chilled with liquid nitrogen flowing through valve 415. A sample of the argon cover gas is brought into the PTB through valve 411. At this point the Secondary Tag Bed is chilled and heat is applied to the PTB to bring it to a specific temperature to drive off only the sample and pass it to the STB through valve 510. The system waits until the Analysis System is free. When this occurs, the STB is heated to drive off the sample and pass it to the Sample Vial through valves 513, 562, and 570. The previous two stages are further purification steps to ensure the Mass Spectrometer obtains a pure sample to analyze. After the sample is passed to the Mass Spectrometer through valves 570 and 710 and analyzed, the system performs a cleanup state to get ready for a new sample.

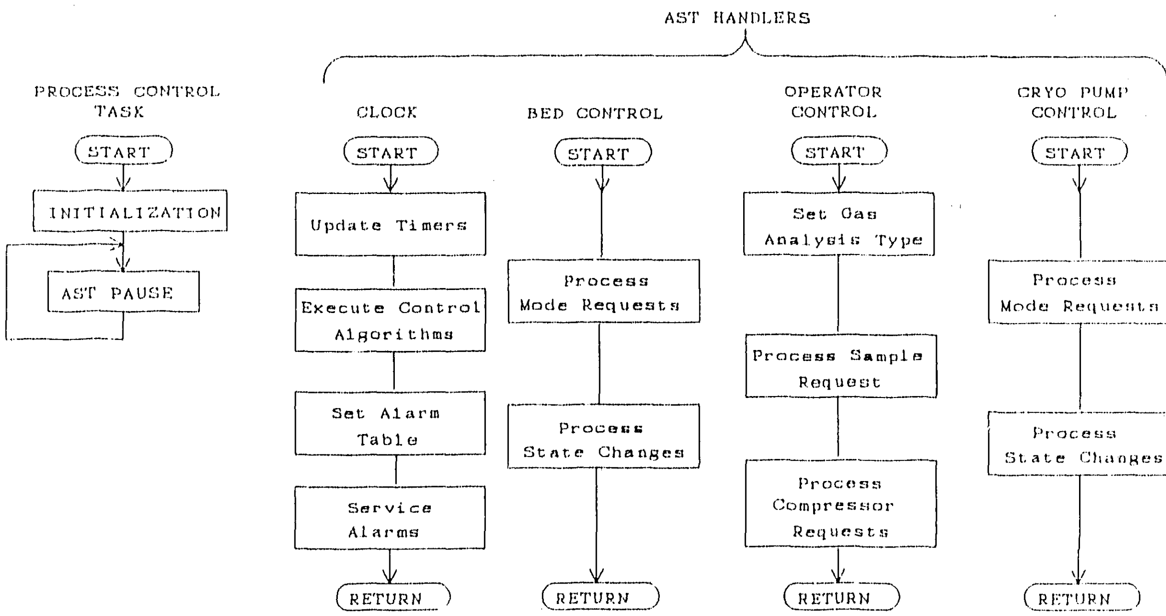

Figure 6 - Process Control Task Program Flow

The control for this system is very complex because of the sequencing through many different tightly specified configurations and temperature ranges. The PCT is an interrupt driven task that initializes it's data segments and then waits for an AST from one of the other tasks or it's own internal timers. Figure 6 shows the high level program flow of PCT. There are a number of timers that are needed to keep track of the different states within the tag system. The Chill state for instance takes from 3 to 4 hours for the PTB to reach the chill temperature from ambient temperature. Other timers help control the configuration changes that occur when the tag system moves from one state to another. When a valve is requested to open, there is delay time that PCT waits before it checks the actual state to see if a valve misoperation alarm is to be issued. Essentially every component in the system has a timer associated with it and each component has a specific period of time it is given to change state before an alarm is issued. If the component has not reached the desired state within the time allowed for it, an alarm is posted. The flow diagram labeled "Clock" in figure 6 illustrates this. On one second intervals, the "Clock" handler is executed. Timers are updated, the control algorithms are executed, the system is checked for out-of-state conditions, the alarm table is set, the alarms are serviced, and an "I'm alive" flag bit is set in shared memory to let the Communications Task know that the Process Control Task is running.

The "Bed Control" handler is primarily used to process ASTs passed from the Operator Interface Task. This handler processes mode requests and state changes. A state change is a request that can cause the system to enter one of the recovery states. The recovery states are: 1) Purge PTB thru STB, 2) Clean up STB, 3) Clean up STB and Analysis System, and 4) Clean up Analysis System. These states are usually entered when the operator requests a sample to be aborted or requests a state that will cause the bed path to return to the OFF state. In this case, a clean-up sequence is executed.

The "Operator Control" handler also handles ASTs from the Operator Interface Task. This handler receives the operator requests to set the analysis gas type, process a certain number of samples, and turn on or off compressors related to both the Tag System and Main Loop. With the upgrade software the operator is able to take multiple samples within a given period and analyze a particular sample a number of times.

The Process Control Task is a complex task that has a predetermined number of states that it monitors and controls. If at any time the system fails to respond in the required period of time, an alarm occurs. Any control commands that need to be executed are posted in shared memory and then an AST is sent to the Communications Task telling it to send the commands to the front-end and distributed control computers. When the configuration change has been executed the result of the change is sent back to the Communications Task in the data response messsages and then posted in shared memory for the Process Control Task to verify.

Mass Spectrometer Control/Analysis Task

The mass spectrometer control/analysis task controls the inlet valves to the mass spectrometer, the mass spectrometer magnet, the number of electrometer readings that are taken at a magnet setting, and analyzes the data collected by the mass spectrometer. The inlet valves are open/close valves that allow the inlet piping to the mass spectrometer to be purged with a vacuum pump, filled with xenon gas from the sample vial, and then allow the gas to be bled into the mass spectrometer. The magnet control calculates the 16 bit analog output values that drive the magnet so that ionized atoms of a particular xenon isotope, or atomic mass unit, of interest are directed at the mass spectrometer electrometer. The electrometer outputs a signal that is proportional to number of atoms in the sample at the particular magnet setting.

Ten xenon isotopes are of interest. These have atomic mass units (amu's) of 124, 126, 128, 129, 130, 131, 132, 133, 134, and 136. Two of the isotopes are in every cover gas sample - 131 and 136. These isotopes are used to calibrate the mass spectrometer at the beginning of every sample analysis run. To perform the calibration the control program outputs a value to the magnet that is above that needed to direct amu's of 136 at the electrometer. The program then controls the magnet in a downward sea... until it finds the amu 136 peak. Once the peak is found, peak edges are found, and from the edges the peak center is found. The magnet value required to get the peak center is saved. The program then searches for amu 131 starting near magnet setting where it expects the isotope to be. The program goes through the same search process as for 136 and saves the magnet value required to get the peak center for amu 131. After the peaks for the two isotopes are found, the program searches for another peak starting at amu 124 and searching upward. The peak locations for 131 and 136 are used to get near the tops of the peaks for the other isotopes. If a third peak is found the magnet value for the peak center is located in the same manner as for 131 and 136 or, if a peak is not found, data from a test run is used to closely approximate the location of a third peak. The 131, 136, and third peak data is fed to a curve fit routine that gives an equation relating amu to 16 bit magnet drive values. This equation is used to get the magnet values for the remaining isotopes.

Using the magnet control data from the calibration process the program then scans up and down through the ten isotopes a number of times collecting peak readings and readings at points between the peaks. The readings from the points between the peaks are averaged and subtracted from the peak readings to get the amount of isotope relative to a background or noise baseline.

When the scanning data collection is completed the data is averaged by isotope and atom percents and 95 percent confidence levels are calculated. The atom percent and confidence level data is saved, sent to the EBR-II DAS, printed on the tag system printer, and displayed on one of the graphics terminal views. This data, which gives the relative ratios of the ten xenon isotopes in the cover gas, is used to determine which fuel pins have breached.

The inlet valve manipulation, calibration, isotope data collection, and atom percent and confidence level calculations are performed by a straight line program in the mass spectrometer task that performs each major function in sequence. See Figure 7. This task is different from the process control task and the communications task in that the program functions are not run as AST handlers.

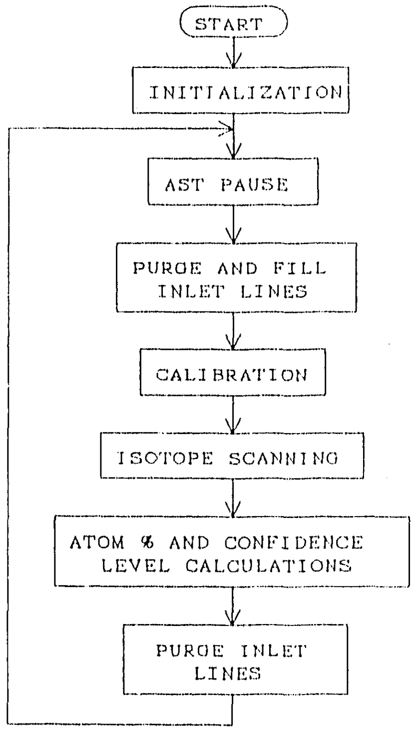

Figure 7. Mass Spectrometer Task Program Flow

When the task is first started, data initializations take place, log files are opened, attachment is made to shared memory, the process is made real-time and locked into memory, process ID's and AST handler addresses are posted in shared memory, and the task enters an AST pause. When a "begin mass spectrometer analysis" AST is received from the process control task, the mass spectrometer task runs the program as described above.

When a magnet control value is to be output to the mass spectrometer and electrometer readings taken, the 16 bit control value and the number of readings to be taken is stored in shared memory. A "control magnet" AST is then sent to the communications task and the mass spectrometer task pauses. A communications task AST handler builds a magnet control message that is sent to the tag system front end computer. The front end computer outputs the magnet value, collects the electrometer readings, and sends a message back containing the data. The communications task stores the data in shared memory and sends a "new mass spectrometer data" AST back to the mass spectrometer task. The mass spectrometer task continues operation when the AST is received.

After the atom percent and confidence level calculations are completed the resulting data is stored in shared memory. An "analysis complete" AST is sent to the communications task. The communications task AST handler sends a message containing the data to the EBR-II DAS, sends another message with the data to the tag system front end computer for the CGCS building printer, and sends a "new data available" AST to the operator interface task so it can be displayed on a mass spectrometer view. The inlet lines are purged, the mass spectrometer is isolated from the sample vial, and an AST is sent to the process control task telling it that the bed path that supplied the gas can go on to its next operating state.

At this point the task returns to the AST pause at the beginning of the program and waits for another analysis request.

Inlet line purging and filling take anywhere from 38 seconds to 60 seconds. These time intervals are handled by one-shot clock ASTs. The inlet valves are lined up for purging or filling, the clock AST time interval is initiated, and at the end of the time interval the clock AST is received and the task continues operation.

The task also has a repetitive interval clock AST that is received every 2 seconds. On receipt of this AST a bit in a shared memory variable is set. This is an "I'm alive" flag bit that lets the communications task know that the mass spectrometer task is still there and operating.

Communications Task

The communications task handles the communications with the tag system front end computer, the main loop distributed control computer, and the EBR-II DAS computer. The task builds messages using commands and data from shared memory; initiates transmission of the messages to the tag system computer, main loop computer, or DAS; receives messages from the tag system and main loop computers; converts raw data from the messages into engineering units; stores the raw and converted data into shared memory; sends ASTs to the mass spectrometer control task and operator interface task when special conditions occur; and checks the operating status of the operator interface and mass spectrometer control tasks.

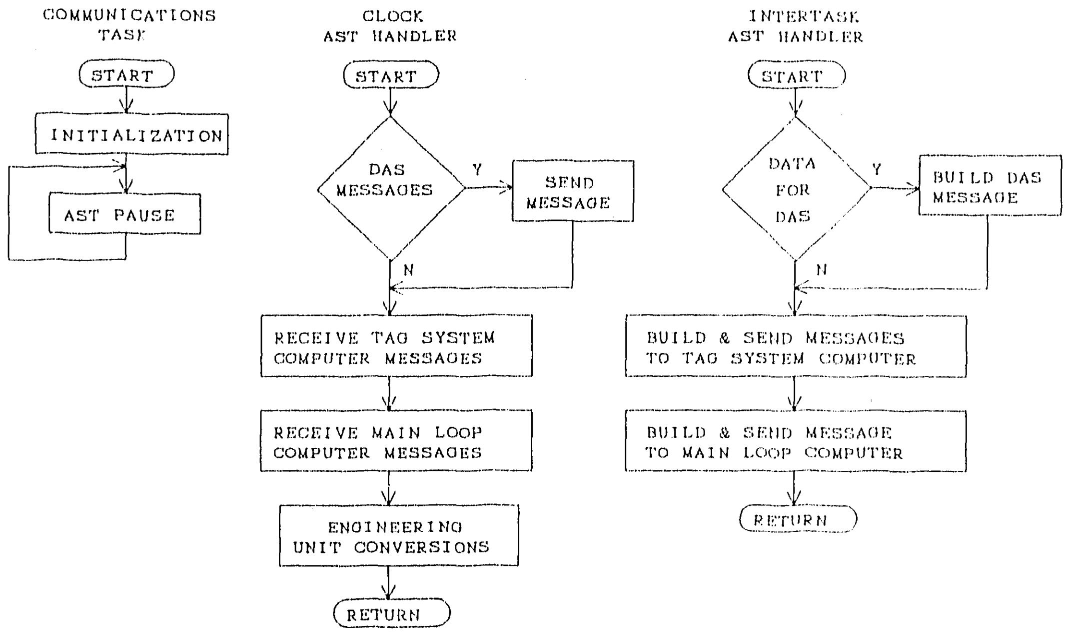

Figure 8. Communications Task Program Flow

When the communications task is first started, local data areas are initialized, a log file is opened, attachment is made to shared memory, the process is made real-time and locked into memory, process ID's and AST handler addresses are posted in shared memory, and the task enters an AST pause. From this point on the task operates in response to intertask ASTs and clock ASTs. See Figure 8.

Intertask ASTs are received from the process control task and the mass spectrometer control task. The process control task sends an AST every second, after it has run its once-a-second control and limit check calculations, and when a bed path operating state changes. The mass spectrometer control task sends ASTs when the mass spectrometer magnet is to be controlled and electrometer data collected and when data is to be printed on the tag system printer.

In response to the "once-a-second" AST from the process control task the communications task builds command messages for the tag system front end and main loop distributed control computers, calculates and appends a CRC-16 checksum to the messages, and initiates transmission of the messages to the two computers. When a "bed state change" AST is received the communications task builds a message containing the bed path number and the new operating state and the message is stored in a queue for transmission to DAS. If the new bed state is the one following the mass spectrometer analysis, the atom percent and confidence level data stored in shared memory is converted from IEEE floating point format to a format native to the DAS computer and the data is included in the message.
In response to a magnet control or print data AST from the mass spectrometer control task the communications task builds the apropriate message, a CRC-16 checksum is calculated and appended to the message, and transmission of the message to the tag system computer is initiated.

A clock AST is received by the communications task every 1/10 of a second. In response to this AST the task checks for messages in the DAS queue. If there are messages, transmission of the first message to DAS is initiated and a timer is set to delay the sending of any other DAS messages for 1 second. This is followed by a task status check. The shared memory status variable has individual bits that indicate the operational status of the operator interface task and the mass spectrometer task. If the bits are set, the tasks are alive and operating. After the bits are checked they are reset. If one or both of the bits are already reset, this information is sent to the tag system front end computer in the next "once-a-second" command message. The failure information will then be conveyed to a EBR-II control room alarm terminal by a tag system computer output. Finally, the tag system and main loop computer receive message buffers are checked. If any characters are available they are assembled into local message arrays. When a complete message is received the apropriate tag system or main loop message receive functions are called. These functions calculate the message CRC-16 checksum and compare it to the one appended to the message; store the data from the messages in shared memory; convert raw data to engineering units and store the unit data in shared memory; if the message is a mass spectrometer data message, an AST is sent to the mass spectrometer control task to let it know new data is available; and, if the data contains new set points or compressor commands that were entered at the main loop backup control terminal, an AST is sent to the operator interface task letting it know that set points or compressor commands have changed.

At the end of the AST handling described above the communications task returns to the AST pause and waits for the next intertask or clock AST.

CONCLUSION

The main control computer with its real-time enhanced UNIX operating system has proven to be an effective means of controlling the CGCS. The intertask and clock AST enhancement has been of particular benefit since real-time control systems are typically cyclic in nature, multi-tasking, and require prioritization of responses. The use of a system with two CPUs, one dedicated to real-time, has enabled the real-time tasks to operate without being detrimentally affected by operating sytem and X-windows overhead. Use of an operating system that looks and feels like UNIX enabled application code development to proceed without first learning a new real-time operating system. This enabled the upgrade project software development to be planned and completed on a realistic schedule.

REFERENCES

1. Jeffery D. Staffon and Gregory G. Peters, "EBR-II Cover Gas Cleanup System Upgrade Graphical Interface Design", *Proceedings of the 8th Power Plant Dynamics, Control & Testing Symposium*, Knoxville, TN, (1992).

2. Reed B. Carlson, "EBR-II Cover Gas Cleanup System Upgrade Distributed Control & Front End Computer Systems", *Proceedings of the 8th Power Plant Dynamics, Control & Testing Symposium*, Knoxville, TN, (1992).

END

DATE
FILMED
6/11/92