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UCRL-53090

# Supervisory control and diagnostics system for the mirror fusion test facility

## –overview and status 1980

P. R. McGoldrick

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UCRL-53090
Distribution Category UC-20
20f,d

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## TABLE OF CONTENTS

# Supervisory control and diagnostics system for the mirror fusion test facility

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ABSTRACT

The Mirror Fusion Test Facility (MFTF) is a complex facility requiring a highly-computerized Supervisory Control and Diagnostics System (SCDS) to monitor and provide control over ten subsystems; three of which require true process control. SCDS will provide physicists with a method of studying machine and plasma behavior by acquiring and processing up to four megabytes of plasma diagnostic information every five minutes. A high degree of availability and throughput is provided by a distributed computer system (nine 32-bit minicomputers on shared memory). Data, distributed across SCDS, is managed by a high-bandwidth Distributed Database Management System. The MFTF operators' control room consoles use color television monitors with touch sensitive screens; this is a totally new approach. The method of handling deviations to normal machine operation and how the operator should be notified and assisted in the resolution of problems has been studied and a system designed.


INTRODUCTION

The 130-million-dollar Mirror Fusion Test Facility (MFTF) is the most extensive mirror experiment yet undertaken in the United States magnetic fusion energy program. MFTF will be capable of investigating critical issues of scale, high-temperature, high-density, and long-confinement time at plasma volumes not far below the requirements projected for future fusion power plants.[1,2] MFTF has technology goals to provide:

- Vacuum and cryogenic systems to support a large vacuum vessel.
- Large superconducting magnets for plasma confinement.
- High-voltage electrical power supply system to drive high-power neutral beams.
- Control system to operate the facility.

The MFTF is being designed to have an availability of 0.8 over a useful life of 10 years.[3] The MFTF project[4] was approved by DOE October 1977 and is scheduled for completion by October 1981. The plan to convert MFTF into a tandem mirror machine may modify the above schedule. However, this is beyond the scope of this paper.

The Supervisory Control and Diagnostics System (SCDS) provides for operator control and diagnostics of the MFTF. SCDS is responsible for control of an MFTF experiment, collection of experimental data, and providing an environment for manipulation and display of the data in meaningful form. Figure 1 shows a system diagram of the MFTF control and diagnostics system and in the following sections each part of the control system will be examined. For additional information on the system consult the reference section.

## LOCAL CONTROL PROCESSES

The Local Control Process (LCP) subsystems shown at the bottom of Fig. 1 represent the nine MFTF subsystems controlled by SCDS. The plasma streaming, start-up neutral beam, and sustaining neutral beam subsystems initiate and sustain the MFTF deuterium plasma.[3] These three subsystems may individually shoot once per minute, but can participate in a coordinated plasma physics shot only once every five minutes. The remaining subsystems support the MFTF vessel or the MFTF facility. The magnet, vacuum, and cryogenics subsystems require true process control from SCDS.

It is beneficial to have SCDS interface to the nine LCP subsystems in a uniform manner. Furthermore, it is desired that these interfaces be intelligent and relieve SCDS from having to do any fast feedback control (less than two seconds). The interfaces would perform chores for SCDS and report only interesting developments. Digital Equipment Corporation LSI-11 computers were chosen for the interfaces[5] (about 60 computers total). The system of interface computers is called the Local Control and Instrumentation System (LCIS). The LCIS computers do not communicate among each other, but rather each acts as an intelligent interface between SCDS and the equipment being controlled and monitored. The major design criteria for the LCIS system are:

- Allow SCDS to specify the current hardware configuration of the devices connected to each LCIS computer. One would expect hardware to change either because of modification, addition, or substitution

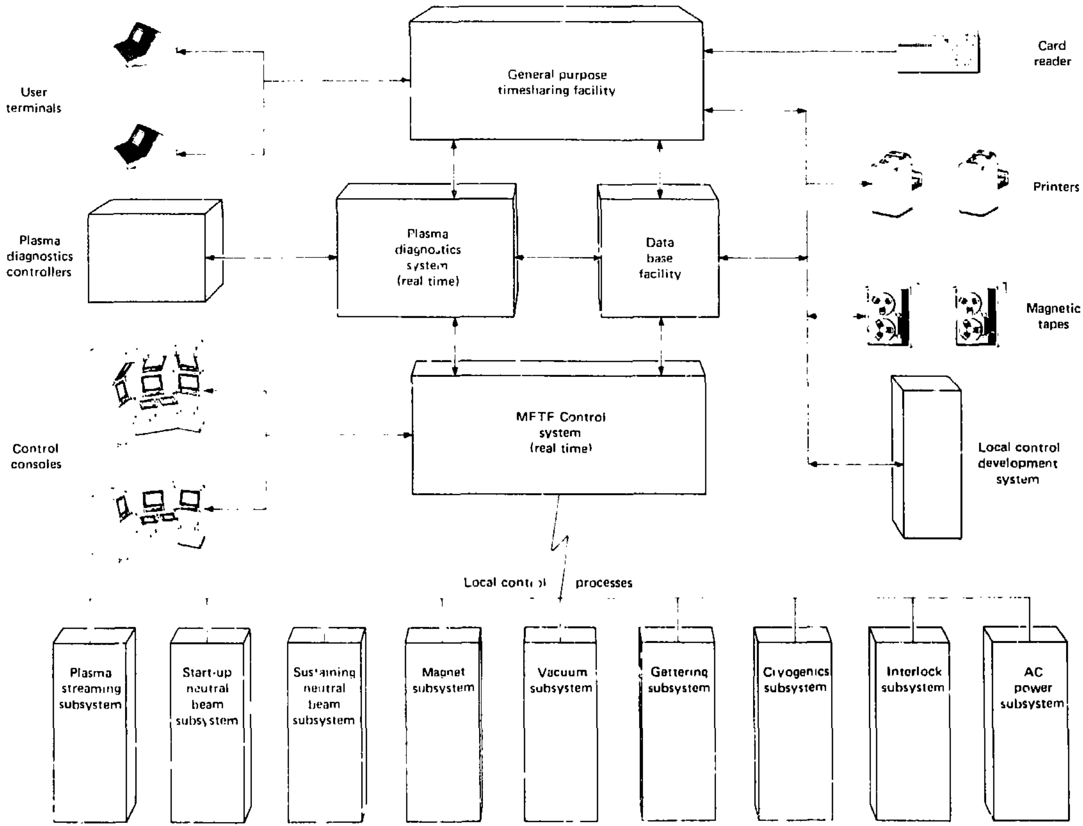


Fig. 1. MFTF control and diagnostics system - system diagram.

of equipment. Since configuration is controlled by SCDS, LCIS computer hardware can be reconfigured without deleterious effect.

- Allow SCDS to reference any MFTF device by the device name specified by SCDS at configuration time. This allows SCDS to be hardware independent once the configuration is done.
- Monitor MFTF devices at the discretion of SCDS and report changes as they occur. SCDS should be able to set the sensitivity of the monitor so that SCDS does not have to be bothered by minor uninteresting fluctuations.
- Allow SCDS to set exception limits on a device being monitored such that SCDS will be notified if the value being monitored crosses an exception limit.
- Allow execution of high level control programs sent by SCDS. The control programs to be accommodated need not be extremely complex but should be able to set time-outs and specify what is to happen if certain operations fail.

Peterson, Labiak, Langer, et al. believe that the above criteria could be best met by implementation of a software executive (PLEX) for the LCIS computers.[6-8] PLEX was completed in 1980 and tested on the Tandem Mirror Experiment.

## DATABASE FACILITY

The Database Facility is central to SCDS, containing the current state of MFTF's many sensors and controls. The database also contains plasma and machine diagnostics data taken from each experiment. Since each experiment can generate up to four megabytes of plasma diagnostic information and a quarter of a million bytes of machine diagnostic information, and since an experiment can be performed every five minutes, the handling of this large amount of data is not a simple task. Estimates based on a five-year lifetime for MFTF show that the database is expected to accumulate plasma physics data from nearly 50,000 shots[3] ($2 \times 10^{11}$ bytes of information).

Further constraints placed on the database provide that the database:

- must not lose any information
- must allow, within a reasonable time, access to any data taken on any experiment

- must be fast enough to allow processing of the 4.25 million bytes of information every five minutes.

Studies done by Choy[9] in 1979 show that commercial database management systems available to SCDS were far too slow for the requirements of MFTF. Choy's tests show that it would take over 20 minutes to store the 4.25 megabytes of diagnostics data (over four times longer than the five minute requirement). A Database Management System (DBMS) has been designed that will meet the requirements of MFTF[10] and is partially implemented. Some interesting features of the DBMS are:

- relational in nature
- supports a database that is distributed across several computers
- supports data contained in or on the following:
    - local memory
    - shared memory
    - magnetic disks
    - magnetic tapes
- important data tables can be declared as "backed up" (The "backed up" tables will then be kept on two different computers to assure that a single point failure will not make the tables unavailable.)
- allows programs to be notified if a value in the database changes or if a value changes outside of a specified range.

The approach to accessing the database was done by Wade.[11] It is desired that programmers have a very simple method to put database accesses into their programs while maintaining fast database access.

Commercial database systems usually have programmers access the database via simple procedure calls. Unfortunately, to keep the procedure calls simple, the calls carry minimal information, thus increasing the database system's overhead.

Wade's solution is to put database references in the programming language, which allows database objects to be manipulated much like program variables. A precompiler was built that inputs programs with database references and outputs Pascal programs with complex database system calls. The precompiler allows programmers simple access to the database yet passes the database system enough information (by the complex procedure calls produced by the precompiler) to allow efficient access.

## PLASMA DIAGNOSTICS SYSTEM

The purpose of the Plasma Diagnostics system is to control the plasma diagnostics equipment, collect up to four megabytes of plasma diagnostic information per shot, and perform intershot data processing.

The intershot data processing allows physicists a quick look at how the experiment is progressing, so that machine and diagnostic parameters may be modified, if necessary, for subsequent shots.

The following numbered paragraphs refer to Fig. 2.

1. Physicists interface with the Plasma Diagnostics System by means of graphics terminals and programs they write. It should be noted that there are plasma diagnostics that are critical to diagnosing machine operation. These critical diagnostics are part of the control system and not the plasma diagnostics system. They are controlled by MFTF operator consoles described later in this report.
2. In order to interface with a diagnostic directly for testing or calibration, the physicist must get an access permit from the plasma diagnostics manager. The plasma diagnostics group decides on the method of granting the access permit (password or explicit granting of access by the lead physicist are possibilities).
3. Once the physicist has the access permit, he or she is allowed to access the diagnostic directly until he or she returns the access permit to the plasma diagnostic manager.
4. Data obtained from the above direct interface with the diagnostic equipment may be used to place important calibration information into the database. Physicists may also use their access permit to modify set-point information in the database for future shots.
5. When the "shoot" button is pressed on an MFTF operator's control console, it causes a shot manager to proceed through a shot sequence. A normal shot sequence for plasma diagnostics is as follows:
   - 5.1 Shot manager requests OK-to-shoot from plasma diagnostics manager and receives an OK (or not).
   - 5.2 Shot manager issues a prepare-to-shoot command for each plasma diagnostic that is to be included in the shot. The prepare-to-shoot routines send shot parameters to their respective diagnostics and tell the shot manager when the diagnostic is prepared.

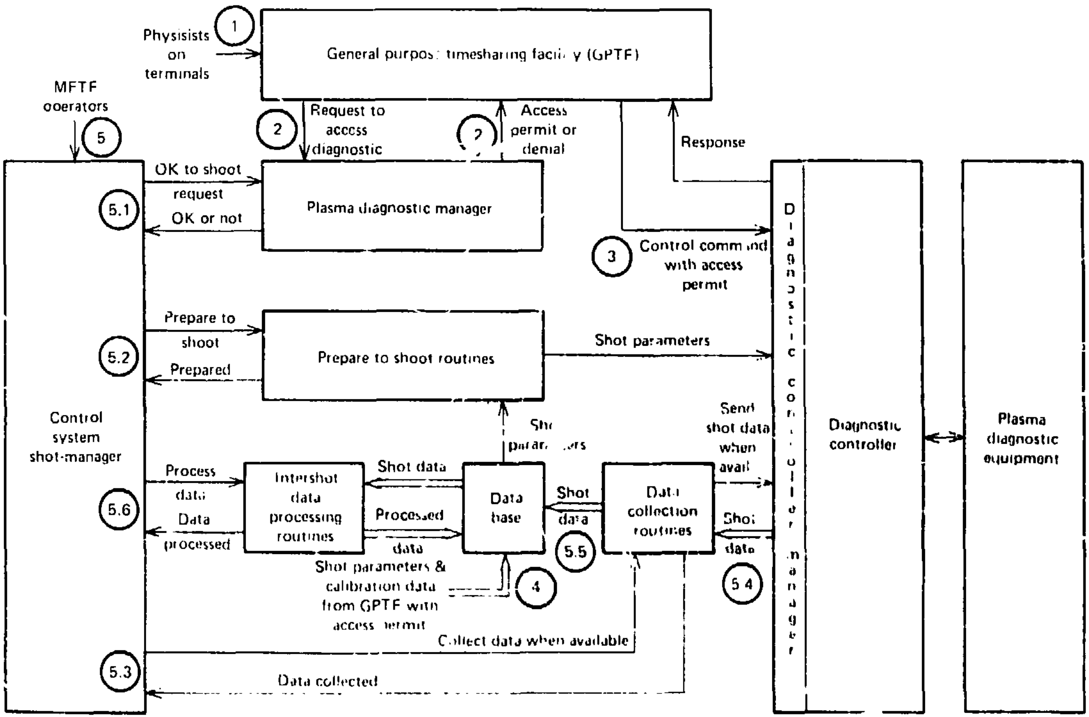


Fig. 2. Plasma diagno tics sv tem.

5.3 The shot manager tells the data collection routine for each plasma diagnostic to collect the data when it's available. The data collection routines pass the request on to the diagnostic controllers. The shot manager turns on timing and firing circuitry that fires the shot.

5.4 As data becomes available it is sent to the data collection routines and on to the database (5.5). The data collection routines may do some conversion of data to engineering units, provided the process is invertible. In case it is discovered later that the conversion was in error.

As each data collection routine completes its collection, the routine notifies the shot manager of the completion.

5.6 The shot manager then collects data collection completion notices. When the shot manager determines (by tables in the database) that enough data has been collected to start a data processing routine, it will start that routine. The above process continues until all the data has been collected and all the data processing routines have been started.

As each data processing routine is completed it notifies the shot manager.

The Plasma Diagnostics system design provides the following benefits:

- Allows physicists direct control over a diagnostic.
- Controls access to diagnostics.
- Data collection and processing performed is based on data availability (i.e. a diagnostic that collects data only during plasma buildup can be collected and processed before the shot is over--assuming long shots).

For more information on the Plasma Diagnostic system, see Ref. 12.

## GENERAL PURPOSE TIMESHARING FACILITY

The General Purpose Timesharing Facility (GPTF) provides a facility upon which program development and post-shot analysis can be done. Also, physicists on the GPTF may control certain plasma diagnostics by access permits from the plasma diagnostic manager.

The GPTF currently supports 24 terminals located at several sites around MFTF. The GPTF is running on two 32-bit Perkin-Elmer computers and 's implemented with manufacturers software.[13] The Facility is currently in heavy use by SCDS programmers for program development.

Once MFTF comes on-the-air it is not clear how much post-shot analysis should be done on the GPTF using our current hardware. Decisions regarding post-shot analysis are still to be made. Among possible post-shot analysis scenarios are to limit post-shot analyses when MFTF is not running experiments, to expand the SCDS hardware to allow post-shot analysis concurrent with MFTF experiments, to send all MFTF data to the MFE computer center for analysis there.

## MFTF OPERATOR CONSOLES

The purpose of the MFTF control room is to allow operators independent control over the various MFTF subsystems and also coordinated control of all the subsystems when appropriate.

The "classical" approach to control room design has been to let each engineer in charge of a subsystem have so many feet of rack or control panel space to mount his switches, dials, and gauges. Each engineer then comes up with his own design and method of operation. The difference in operating the controls for the different subsystems is often startling increasing the operator learning time and chance of error.

The fact that MFTF is a physics experiment further complicates control room design. Changes and additions are expected from alert and inventive research teams and must be easily accommodated. The author and others in SCDS have been impressed by the number of gauges and switches taped over or labeled with "DO NOT OPERATE" at other experimental facilities. Until a few years ago there had been little choice in control room design. For the above reasons and because of the complexity of MFTF, the SCDS group was chartered to study and implement a better control room design. The study is now complete and a prototype MFTF operator's console has been built. Some results of the study are as follows.

Independent control of certain MFTF subsystems are required, especially when these subsystems are coming on-the-air or are being tested; this will require seven MFTF operator work stations (consoles). Each console can control more than one subsystem, so any one console can become inoperative without serious effects on MFTF operations. Five consoles will be similar to the prototype console shown in Fig. 3. Two consoles are assigned the responsibility to coordinate all subsystems when required, and should look similar to the one shown in Fig. 4.[14]

The main components of a console are:

- Three or six color television monitors placed at or above eye level for display of MFTF status information.
- Two desk-top mounted color television monitors with touch sensitive screens for display of control panels and input of operator commands respectively. Rather than cutting the control panels out of metal, we have the computer paint the control panels on the two television monitors as desired.
- A badge reader to uniquely identify the operator to the control system. The control system only allows the operator to control subsystems and perform those actions for which the operator is licensed.
- A hardwired "SCRAM" button for emergency shutdown of the facility.

There are several important advantages in having the computer paint the control panels in front of the operator.

- The control panels rapidly become available to the operator; the operator does not have to walk or run to the panel.
- The cost of changing a misdesigned or confusing panel is very low. Currently a rearrangement of buttons takes only minutes with our graphics editor.
- The addition of new panels does not increase control room size and is cost effective. New panels may be generated in a matter of a few hours.
- Basic operational methodology can be standardized across all subsystems.[15] In SCDS all green buttons are things that can be controlled (pumps, valves, power supplies, etc.) while blue buttons perform some action (open, close, on, off, set voltage, etc.). Normal operation is to touch some number of green buttons followed by a blue button. Figure 5 shows a vacuum map before and after valve V1 has been selected. Notice the open and close operators are in dotted boxes initially. A dotted box means that the button is unavailable and that touching it is inappropriate at the time and will have no effect. After the MFTF operator touches V1, the dotted open and close buttons brighten-up as they become solid, which allows the operator to perform the open or close operation on V1.

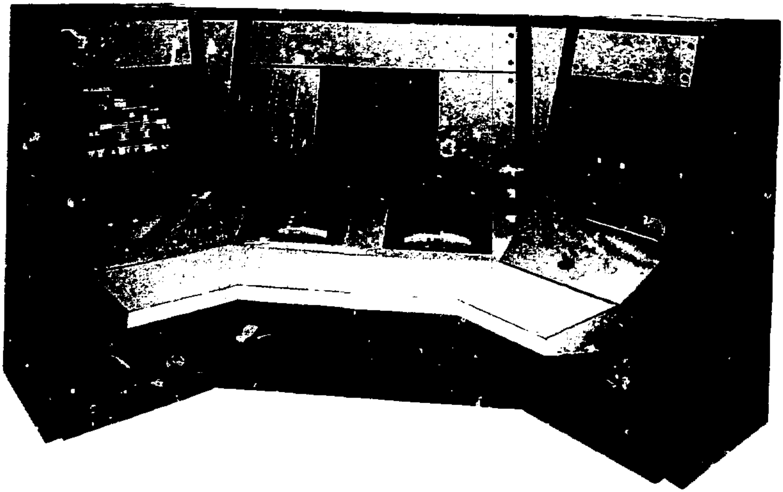

Fig. 3. Prototype console.

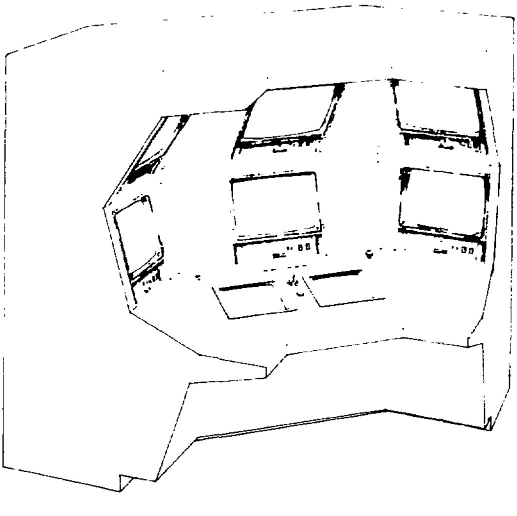

Fig. 4. System console.

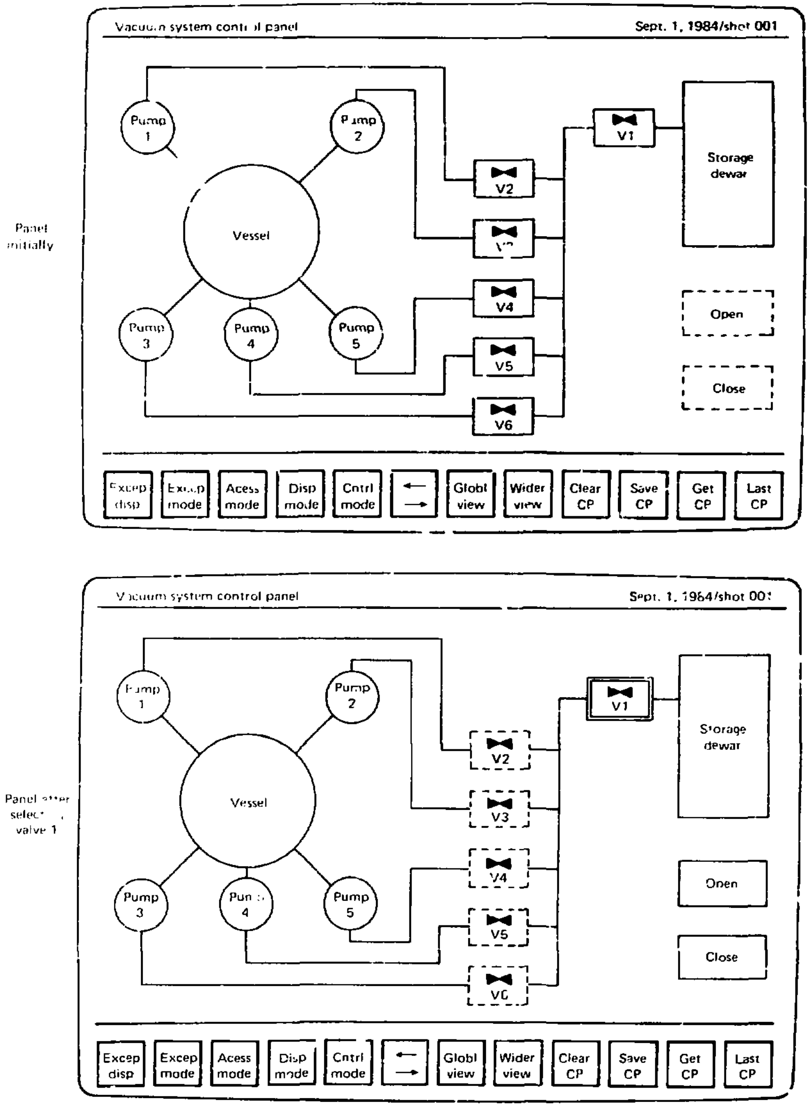


Fig. 5. BNF syntax defintion allows dynamic presentation of legal buttons. Syntactically incorrect commands connot be entered.

It is also interesting to note that the particular panel in Fig. 5 was designed so that only one valve may be opened or closed at a time. This is shown by the fact that the other valves become unavailable when V1 is selected.

The ability of the console system to prevent operators from inputting a syntactically illegal command should prevent many operator accidental errors.

- Control panels can be designed that are optimized for any operation the MFTF operator wishes to perform. For example, a control panel can be designed that contains all the controls necessary to do an atmospheric pump down of the vacuum vessel, while a different panel exists with some of the same controls presented in a different manner for steady state operation.

The above are a few of the important features of the MFTF control consoles.

In August 1980, we started receiving the seven control consoles. For those at LLNL who wish more information about our consoles and their operation, there are several films and video tapes available from the SCDS group.

## MFTF CONTROL SYSTEM

The MFTF Control System allows the MFTF operator manual and automatic control and diagnosis of the MFTF. The major pieces of software that comprise the control system are (as shown in Fig. 6):

- The Subsystem Managers that start-up and shutdown supervisory control of an MFTF subsystem. There is one Subsystem Manager for each MFTF subsystem, which initiates monitoring of sensors for the MFTF subsystem, establishes the subsystem's current state, and establishes operational limits given the current state.

  MFTF operators can also tell the Subsystem Manager the operator's intended use of the subsystem, for example, to shoot shots. The Subsystem Manager will configure the system such that the operator would be notified of any conditions contrary to his or her specified intended use.

- The Exception System which attempts to ensure that operators become quickly aware of emergencies, that they have sufficient details about the nature of the emergency to respond properly, and that they

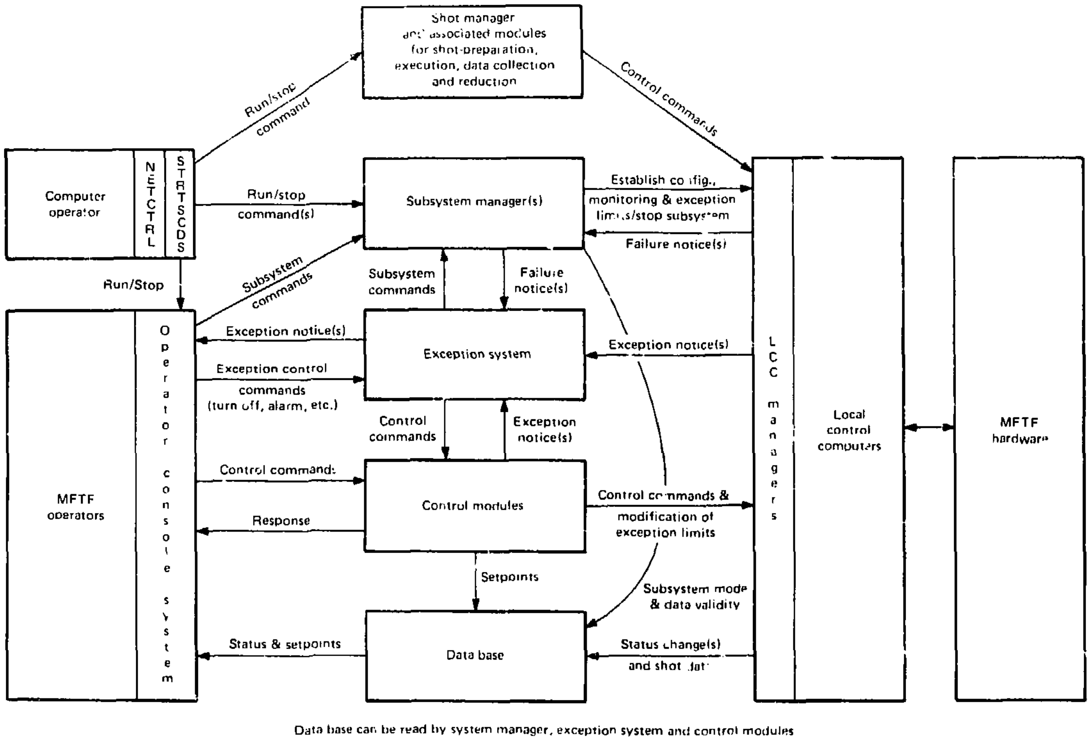


Fig. 6. MFTF control system.

have adequate control to respond to exceptions so that they may return to their normal functions as quickly as possible.[16]

The operational safety of MFTF is not entrusted exclusively to SCDS and hence each MFTF subsystem is required to be self-protecting. Action taken by these hardwired safety systems may make the MFTF machine safe, but the action may not be in the best interests of continued operation. SCDS views hardwired caused shutdown of a subsystem as an undesirable condition that rarely occurs. The Exception System is being designed to allow handling of the vast majority of problems before the hardwired system needs to be invoked.

- A Local Control Computer Manager (LCCMGR) for each local control computer attached to SCDS handles all messages between programs in SCDS and the local control computer. The LCCMGR also is charged with logging sensor changes in the MFTF database, and notifying the exception system if the local control computer sends an exception limit violation. The LCCMGR helps to assure the very important design criterion that the MFTF database accurately reflects the current state of the MFTF.
- A shot manager has the following responsibilities:
  - Verify that the operator is licensed to shoot a shot.
  - Verify that that it is okay to shoot.
  - Set up the shot.
  - Set up data collection routines.
  - Fire the shot and handle aborts to the shot sequence.
  - After data is collected, to start appropriate intershot processing.

## HARDWARE AND OPERATING SYSTEM

Up to now we have mentioned little or nothing about the hardware and operating system upon which the SCDS software resides. Control systems like the one described herein place several requirements on the choice of hardware and design of the system.[17]

- Availability: The control system must be available. Our design criteria are such that down-time for a single-point failure should be no more than ve minutes.

- Flexibility: As was stated earlier, MFTF is an experiment and as such change is to be expected. The devices that are controlled or monitored may change regularly. New devices may be added (possibly requiring additional computers, memory, data storage devices, or interfaces for control).
- Data Throughput: SCDS may have to collect, process, and display in meaningful form as much as 4.25 million bytes of information every five minutes

## HARDWARE

Nine computers comprise SCDS (as seen in Fig. 7), and each has its own local memory while each shares some common memory.[18] To keep in line with our availability requirement, the shared memory consists of two separate units. If one shared memory fails, the other is usable. Notice that the nine computers divide up the MFTF workload. The division was made so that each computer could do its function with minimal interaction with the others while the shared memory provides a high bandwidth data path between computers when necessary.

## DISTRIBUTED OPERATING SYSTEM

To meet the availability and flexibility requirements an Interprocess Communications Sytem (IPCS) was developed.[17] The author placed further design criteria on the IPCS.

- Programs should run on "functional machines" rather than physical computers. The "functional machines" can then be bound to physical computers by the computer operator. Reassignment of "functional machines" allows easy recovery after a computer failure, easy addition of computers and easy system tuning.
- Programs should be able to record passing a milestone in their execution so that if the computer upon which the program is running fails, the program can be restarted on another computer with the record of the program's earlier progress.
- Communication between programs should be simple and uniform regardless of where the programs reside.

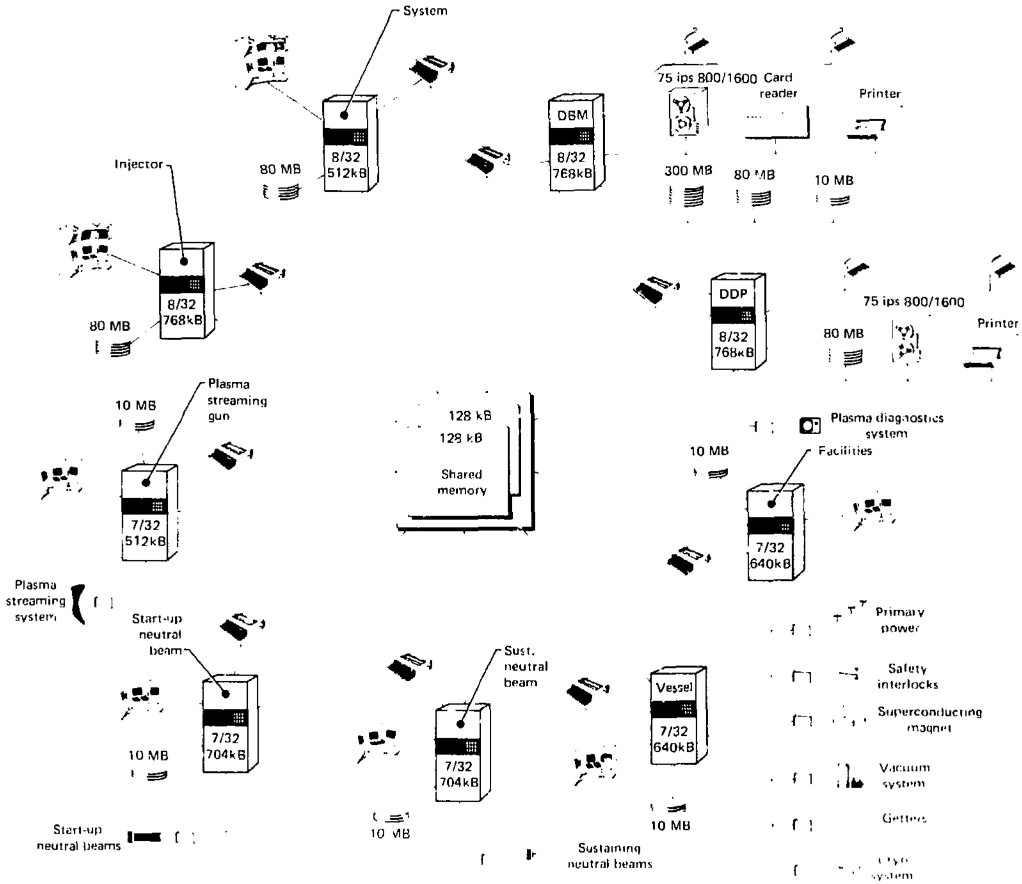


Fig. 7. MFTF control and diagnostics system hardware.

- Control systems are usually event driven (i.e. when an event occurs a program runs, handling the event). The IPCS should easily allow programmers to write event driven programs in the highest level, best language available (Pascal).

  The IPCS should allow programs to activate subprograms and to specify what the subprogram is licensed to do. Licenses should be required to access certain critical resources (vacuum system, sustaining neutral beams, etc.) and to perform certain critical functions (shoot MFTF shot, override interlock, etc.). The IPCS should maintain the set of licenses (i.e. access rights) for each program invocation and prevent programs from granting licenses that they are lacking. The author believes that access rights management will prevent some programming errors from having obscure and perhaps dangerous effects in the system. We wish, for example, to feel secure that when a program starts a subprogram and grants the subprogram only an access right to sustaining neutral beam 22, the subprogram will be allowed to access only sustaining beam 22 and no other part of the system.
- Real time systems have been notorious for having debugging problems. The IPCS should assist in program development by forcing good programming practice and providing debug tools. The IPCS tends to force programmers to write small event driven programs that are formed into hierarchies. Work by Dijkstra[19] and Jammel[20] have shown that programs written in that way are easier for programmers to understand and are less likely to contain error. To assist debugging, a snap shot of all the programs active in the system should be available and symbolic debugging of hierarchies of programs should be provided.

The IPCS has been in use for over a year and has met the above criteria.

## SCDS MODEL

The performance of computer systems is often counter-intuitive. To assure that SCDS would perform as required, Wyman constructed a computer model[21] in CDC "ASPOL"[22] of the SCDS system as designed.

Wyman modeled SCDS with seven MFTF operators interacting with SCDS. The operator actions and how these actions were proportioned as input to the model are as follows:

- Bringing up new control panels (40%)
- Bringing up new displays (20%)
- Changing a system parameter (30%)
- Requesting historical data from the database (10%)

The results from the above model show that operator interactions have little loading effect on SCDS and reasonable system response can be expected.

Wyman added shot-data collection to the model and verified that even though the system is very busy after an MFTF shot, there are no serious problems with the SCDS design.

We believe that the model has been helpful in verifying our designs and will be useful in evaluating proposed system changes.

## SOFTWARE DEVELOPMENT

The software development for SCDS is estimated to be a 50 man-year effort. Very early in the project a need was seen for control of software development and a QA/QC plan was born. Chief programmer teams were chosen and a librarian was selected for control of software and documentation.

All software goes through a formal review process which tends to eliminate bugs early in the development cycle and forces documentation. SCDS is the first large project at LLNL to use the above modern programming practices and to use an enhanced Pascal[23] for the programming language. All software, except a few interface routines, is written in Pascal.

We have been happy with our method of software development and use of Pascal. Statistics are being gathered on the effectiveness of this development and these statistics should be the topic of a future paper.

## CURRENT STATUS

SCDS is on schedule and over half complete. The computer hardware has been operational since February, 1979 and over 100,000 lines of debugged code have been written. The Distributed Operating system is in use. The design of the console system has been verified with a prototype console and the final version of the MFTF control consoles started arriving in August, 1980. The

Exception system has been designed, but not yet implemented. The Database system is just coming on line and application codes are being written to use it.

During the next year the Vacuum and Cryogenics system will come on-the-air and the first sustaining neutral beam power supply will be controlled.

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U. S. Government Printing Office: 1981/2--789-057/119